International Journal of Environment and Climate Change

Volume 13, Issue 8, Page 1077-1089, 2023; Article no.IJECC.99564
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Spatio-temporal Distribution and Biochemical Composition of Phytoplankton along the Coastal Waters of Dakshin Kannada District, Karnataka, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i82046

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/99564

Original Research Article

Received: 08/03/2023
Accepted: 10/05/2023
Published: 09/06/2023

ABSTRACT

The phytoplankton distribution and biochemical composition concerning water quality parameters were studied in the coastal waters off Mangalore, Monthly sampling was carried out from October 2020 to May 2022 at selected stations of Netravathi-Gurupura estuary, latitude 12°50'38.56" N, longitude 74°50'0.23° to coastal waters off Padubidri latitude 13° 8'0. 57" N longitude 74°42'9.47° with an average depth of 8 meters. Spatiotemporally the phytoplankton, chlorophyll-a and phytoplankton biochemical composition showed a significant difference for the entire duration. During the present investigation, 35 different phytoplankton genera belonging to 3 groups were observed with complete domination from diatoms with 27 genera followed by Dinoflagellates 7 and blue-green algae. distribution and abundance of the phytoplankton were mainly *Chaetoceros sp.*,

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Ceratium sp., Thallasiocera sp., Biddulphia sp., Coscinodiscus sp., Rhizosolenia sp., Ditylum sp., Triceratium sp., Nitzschia sp. and blue-green algae under Chrysophyta, Bryophyta, Chlorophyta, Cyanophyta were observed, while in biochemical composition of phytoplankton, the carbon contributed to the highest percentage and hydrogen constitute to the lowest percentage. Crude protein and Lipid contents are maximum during post-monsoon and carbohydrates showed their highest content during pre-monsoon for phytoplankton. There is a direct relationship between the biochemical composition and the physiochemical and environmental conditions including nutrients, especially nitrates and phosphates.

Keywords: Phytoplankton; chlorophyll-a; crude protein; lipid; nutrients; Mangaluru.

1. INTRODUCTION

Plankton is considered a good bioindicator in coastal waters. Plankton is a diverse group of organisms that live in the water column and cannot swim against the current. They reflect the effect of environmental changes in a short time. The spatial and temporal variation in the community structure of phytoplankton is influenced by the alterations in the physical and Hydrobiological variables in the marine environment [1-3]. Research in the recent past from the present study domain shows the strong biophysical coupling between hydrographical parameters and the kind of plankton existing in diverse environments [4-6]. The major features of phytoplankton are its shape and size which controls biochemical Functions such as plankton growth and nutrient intake. Based on the phytoplankton size structure, the total chlorophyll concentration is classified into three functional classes [7].

2. MATERIALS AND METHODS

The sampling stations were selected along the coastal waters off Dakshina Kannada, South West coast of India. A total of five stations were selected with an average depth of 8 m. Seven stations were selected in coastal waters off Dakshina Kannada district and designated as Gurupura-Netravathi Estuary S_1, Barmouth region of Netravathi S_2, Coastal waters off Thannirbhavi S_3, Coastal waters off Panambur S_4, Coastal waters off Suratkal S_5, Coastal waters off Mulki S_6 and Coastal waters off Padubidri S_7.

Monthly sampling was carried out at selected seven stations from the Barmouth region of Netravathi estuary, latitude 12°50'38.56" N, longitude 74°50'0.23° to coastal waters off Padubidri latitude 13° 8'0. 57" N longitude 74°42'9.47° with an average depth of 8 meters. Phytoplankton samples were collected using a Heron-Tranter net from all the stations. The Heron-Tranter net was hauled horizontally in each station leaving a two-meter safe depth from the bottom. The net is square-shaped with a mouth area of 0.25 m^2 and has a filtering cone of 1.2 m length with a 60 µ pore size. The net towed for one minute. Phytoplankton samples were then preserved in 4 % seawater formalin on board the vessel for further analysis. Samples were then briefly rinsed with distilled water while still under vacuum, wrapped with aluminum foil, placed into sealed plastic bags, and stored in a freezer. In the laboratory, frozen samples were weighed and then freeze-dried to obtain dry mass. The water content in the samples was calculated from the difference between wet mass and dry mass and expressed as a percentage of wet mass.

The samples of phytoplankton were brought to be identified and classified by a microscope at a magnification of 400x and identification with appropriate tools [8]. The Phytoplankton abundance is the number of individuals or cells per unit volume was calculated using the following equation. N=n ×Vr/Vo×1/Vs, N= phytoplankton abundance (cell/l), n=number of observed phytoplankton, Vr=volume of filtered water (30 ml), Vo=concentrate volume of Sedgwick rafter Counting Cell (ml), Vs=volume of filtered water sample (100 lit.). Chlorophyll-*a* was counted using the following equation [9] Chlorophyll-*a* (mg/m^3) = {(11, 85(E664-1.54(E647-0.08(E630} XVe/Vs}.

