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Diatom diversity in relation to physico-chemical parameters of coastal waters of Mangalore and Padubidri, Southwest coast of India

Shruthi[1], Dr. Padmanabha A[2], Dr. Lakshmipathi M T[3]

[1] Research Scholar, Department of Aquatic Environment Management, Karnataka Veterinary, Animal & Fisheries Sciences University, College of Fisheries, Mangalore, Karnataka, India

[2] Assistant Professor, Department of Aquatic Environment Management, Karnataka Veterinary, Animal & Fisheries Sciences University, College of Fisheries, Mangalore, Karnataka, India

[3] Professor and Head, Department of Aquatic Environment Management, Karnataka Veterinary, Animal & Fisheries Sciences University, College of Fisheries, Mangalore, Karnataka, India

Abstract

In this paper, attempt has been made to study the physico-chemical parameters of coastal waters of Mangalore and Padubidri, Southwest coast of India with special reference to diatom diversity for a period of 9 months from September 2014 to May 2015. The air and water temperatures ranged from 24.1 to 28.9^{0}C and 25.7 to 32.3^{0}C respectively, light extinction coefficient varied from 0.31 to 1.48m, total suspended solids ranged between 32 and 164mg/l, pH varied from 7.36 to 8.49, salinity fluctuated from 15 to 35PSU, dissolved oxygen ranged from 4.08 to 7.76mg/l, ammonia varied from 0.78 to 20.32µg-at NH_3-N/l, Concentrations of nutrients, *viz*., nitrite and nitrate ranged from 0.06 to 11.70µg-at NO_2-N/l and 0.08 to 39.77µg-at NO_3-N/l respectively, phosphate and silicate varied from 0.10 to 2.80µg-at PO_4-P/l and 8.35 to 52.35µg-at SiO_3-Si/l respectively were recorded. The total of 55 species belonging to 27 genera of diatoms was recorded from six stations. Water temperature, dissolved oxygen showed significant positive correlation with total diatom species number, species richness, evenness, diversity and abundance. Nutrients, salinity showed significant negative correlation with species richness and evenness. The species diversity of diatoms were high in bar mouth region of Nethravathi and Gurupur estuary and the single species dominated during pre-monsoon season could be due to deterioration of water quality.

Keywords: diatoms, mangalore and padubidri coast, species diversity, water quality

Introduction

Diatoms are a major group of microscopic unicellular algae, and are among the most common types of phytoplankton. Among unicellular micro algae, diatoms probably represent one of the most diverse groups, in the world number of species estimated between 10,000 and 1,00,000 (Mann, 1999) [16]. Hence they constitute an ideal group to study their biodiversity and it could be correlated with the coastal water quality. Diatoms tend to have significantly higher maximum uptake rates of nutrients than any other group (Litchman *et al*., 2006) [14] and are considered as a euryhaline and eurythermal phytoplankton group, which grow quickly under estuarine conditions. They prefer to inhabit and dominate the phytoplankton community in shallow, turbulent and upwelling region i.e. coastal region. Diatom communities are a popular tool for monitoring environmental conditions, past and present, and are commonly used in studies of water quality (Reid *et al*., 1995) [26]. They are especially important in oceans, where they are estimated to contribute up to 45% of the total oceanic primary production.

Hydrological study of physico-chemical parameters are of utmost importance, as it is having lot of influence on the composition, density and relative abundance of planktonic communities which are finally going to decide the fate of productivity of coastal waters. Diatoms constitute the dominant phytoplankton group in tropical coastal waters of the Arabian Sea (Schiebel *et al*., 2001, 2004) [28, 29]. Diatom production is directly influenced by the combination of light, nutrients and temperature (Spilling *et al*., 2015) [31]. Diatoms are an important indicator of environmental changes where individual species respond directly or indirectly and sensitively to changes in physical and chemical parameters such as nutrients, silicate, phosphorous, nitrogen, pH, light and temperature (Stevenson and Pan, 1999) [32]. Diatoms are being extensively used as bio-indicators in water quality assessments as they have short generation time and many species have a specific sensitivity to ecological characteristics (Stevenson and Pan, 1999; Goma *et al*., 2005) [32]. Spatial and temporal variations in physico-chemical parameters have impact on diversity of diatoms and thereby it gives indication about the coastal water quality. Hence the present work was undertaken to study the diatom diversity in relation to physico-chemical parameters for early detection of water quality in the coastal waters of Mangalore and Padubidri, Southwest coast of India.