3. RESULTS AND DISCUSSION

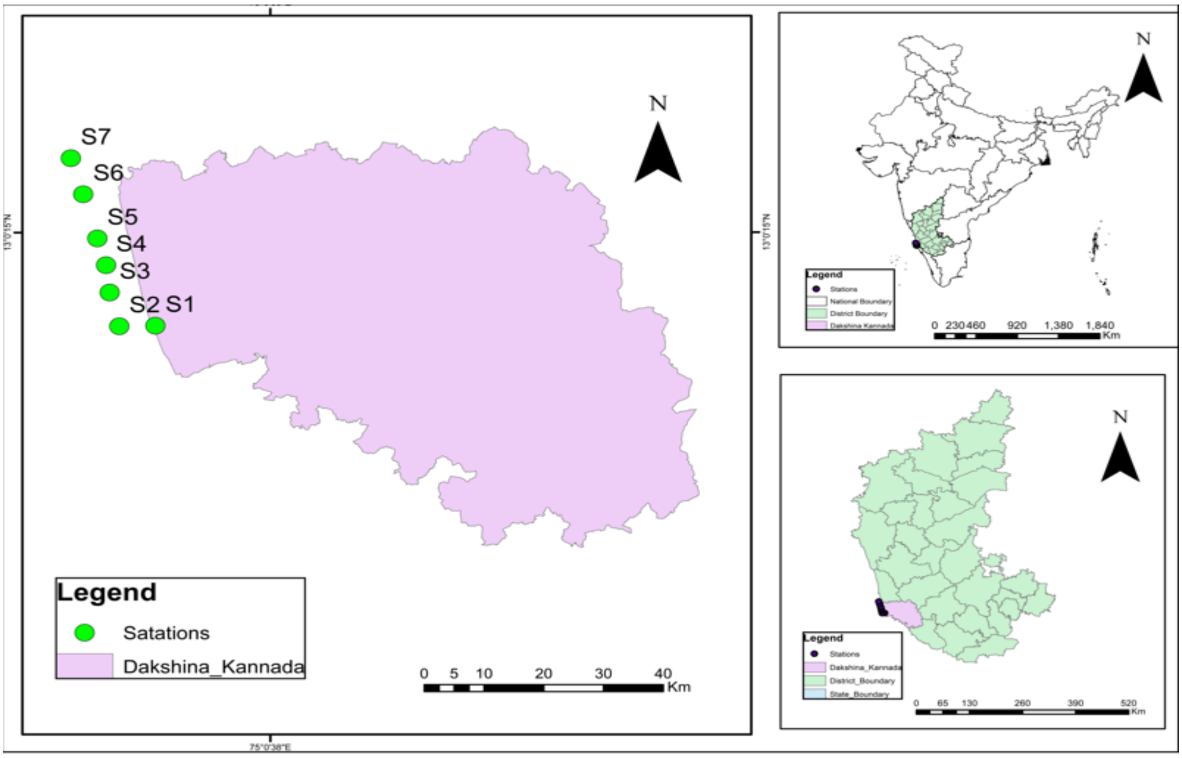
The dynamics of phytoplankton populations are controlled by multiple factors including physiological and evolutionary adaptations, environmental and biological processes. The evaluation of physicochemical characteristics in India's southwest coastal waters serves as a visible tool for investigating water quality (Dayala et al. 2014). The interactions between the different factors are important in understanding the response of organisms to these variables. The air temperature of the study area varied between 27.43°C and 32.59°C with the highest in the pre-monsoon season and the lowest in the monsoon season. The annual Precipitation averaged 3479 mm during the study period (Agril. Research Station, Mangaluru). The surface water temperature of the coastal waters ranged from 28.01°C to 31.65°C. The maximum mean surface water temperature was observed in the pre-monsoon season (29.39 ±1.0°C) and the minimum in the wet season (28.01°C) showed in Table 1. Surface water temperature demonstrated a significant positive correlation with air temperature, and salinity and a negative correlation with chlorophyll-*a*, silicate and rainfall showed in Table 2. Andrade et al. (2011) examined maximum and minimum surface water temperatures in Mangalore coastal water during the summer (34.75°C) and winter (28°C) seasons and discovered that this is related to increased solar radiation, evaporation and entry of fresh water. Vajravelu et al. (2018) found temperature fluctuations in the Parangipettai coastal waters, Bay of Bengal, South East Coast of India, during the monsoon and summer seasons, due to substantial rainfall throughout the monsoon season, low temperatures were reported. The overall pH values during the study period ranged from 7.23 to 8.62 with its maximum value in the pre-monsoon season. There revealed a significant positive correlation between pH, and salinity. According to Kumar et al. (2013), various factors such as rainfall, CO_2 removal by photosynthesis and dilution of seawater by freshwater intake, salinity decrease and temperature control seasonal variations in water pH. Tenjing et al. (2017) found that the pH of seawater in Panambur and Padukere along the Karnataka coast ranged from 7.92 in September to 8.26 in May. According to Krishnankutty et al. (2019) seasonal pH changes in coastal waters off Cochin, in the south-eastern Arabian Sea, revealed that the monsoon has low pH levels. Salinity ranged from 26.07 to 35.28 PSU for the whole study period.

Mean salinity was found in the dry season (30.83 ± 2.48 PSU) Salinity also showed a positive correlation with temperature and pH and a negative correlation with dissolved oxygen chlorophyll a and productivity dissolved oxygen ranged from 3.41 to 7.07 mg L−1 during the study period Bharathi et al. (2017) have revealed that salinity levels were higher in the summer and lowest in the monsoon seasons, which could be owing to higher evaporation during the summer season and the lowest salinity in the monsoon season due to heavy rainfall in the Puducherry coastline waters. Madhavi et al. [10] reported a low value of dissolved oxygen during a post-monsoon season in the coastal waters of the Dakshina Kannada and Udupi districts. However, the mean value of dissolved oxygen was observed in the dry season (4.67 ± 1.25 mg L−1). Dissolved oxygen revealed a positive correlation with phytoplankton abundance. The Ammonia, Nitrate, Nitrite and phosphate value in the coastal waters ranged from 0.17 µg/l to 17.20 µg /l, 0.0 µg /l to 5.40 µg/l, 0.15 µg/l to 4.25 µg/l and 0.03 µg/l to 7.58 µg/l respectively recorded for the whole study period. Meanwhile, the highest mean of silicate was observed in the dry season (0.70.58 to 43.70). In 2010 and 2011, off the coast of Mangalore in the Arabian Sea, Sulochanan et al. (2014) discovered substantial relationships between rainfall, silicate, and phosphate. Krishnan and Tharavathy (2016) observed that nutrients such as nitrate, nitrite, inorganic phosphate and reactive silica were high during the monsoon in coastal waters at Kushalnagar Beach, Kasaragod, Kerala. The mean value of Organic carbon was observed (12.97%). The maximum mean of chlorophyll a was found in the post-monsoon season (2.02) and the minimum in the monsoon season (0.28). Significant seasonal variations were observed among some hydrological parameters such as surface water temperature. The mean value of phytoplankton demonstrated higher concentration in the dry (1.61 mm/m^3) season followed by the intermediate (9.25 mm/m^3) season. Phytoplankton demonstrated positive correlation with chlorophyll a and Net primary productivity and negative correlation with water temperature and salinity (Table 2). Silicate (SiO_2) mean found to be in the 14.76. Similarly Madhavi. K. et al. [11] observed the correlation among the hydrographical and biological parameters showed spatial variations and it could be due to different hydrology of different stations.

3.1 Quantitative Phytoplankton Analysis

The qualitative analysis of phytoplankton revealed the presence of a large number of phytoplankton cells belonging to different groups such as diatoms, dinoflagellates and blue-green algae (BGA). Spatially shallower water showed a maximum number compared to deeper water with the maximum being recorded at 8m depth.

Throughout the study period, Diatoms are the dominant group of phytoplankton contributing to the total phytoplankton production. Greater numbers of diatoms were reported at shallower depths with a variation of 7650 to 17917000 cells/m^3 at 8m depth in stn. S_3. Dinoflagellates were reported variation of stn. S_7 67500 to stn. S_3 480000 cells/m^3 at stn. S_3 Spatially shallower waters reported greater numbers with a positive response to increased sea surface water temperature. Temporal variation exhibited a bimodal variation over time.



Map 1. ArcGIS map showing the selected stations of the study area

Table 1. Mean, minimum and maximum values of different physicochemical parameters in different months during the study period in selected stations

Parameters	Mean	Minimum	Maximum	Median	Std. Error
Air temperature ^{o}c	30.08	27.43	32.59	30.06	0.13
Water temperature ^{o}c	29.39	28.01	31.65	29.46	0.06
pH	8.04	7.23	8.62	8.03	0.02
Salinity (PSU)	30.83	26.07	35.28	30.93	0.21
Dissolved oxygen (mg/l)	4.67	3.41	7.07	4.54	0.10
BOD (mg/l)	1.90	0.36	6.93	1.63	0.11
Ammonia-Nitrogen (µg/l)	5.51	0.17	17.20	4.15	0.41
Nitrate-Nitrogen (µg/l)	1.13	0.00	5.40	0.65	0.11
Nitrite-Nitrogen (µg/l)	1.40	0.15	4.25	1.21	0.09
Phosphate-phosphorus	2.61	0.03	7.58	2.14	0.20
(µg/l)	14.76	0.10	43.70	13.39	0.83
Silicate-silicon (µg/l)	12.97	0.10	43.70	12.19	0.81
Organic carbon%	0.43	0.15	2.02	0.28	0.03
Chlorophyll-*a* (mg/m^3)	2.81	1.61	9.29	2.14	0.14
Phytoplankton(mm/m^3)	3276793.88	111220.00	10798000.00	2369000.00	277955.07
Phyto. abundance(cells/m^3)	28.50	8.82			1.92