Materials and Methods

1. Study Area

A total of six stations were selected in the coastal waters with an average depth of 8m (Figure.1). Out of six stations selected, five stations were located in coastal waters of Mangalore and designated as S1, S2, S3, S4, S5 whereas one station was located along the coastal waters of Padubidri and designated as S6. The first station S1 was selected adjacent to the bar mouth region of Nethravathi and Gurupur estuary(12°50'766''N and 74°48'576''E), second station S2was selected in the Thannirbhavi region (12°54'468"N and 74°47'853"E), third station S3 was selected in the Chitrapur region (12°57'338"N and 74°47'085"E), fourth station S4 was selected along the coastal waters of Surathkal (13°00'535"N and 74°46'179"E), fifth station S5 was selected in the coastal waters of Mulki region (13°03'997"N and 74°43'438"E), sixth station S6 was selected along the coastal waters of Padubidri region (13°08'149"N and 74°44'336"E).

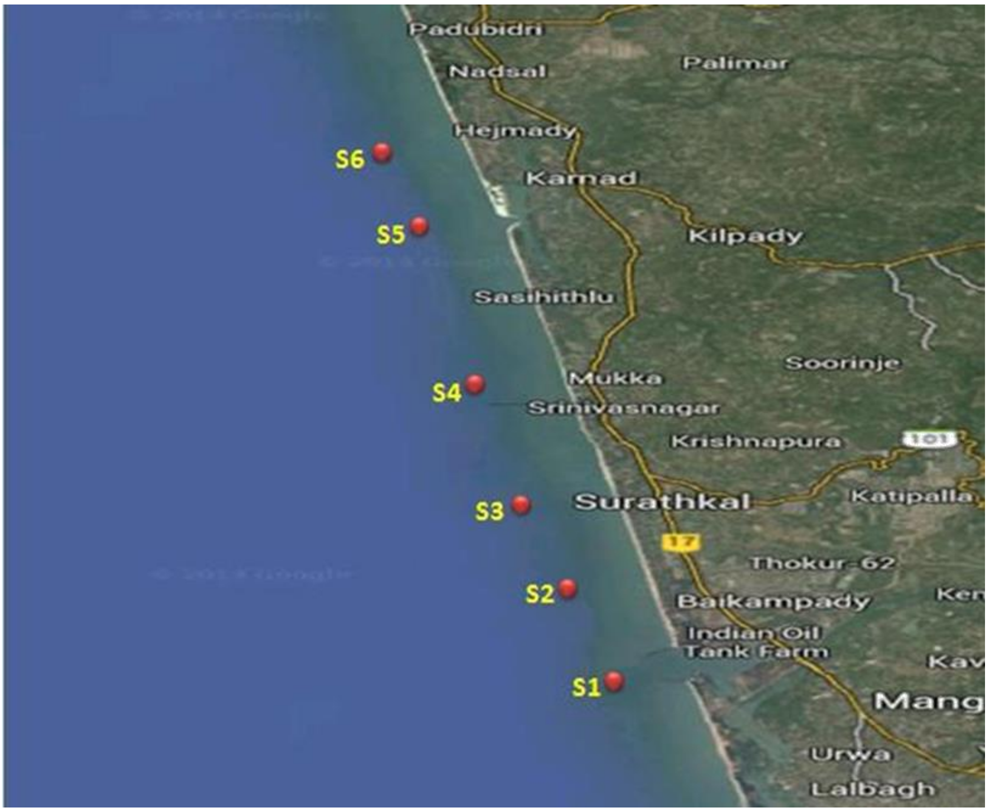

Fig 1: Map showing the location of sampling stations.