3.1.1 Diatoms

The greater numbers of diatoms were reported in December 2021 at stn. S_3 with a maximum of 17917000 cells/m^3. 27 species of diatoms were reported during the investigation period and the species which occurred more than 78 percent in the entire duration. Spatially shallower depths exhibited a higher number of *Biddulphia sp.* with an average monthly range of 1179 to at stn. S_5, 195000 cells/m^3. The maximum numbers of *Biddulphia sp.* were recorded in October 2021 and the minimum was recorded in the Feb, March and April 2022. During the entire study duration. Temporarily an increasing trend was observed with a narrow range of differences in seasons during the study period with the pulsating trend with many minor peaks in the entire study duration. *Chaetoceros sp.* was the most dominant diatom reported during the entire study duration with a range of 835 to 12525000 cells/m^3at station S_6, in November 2021. The monthly average data did not exhibit spatial variation even though greater numbers were reported in the shallower depth contour. Temporally an increasing trend of *Chaetoceros sp.* was observed over time and the variation was much narrow during the last three months of the study period. Two peaks were exhibited starting from October (post-monsoon) to February (pre-monsoon) then the decreasing trend continued till September 2021 with a second peak later on. The present observation was supported by Lathika et al. (2013). They reported the dominance of *Chaetoceros sp.* in the upwelling system of the south-eastern Arabian sea, with a contribution of 60-90% of the total cell density and revealed that these species have high spore production and reseeding rates, which favors their occurrence in the upwelled waters *Cosinodiscus sp.* distribution exhibited a variation of 0 to 1050000 cells/m^3 for the entire study duration. The Monthly average data showed no difference in the stations as the variation between the various depths is narrow but even then greater numbers were recorded at station 5 with a range of 8514 to 1050000 cells/m^3. Temporal variation of *Cosinodiscus sp.* did not exhibit any noticeable trend for the entire 16 months with maximum peak in post-monsoon February, March and April, with an average of 75000 cells/m^3. No spatial variation was reported in the distribution of *Ditylum sp.* in the first 4 Months. For the next 12 Months, a pulsating trend with a maximum peak in the month of S_6 April 2021 was reported and then the variation in different stations was very much narrow. Temporal variation exhibited a maximum peak in S_5 with 110000 cells/m^3 of *Ditylum sp.* numbers and a total of 2 peaks were reported in S_6 and S_7. The absence of the *Ditylum sp.* distribution in S_2 and S_3 post-monsoon season became a setback in clear-cut temporal trends. Spatial distribution exhibited at S_2, S_4 and S_7 reported maximum numbers of *Nitzschia sp.* with a variation of 500 to 85000 cells/m^3 throughout the investigation. Temporal variation exhibited the highest peak in the year 2021 months of October, November and March at S_4 and S_7 with an average of 8500 12500, and 21250 cells/m^3 respectively, Several small peaks in the early stage and then a slightly increasing trend was observed till the pre-monsoon season later decreased till December in S_3 and S_5. The dominance of *Nitzschia sp.* among pennales in the upwelling system of the south-eastern Arabian Sea was also observed by Shruthi. G et al. [12]. Overall the temporal variation of *Nitzschia sp.* exhibited two major peaks in S_4 and S_7. The spatial distribution of *Planktoniella sp.* was found to be more at stations S_6 and S_7 with a variation of 835 to 42500 cells/m^3. The deeper waters recorded more values only during October, and November at S_6 and S_7 with a variation of 10002 to 42500 cells/m^3. Temporal variation exhibited an increasing trend with the highest peak during October and November 2021 with 100 to 27500 cells/m^3 and over the period, totally a trimodal oscillation was exhibited. For the entire duration of the study, the *Planktoniella sp.* numbers varied from 0 to 42500 cells/m^3. The spatial distribution of *Pleurosigma sp.* at various depths was not clear due to narrow variation with greater numbers at deeper waters. The *Pleurosigma sp.* numbers at 4m, 8m 12m and 15m varied from 89 to 99717, 747 to 490885, 49 to 80400 and 665 to 1065286 cells/m^3 respectively. The maximum number was noticed at 15m depth with 1065286 cells/m^3. Temporal variation exhibited an increasing trend without much clear variation except with a few minor peaks from 1998 to 2006. Overall a slight increase in the *Pleurosigma sp.* numbers was observed with the highest numbers (1065286 cells/m^3) being recorded in 2011. Estuarine waters recorded maximum numbers of *Rhizosolenia sp.* with a variation of 7500 to 975000 cells/m^3 at S_1 and S_5. Second dominance was found at S_3 and S_4 with a variation of 1000 to 54000 cells/m^3, *Rhizosolenia sp.* numbers were abundantly present at shallower waters compared to deeper waters which were supported by the decreased salinity. For the entire period of investigation. Temporal variation showed bimodal oscillation with two clear peaks during October, November 2021 and 2022. An increasing trend till early pre-monsoon was observed with a maximum number of 54000 to 97500 cells/m^3 and later decreased till March and April with the lowest numbers of 0 to 250 cells/m^3. Overall a bimodal oscillation was exhibited by the *Rhizosolenia sp.* distribution with a slight increase in the number over the period. Similar observations were also made by Jiyalalram et al. (1989), Naik et al. (1990), Ramesh (1992), De'souza (2001), Katti et al. (2002), Raveesha (2007), Saravanakumar (2008), Karolina et al. (2009), Kadam et al. (2011), Sushanth and Rajashekhar (2012) and Madhavi [10] along the west coast of India. Similar reports were also observed along the east coast of India by Gouda and Panigrahi (1996), Sarojini et al. (2001), Prabhakar et al. (2011), Smitha et al. (2010), Muruganantham et al. (2012) and Babu et al. (2013).

3.1.2 Dinoflagellates

Dinoflagellates are the second most dominant group after diatoms contributing to the total phytoplankton. Shallower waters (4 m depth) recorded more numbers of dinoflagellates with a variation of 800 to 480000 cells/m^3. At S_3 1800 to 480000 population varied and in S_1 1800 to 69723 cells/m^3, Spatially coastal waters reported greater numbers with a positive response to increased sea surface water temperature and decreased sea surface salinity. Temporal variation did not exhibit any significant variation over time. The greater numbers of dinoflagellates were reported in the pre-monsoon season with a maximum of 3507 to 480000 cells/m^3. Three main species occurred more than 80 percent in the observation duration which is found to be *Ceratium sp., Dinophysis sp.* and *Peridinium sp.* The most dominant dinoflagellate with the maximum number found to be at S_5 and S_7 water with a variation of 2500 to 115000 to 1700 to 67500 cells/m^3 respectively, for the entire study duration shallower waters dominated in the *Ceratium sp.* distribution numbers except in few pre-monsoon months. Greater numbers were reported from October to November which is in agreement with the decreased salinity during the same duration of the study. Temporal variation exhibited a pulsating trend with a noticeable peak from October to January and a decreasing trend was observed in pre-monsoon season and then an increasing trend reappeared to form a second peak in September 2021. *Dinophysis sp.* is the third most dominant dinoflagellate with a variation of 0 to 10000 cells/m^3 at S_3, 0 to 300000 cells/m^3 at S_4, 0 to 22000 cells/m^3 at S_7 and 0 to 12500 cells/m^3. Deeper waters reported greater numbers of *Dinophysis sp.,* compared to shallow waters throughout the study period. The total Monthly variation of *Dinophysis sp.,* showed a variation from 0 to 300000 cells/m^3. Temporal variation exhibited three peaks with a maximum peak from 1996 to 1998. A secondary peak was observed to be in the year pre-monsoon and then it decreased to the lowest numbers in the year during the post-monsoon. The third peak was observed in November, December and January at S_3. *Peridinium sp.* was found to be the second most dominant dinoflagellate with a variation of 0 to 15500 cells/m^3 throughout the study period. Spatially, shallower water recorded higher values from September to November at S_1 and S_3 and then it was reversed from December to April in S_2 and S_3. Temporal analysis showed an increasing trend from pre-monsoon to post-monsoon and later a decreased pulsating trend with few minor peaks. The maximum number of *Peridinium sp.* was recorded in December S_3 with 15500 cells/m^3. The overall no clear-cut temporal trend was exhibited for the entire study duration.