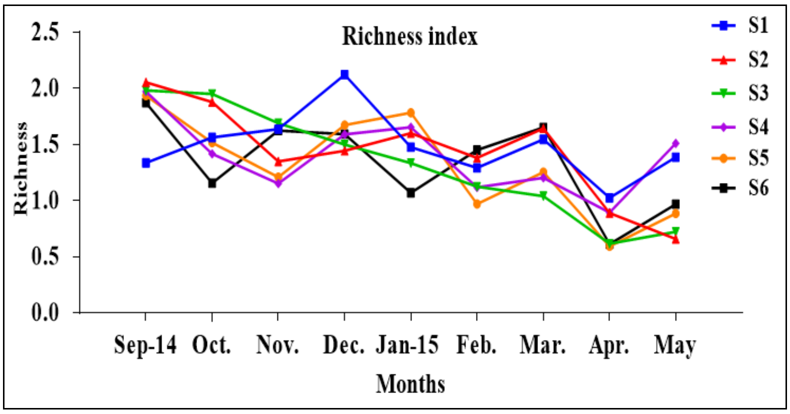

Fig 2: Spatio-temporal variations in richness of diatoms.

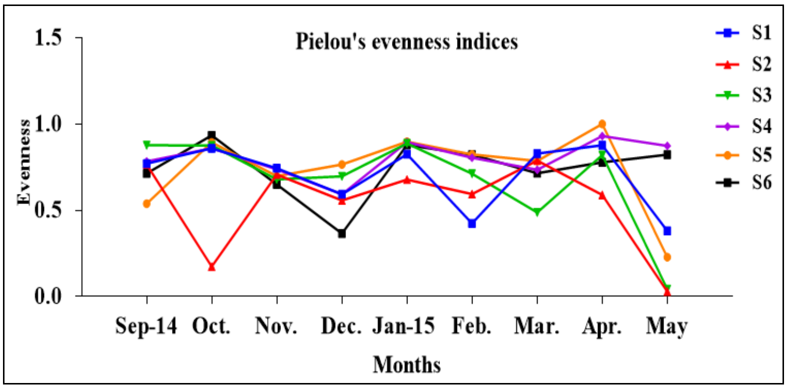

Fig 3: Spatio-temporal variations in evenness of diatoms.

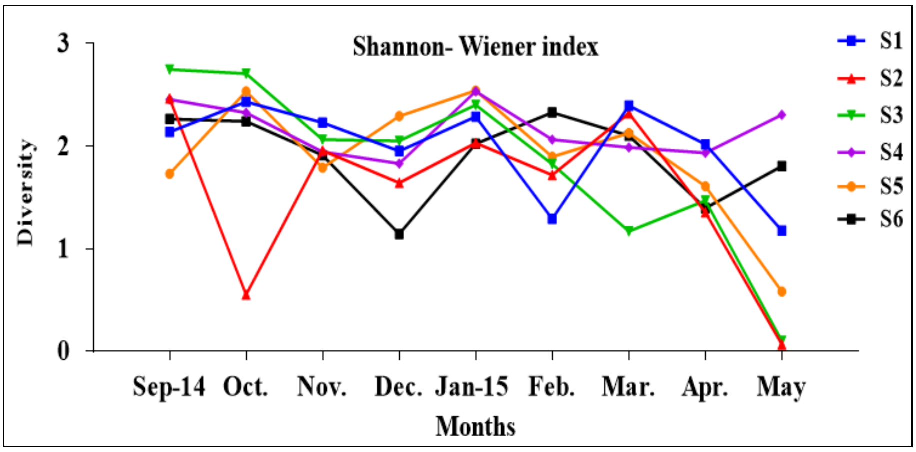

Fig 4: Spatio-temporal variations in diversity of diatoms.