3.1.3 Blue green algae

Blue-green algae showed clear spatial variation from S_1 and S_5 due to the Fresh water in flow. As the different genera among the Blue-green algae by numbers and abundance, hence all the genera were pooled together to form a single Blue-green algae group which accounted for several chains of each species rather than several cells individually. Blue-green algae varied from 0 to 341000 cells/m^3 at S_4, 100 to 65000 cells/m^3 at S_1, 0 to 70056 cells/m^3 at S_5 and 1000 to 341000 cells/m^3 at S_4. Temporally, a decreasing trend was exhibited with a maximum peak in January and February with 110000 cells/m^3. From January maximum peaks were observed and then a decreasing trend to indicate over time there is a decreasing trend which is in agreement with the decreasing salinity and increasing surface water temperature. Rath, A.R., et al., 2018 Karati, K.K., 2021 Padmakumar, K.B., 2018 reported Overall 54 phytoplankton species (35 genera) were observed in Mangaluru coastal waters according to Rath, A.R., 2018 Diatoms were the dominant group (surface: 80-99.9%, NBW: 97.1-100%), followed by dinoflagellates (surface: 0.1-20%, NBW: 0.1-3.7%) and silicoflagellates (surface: 0.1-0.2%, NBW: 0.1-0.2%) (Fig. 3). Phytoplankton abundance ranged from 1.54 x

104 (MON; outer zone) to 3.73 x 105 cells L-1 (PRM; channel zone) in surface waters and 1.03 x 104 (MON; outer zone) to 4.85 x 105 cells L-1 (PRM; outer zone) in the NBW.

3.2 Biochemical Analysis

3.2.1 Crude protein

Protein was the principal organic constituent in all species. It represented at least 40 % of the dry weight of cells in all species of diatoms. Seasonal variations in crude protein content in percentage of (dry weight) at selected stations are graphically represented in Fig. 1. In the present study protein contributed to the maximum when compared to the other biochemical compounds. Crude protein content was observed highest during post-monsoon when compared with pre-monsoon season. The nutrients, especially the nitrates (NO_3) and phosphate (PO_4) indicated the fertility of the water for the increase and enrichment of the biochemical contents. The average nitrate and phosphate contents were high during post-monsoon when compared with pre-monsoon with the values of 7.44 µg-at/l and 1.19 µg-at/l.

The maximum protein content was obtained in post-monsoon, 2021 58.54 ± 0.2 % at station S_4 and a minimum of 27.31 ±1.2 % at station S_1 Pre-monsoon 2021 and followed by maximum content of 56.34 ± 0.1 % at station S_5 Post-monsoon 2022 and minimum content was noticed during post-monsoon, 2022 (37.19 ± 1.0 %) at station S_4 during Pre-monsoon 2022 the study period. Parsons & Strickland (1961). Hedges et al. (2002) also observed protein percentages ranging from 51 – 73 %. Protein generally reflects physiologically healthy phytoplankton with high relative growth rates, and high protein contents suggesting that the phytoplankton had no nitrogen limitation in water mass. Mahmoud (2016) reported that the nutrients, especially the nitrates (NO_3) and phosphate (PO_4) indicated the fertility of the water to increase and enrichment of the biochemical contents of phytoplankton. The various Physicochemical parameters viz., temperature, salinity, pH, dissolved oxygen and nutrients are the factors that mainly influence the production and successful propagation of planktonic life in the coastal biotopes (Santhosh Kumar et al. 2012).

3.2.2 Total lipid

Algal lipids are composed of glycerol, saturated and unsaturated fatty acids, and some fatty acids of ω3 & ω6 families are pharmaceutically important. Seasonal variations in total lipid content in percentage of (dry weight) at selected stations is graphically represented in Fig. 2. During the present study, the total lipid content of phytoplankton reached the maximum in post-monsoon compared with pre-monsoon, but there is no significant difference between the two seasons. The maximum lipid content (5.76 ±1.10 %) was found at station S_7 post-monsoon, 2021 and the minimum (2.43 ±0.77 %) at station S_2 during the post-monsoon 2022 and followed by the second highest percentage (5.65 ±0.10 %) was noticed at station S_6 and second lowest percentage (2.65 ±1.14%) at station S_1 during the pre-monsoon period.

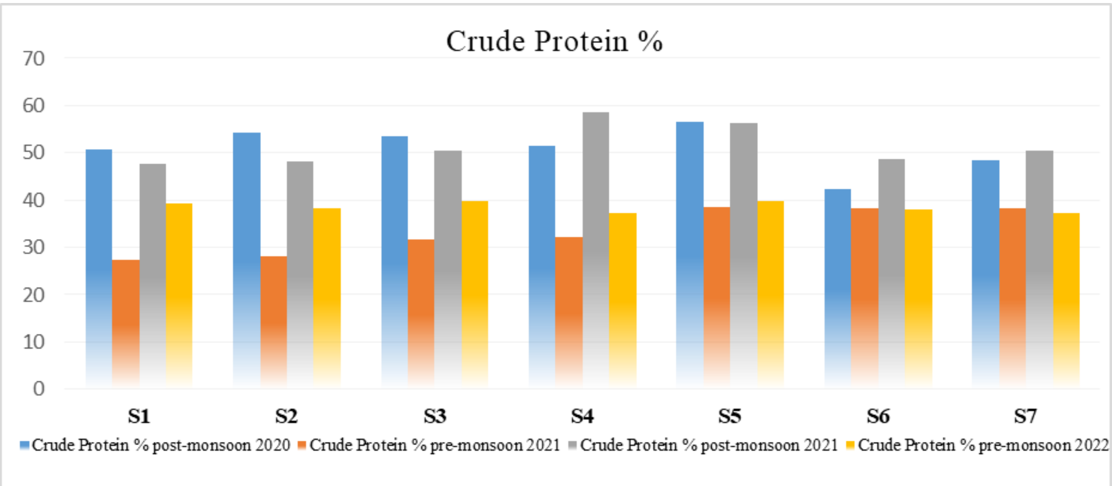


Fig. 1. Seasonal variations in Protein content in percentage (dry weight) at selected stations