2. Sample Collection and Analysis

The water samples were collected at monthly interval for a period of nine months from September 2014 to May 2015 for analysis of different physico-chemical parameters. Atmospheric and surface water temperature was recorded using standard thermometer. The pH and transparency (Light Extinction Coefficient) was measured using pH meter (EUTECH, pH 700) and Secchi disc respectively. The salinity, total suspended solids, dissolved oxygen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorous and silicate-silicon concentration of the sample were estimated following standard methods (Strickland and Parsons, 1972) [33]. The phytoplankton samples were collected by using Heron-Tranter net which was hauled vertically in each station. The net is square shaped with a mouth area of 0.25m^2 and having a filtering cone of 1.2m length with 60µ pore size. Phytoplankton samples were then preserved in 4% seawater formalin onboard the vessel for further analysis. The diatom cells present in every 1ml were identified and counted using a Sedgewick rafter cell under compound microscope (OLYMPUS CK×41) and represented as number/m^3. The diatom species were identified by referring to the standard manuals (Davis, 1955; Subrahmanyan, 1959; Newell and Newell, 1977; Desikachary, 1987; Tomas, 1996) [34, 21, 5, 37].

3. Statistical Analysis

The technique of analysis of variance (2-way ANOVA) was applied to diatom data to find out the significant relation between months and stations and the simple correlation matrix to show the relation between physico-chemical and biological parameters. Diversity indices such as species richness, evenness and diversity were calculated (Margalef, 1967; Pielou, 1975; Shannon and Weiner, 1949) [17, 24, 30].

Results and Discussion

The study of hydrographic properties of coastal waters is important as it is more prone to natural and anthropogenic activities and the variations in the instantly influence on the floral and faunal production. In the present study, monthly variations in physico-chemical and biological parameters such as surface water temperature, light extinction coefficient, total suspended solids, pH, salinity, dissolved oxygen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, silicate-silicon, phosphate-phosphorous and the numbers of diatom species were recorded. Seasonal comparisons were made as pre-monsoon (February-May), monsoon (September-October) and post-monsoon (November-January) and data on the seasonal mean of various physico-chemical and biological parameters were given in Tables 1 and 2. Correlation coefficients between physico-chemical and biological parameters from station S1 to station S6 were given in Table 3.During the study period the total rainfall received was 767.5mm from September 2014 to May 2015 (Source: Agricultural and Horticultural Research Station, Mangaluru). Maximum rainfall was observed in the months of September (291.20mm) and October (255.00mm). These monsoonal rains brought in to the study areas lot of nutrients as land run off. This evident in the present study because of high value of nutrients, supported high diversity of diatom populations like *Coscinodiscus* sp., *Chaetoceros*sp., *Skeletonema* sp., *Rhizosolenia* sp. *Navicula* sp. and *Thalassiothrix* sp. During pre-monsoon period the diatom populations were low at all the stations but high species diversity was found in station S1.