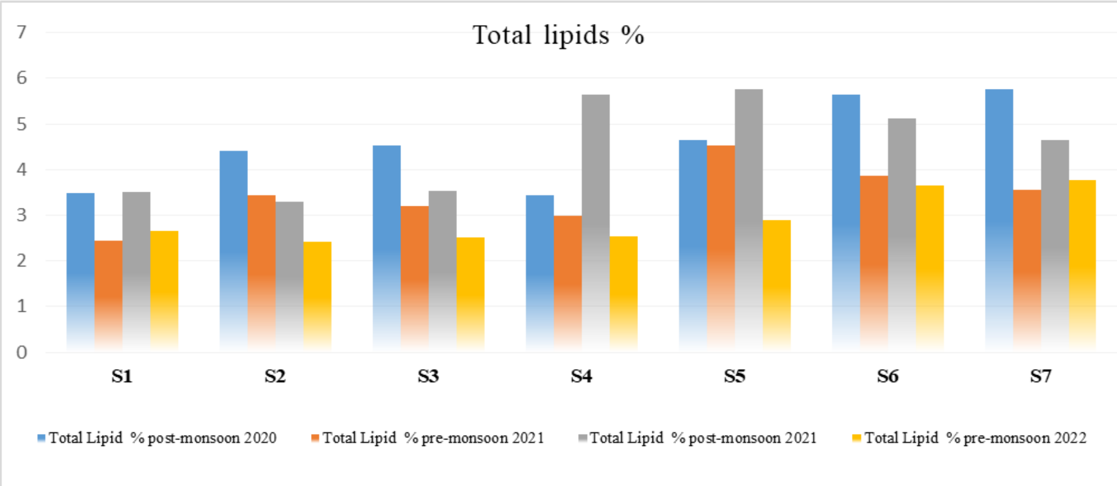


Fig. 2. Seasonal variations in lipid content in percentage (dry weight) at selected stations

Hussian et al. [13] reported that N starvation increased carbohydrate percentage and decreased protein percentage, while lipid percentage remained relatively constant. Abd El-Hady et al. [14] reported that protein constitutes the major part of the biochemical contents of the phytoplankton of Ismailia Canal while lipid constitutes the minor one. According to Mahmoud (2016) the highest values of crude protein and total lipid obtained in autumn 2014 52.76 mg/L, at station 9 & 1.76 mg/L, at station 8 respectively while the lowest value of crude protein and total lipid were in summer 2015 was 1.23 mg/L and 0.08 mg/L, respectively.

3.2.3 Carbohydrate

In the present study, the carbohydrate content of phytoplankton reached a maximum in pre-monsoon compared with post-monsoon. Seasonal variations in carbohydrate content in percentage of (dry weight) at selected stations are graphically represented in Fig. 3. The maximum carbohydrate content (45.54 ±0.12%) was found at station S_2 pre-monsoon, 2021 and minimum (10.97±0.08 %) at station S_1 during the post-monsoon and second highest percentage (44.54 ±0.10 %) was noticed at station S_6 pre-monsoon 2022 and lowest percentage (12.43 ±0.18 %) at station S_7 during the post-monsoon 2021 period. Carbohydrates and protein serve both as structural and storage components and represent the major form of photo-chemically assimilated carbon in the biosphere and are powerful tools in the pathways of biologically important organic materials in nature (Mahmoud, 2016).

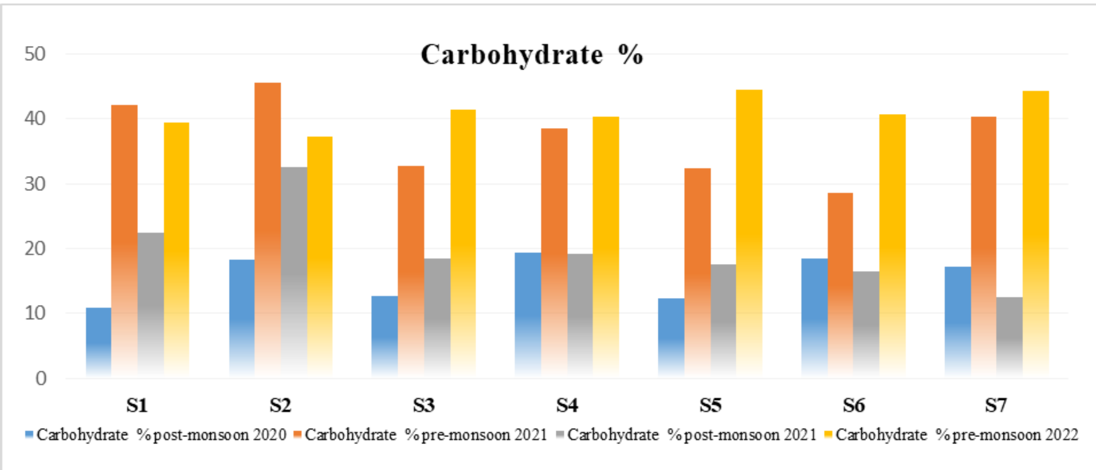


Fig. 3. Seasonal variations in carbohydrate content in percentage at selected stations

Carbohydrates in microalgae are found in the form of starch, glucose, sugars and other polysaccharides [15]. Abd El-Hady [14] reported maximum level of total carbohydrate concentration was found in summer, while the minimum level was detected in autumn. Brown and Jeffrey (1992) reported CHO levels ranging from 5.9 – 16.7 % in 10 species of Chlorophyceae & Prasinophyceae. CHO levels ranged from 8 – 56 % dry weight depending on the growth stage and species. An increase in CHO, variability in lipid content, and decrease in protein with advancing growth stage was reported by Brown and Jeffrey [16]; Wikfors et al. [17], although as already mentioned, growth medium and growth stage will affect biochemical composition [18]. Thomas et al. (1985) also found that N deficiency increased carbohydrate yield in mass cultures of Isochrysis.

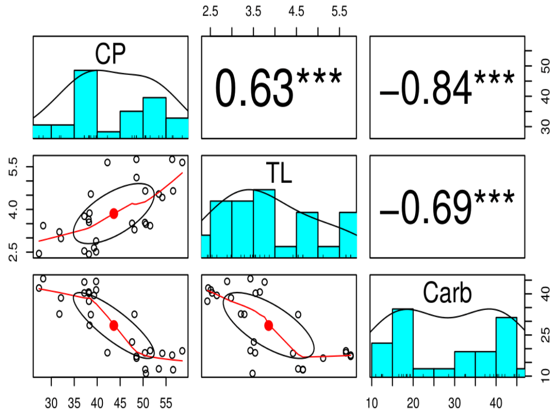


Fig. 4. Correlation plot between the crude protein, total lipid and carbohydrates in phytoplankton

The analysis of frequency distributions of Physico-chemical parameters and chlorophyll-*a* revealed a similar pattern with a marginal difference in the trend between 16 months. Therefore, the data were averaged by month and further analysed for spatiotemporal trends. In the west coast environment, the monsoon plays a critical role in the distribution of Physico-chemical parameters that can directly influence the distribution of chlorophyll-*a* [19]. The analysis of mean precipitation over the study area showed a similar trend as seen in 10 years of average distribution. Monthly chlorophyll-*a* showed a generally bi-modal distribution, with peaks occurring during pre-monsoon (March) and later stages of monsoon (September). During the pre-monsoon period, blooms of diatoms and dinoflagellate have been reported in past studies S. K. Baliarsingh et al. [20]. Indeed, elevated chlorophyll-*a* associated with phytoplankton blooms was observed during pre-monsoon in March. The later stage of monsoon, during September, also experiences higher chlorophyll-*a* in surface waters. This could be attributed to the influx of nutrients due to river runoff after monsoonal precipitation. This elevated chlorophyll-*a* subsequently breaks into patches due to localized effects and moves apart. Confirming the study by Baliarsingh et al. [20] also reported that the maximum spatial variability in chlorophyll-*a* concentrations during March–April was associated with a linear distribution with NO_2, NO_3 and SiO_4. According to Mohanty et al. (2007). During this period, river influx was much less, as evident from salinity distribution, restricting the advection of the bloom offshore [21-30].

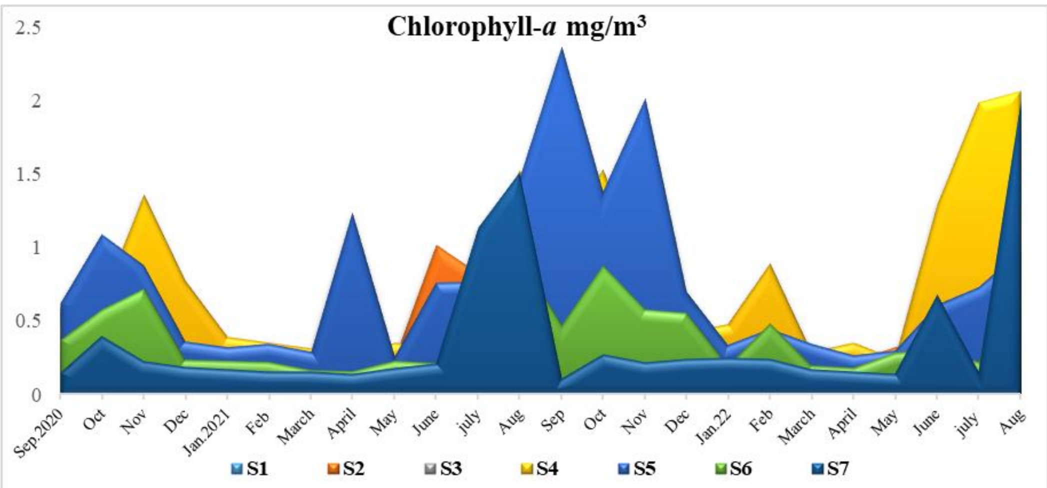


Fig. 5. Seasonal variations in Chlorophyll-*a* mg/m^3 at selected stations

Table 2. Correlation coefficient between and Physico-chemical and biological parameters