Water temperature during the sampling of different seasons was found to vary from 25.7 to 32.3^{0}C. Water temperature showed significant negative correlation with total diatom species number, species richness, species evenness and species diversity. The minimum temperature recorded during the monsoon could be attributed to the rainfall caused by the south-west monsoon (Muruganantham *et al.*, 2012) [20]. The diatom population; *Coscinodiscus excentricus*, *C. jonesianus*, *C. lineatus*, *C. oculus iridis*, *Fragilaria oceanica*, *Nitzschia closterium*, *N. longissima*, *Rhizosolenia crassispina*, *Skeletonema costatum*, *Thalassiothrix longissima*, *Rhizosolenia shrubsolei* were the most dominant species during optimum temperature condition (26-29^{o}C). According to Patrick (1967) [22] the diversity decreased when temperature moved warmer or colder from optimum range. In the present study the maximum diversity index (2.73) was observed during monsoon in low temperature and minimum diversity index (1.14) was observed during pre-monsoon in peak temperature condition. Some species of diatoms stands fairly in wide range of temperature (Sushanth and Rajashekar,2012) like *Chaetoceros curvisetus, C. decipiens, C. compressus, Bacteriastrum comosum, B. hyalinum, Lauderia annulata, Cerautilina pelagic* (<29 to >33^{o}C). Like dissolved oxygen, the temperature, nutrients, salinity and pH are said to be indicators of water quality and important for diatom distribution (Chintapenta *et al.*, 2018) [3].

The increase of temperature leads to fast growth and cause reduced generation of diatoms.

Light is an essential source for the growth of diatoms. The extinction coefficient values indicate the rate of illumination in water column. Turbidity is one of the main factors controlling light availability for the diatom. The recorded value of light extinction coefficient (LEC) was varied from 0.31 to 1.48m^{-1}. LEC not showed any direct relation with diatoms distribution and abundance during the study period. Suspended solids play an important role in the primary production. The total suspended solids in the present study ranged between 32 to 164mg/l. The high value of TSS in station S1 during the month of January may be due to dredging activities in Nethravathi River and estuary and also decayed plant and animal matters carried by the estuary.

The pH for the water samples varied from 7.36 to 8.49 during the study period. The pH showed a significant positive correlation with temperature, total suspended solids and salinity while significant negative correlation with total diatom species number and species richness. The pH concentration gets changed with time due to the changes in temperature, salinity and biological activity (Balasubramanian and Kannan, 2005) [2]. In higher pH the species diversity of diatoms was low and in lower pH the species diversity of diatoms was high. In general, changes in pH levels in marine systems appear to correlate with changes in temperature, dissolved oxygen and diatom production. When pH increases more than 8.8 there is decline in growth rate and photosynthesis. In lower pH 7.2 to 8.25 favours the growth of diatoms (Zepernick *et al*., 2021) [40]. Similar observations found in the present study the diatom species were abundant during monsoon *Coscinodiscus excentricus, Chaetoceros compressus, Rhizosolenia crassispina, Rhizosolenia setigera, Nitzschia closterium, Pleurosigma normanii* and *Skeletonema costatum* were the most dominant species. Whereas some species were restricted in higher pH such as *Bacteriastrum comosum, B. hyalinum, Lauderia annulata, Gyrosigma balticum*. In the opposite conditions like high spore production of *Chaetoceros* species in station S1 at high pH condition during May was due to nutrient enrichment from the adjacent river.

Salinity is one of the key factors that determine the distribution of diatoms. Salinity levels in coastal water vary because of river inputs, tidal and oceanic currents and influx of ground water, variable evaporation rates and freshwater runoff with rainfall. Surface water salinity in the present study was fluctuated from 15 to 35PSU. The maximum salinity was recorded during pre-monsoon season and the minimum was observed during monsoon and post-monsoon seasons. Sushanth *et al*. (2014) [35] recorded lower salinity during monsoon season and higher salinity during summer season along Arabian Sea waters of Kerala, South-west coast of India. Lower salinity associated with high nutrient load during post monsoon season favours the growth of bloom forming diatoms (Raveesha, 2007) [25] like *Skeletonema costatum, Cyclotella stelligera, Nitzschia seriata, Nitzschia longissima, Pleurosigma normanii, Thalassiosira decipiens, Coscinodiscus excentricus, Coscinodiscus lineatus, Coscinodiscus oculus iridis, Coscinodiscus radiatus, Rhizosolenia crassispina, Rhizosolenia styliformis* (15-30PSU). Some of the species were tolerant to higher salinity range (30-34PSU) such as *Bacteriastrum comosum, Bacteriastrum hyalinum, Cerautilina pelagica, Lauderia annulata, Eucampia zodiacus*. Salinity also showed a clear cut decline in pinnate diatom during pre-monsoon due to high salinity (Madhavi, 2014) [15]. Diatoms are key indicators of water health, by observing their response to varying degrees of salinity.