	Airtemp	*watertemp*	*pH*	*Salinity*	*DO*	*BOD*	*Ammonia*	*Nitrate*	*Nitrite*	*Phosphate*	*Silicate*	*OC*	*chla*	*phyto*	*Phytoabundance*	*NPPV*
Airtemp		0.546***	0.188*	0.476***	-0.035	0.028	-0.037	-0.162	-0.121	0.014	-0.216*	-0.119	-0.366***	-0.368***	0.030	-0.258**
watertemp	0.546***		0.286**	0.260**	-0.137	0.098	-0.085	-0.085	-0.167	0.115	-0.213*	-0.081	-0.282**	-0.350***	-0.052	-0.310***
pH	0.188*	0.286**		0.304**	-0.170	0.109	-0.080	-0.236*	-0.034	-0.146	-0.223*	-0.136	-0.093	-0.100	-0.241*	-0.088
Salinity	0.476***	0.260**	0.304**		-0.218*	0.001	-0.192*	-0.384***	0.089	-0.250**	-0.380***	-0.150	-0.340***	-0.358***	0.097	-0.269**
DO	-0.035	-0.137	-0.170	-0.218*		-0.089	0.397***	0.343***	0.045	0.178	0.024	-0.088	-0.021	-0.005	0.216*	0.074
BOD	0.028	0.098	0.109	0.001	-0.089		-0.179	-0.080	-0.089	-0.023	0.028	0.064	0.071	0.081	-0.049	0.048
Ammonia	-0.037	-0.085	-0.080	-0.192*	0.397***	-0.179		0.473***	0.093	0.171	0.056	-0.127	0.011	0.058	0.154	0.058
Nitrate	-0.162	-0.085	-0.236*	-0.384***	0.343***	-0.080	0.473***		-0.057	0.240*	0.309***	0.113	-0.031	-0.008	0.098	0.003
Nitrite	-0.121	-0.167	-0.034	0.089	0.045	-0.089	0.093	-0.057		0.036	0.050	0.034	0.016	-0.000	0.020	0.075
Phosphate	0.014	0.115	-0.146	-0.250**	0.178	-0.023	0.171	0.240*	0.036		-0.015	-0.157	0.079	0.110	0.008	0.002
Silicate	-0.216*	-0.213*	-0.223*	-0.380***	0.024	0.028	0.056	0.309***	0.050	-0.015		0.831***	0.165	0.134	0.081	0.199*
OC	-0.119	-0.081	-0.136	-0.150	-0.088	0.064	-0.127	0.113	0.034	-0.157	0.831***		0.116	0.071	0.086	0.132
chla	-0.366***	-0.282**	-0.093	-0.340***	-0.021	0.071	0.011	-0.031	0.016	0.079	0.165	0.116		0.939***	-0.351***	0.789***
phyto	-0.368***	-0.350***	-0.100	-0.358***	-0.005	0.081	0.058	-0.008	-0.000	0.110	0.134	0.071	0.939***		-0.281**	0.821***
Phytoabundance	0.030	-0.052	-0.241*	0.097	0.216*	-0.049	0.154	0.098	0.020	0.008	0.081	0.086	-0.351***	-0.281**		-0.169
NPPV	-0.258**	-0.310***	-0.088	-0.269**	0.074	0.048	0.058	0.003	0.075	0.002	0.199*	0.132	0.789***	0.821***	-0.169	

Computed correlation used pearson-method with listwise-deletion.

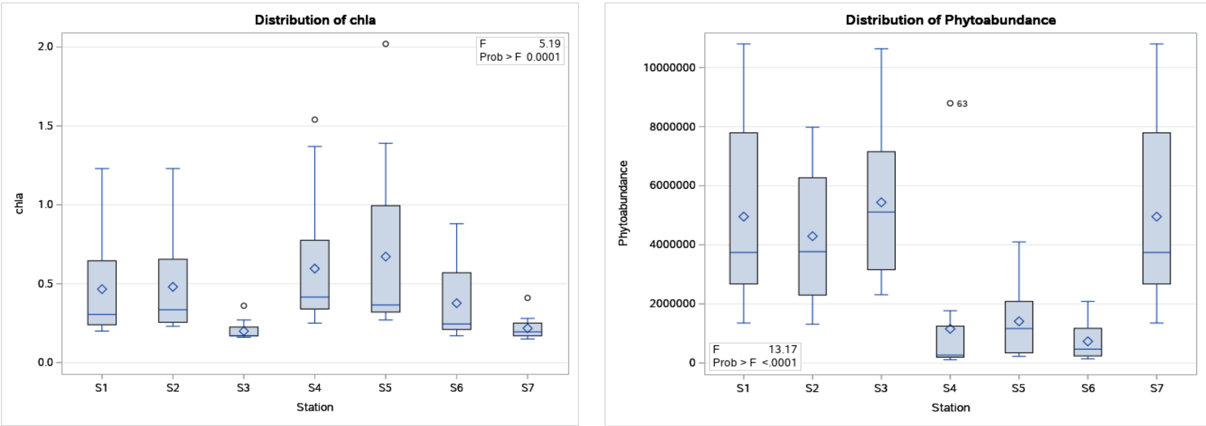


Fig. 6. Variations in the distribution of chlorophyll-*a* and phytoplankton abundance in selected stations

4. CONCLUSION

The results indicated that the phytoplankton species in the coastal waters of Mangaluru and Udupi were dominated by *Chaetoceros sp. sp, Ceratium sp, Thallasiocera sp, Biddulphia sp. sp, Coscinodiscus sp, Rhizosolenia sp. sp, Ditylum sp. sp, Triceratium sp, Nitzschia sp. sp* and blue-green algae under *chrysophyta, pyrophyta, chlorophyta, cyanophyta*. Diatoms were found to be most contributory to the total phytoplankton, remaining dominant species responsible for the high abundance of phytoplankton were *Pleurosigma sp. sp, Coscinodiscus sp., Nitzschia sp. sp*. and *Dinophysis sp*. composition and diversity of phytoplankton were found relatively high in post and pre-monsoon season, this could be due to water quality, favourable hydro-biological condition. The species composition and abundance of phytoplankton in all the stations was high S_1 and S_5 shows in the post-monsoon season, which could be due to the nutrient and freshwater inflow to the selected stations. Other than seasonality, climatic, and hydrobiological parameters like rainfall, ammonium, and silica also demonstrated the influence on the composition and abundance of phytoplankton in the study area. The phytoplankton biochemical compositions of Mangaluru coastal waters are dominated by protein during post-monsoon when compared with pre-monsoon which showed a positive correlation with nutrient concentrations especially nitrates and phosphates in all the selected stations. Lipid contributed to the minor fraction and showed a non-significant difference between all stations. Carbohydrate content is high in pre-monsoon when compared to post-monsoon also the present study provides the importance of the phytoplankton biochemical composition as a biomarker of the ecosystem of different sites in Mangaluru coastal waters. For future study, detailed biochemical compositions besides macromolecular compositions of phytoplankton provide better clues for environmental change effects on physiological conditions of phytoplankton.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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