Dissolved oxygen is an important parameter in assessing water quality because of its influence on the organisms. High diatom production in low dissolved oxygen conditions are characteristics of nutrient enrichment condition in the coastal water. Dissolved oxygen in the present study varied between 4.08 and 7.76mg/l. Maximum dissolved oxygen was recorded during monsoon and post-monsoon seasons and minimum values were recorded during pre-monsoon. Seasonal variation in dissolved oxygen is due to freshwater flow and terrigenous impact of sediments (Kumar *et al*., 2009). Madhavi (2014) [15, 11] observed pre-monsoon minima and post-monsoon and monsoon maxima. Maximum was due to cumulative effects of higher wind velocity, increased turbulence coupled with heavy rainfall and minimum was due to high biological activity besides low solubility of oxygen under high temperature and salinity conditions. Dissolved oxygen showed a significant positive correlation with species richness, species evenness and species diversity. *Chaetoceros compressus, Chaetoceros curvisetus, Chaetoceros decipiens, Chaetoceros densum, Pleurosigma normanii, Coscinodiscus excentricus, Nitzschia seriata* were dominant in high DO content and at low DO *Bacteriastrum comosum, Bacteriastrum hyalinum, Bacteriastrum varians, Lauderia annulata* were most tolerant species. Richness and diversity index showed maximum in high DO and minimum in lower DO and evenness showed maximum and minimum in lowest DO.

In coastal regions, diatoms always prefer to inhabit and dominate the phytoplankton community because the availability of an adequate amount of nutrients and sun light which facilitates this microscopic autotrophs vigorous reproduction. The distribution of nutrients is mainly based on season, tidal conditions and freshwater influx from land source (Saravanakumar *et al.,* 2008) [27]. Ammonia is the most important nitrogen source for phytoplankton growth. Ammonia–nitrogen concentration was ranged from 0.78 to 20.32µg-at NH_3-N/l. Nitrite-nitrogen has been considered to be a very unstable component among the three nitrogenous nutrient and being an intermediately stage in the nitrogen cycle. The nitrite and nitrate values during the study period ranged from 0.06 to11.70µg-at NO_2-N/l and 0.08 to 39.77µg-at NO_3-N/l respectively. During monsoon and post-monsoon seasons nutrients were high so most of the *Chaetoceros* and *Coscinodiscus* species were abundant at this season. *Coscinodiscus* species were predominantly found only in this season and they disappeared when nutrients were low (Gligora *et al*., 2007). *Chaetoceros compressus, Chaetoceros curvisetus, Chaetoceros decipiens, Chaetoceros densum, Chaetoceros lorenzianus, Chaetoceros peruvianus, Coscinodiscus excentricus, Coscinodiscus jonesianus, Coscinodiscus lineatus, Coscinodiscus oculus iridis, Coscinodiscus radiates, Skeletonema costatum, Nitzschia closterium, Nitzschia longissima, Nitzschia seriata, Pleurosigma normanii, Planktoniella sol, Rhizosolenia alata, Rhizosolenia* *crassispina*, *Rhizosolenia setigera*, *Rhizosolenia shrubsolei*, *Rhizosolenia stolterfothii*, *Rhizosolenia styliformis* were most dominant species in high nutrient condition. Nitrite and Nitrate concentrations were showed significant positive correlation with species number and species richness. Diatoms growth mainly depends on silicate availability in addition to nitrate and phosphate. Silicate concentration in the present study varied from 8.35 to 52.35μg-at SiO_3-Si/l. In the coastal waters, diatoms utilize the dissolved silicate from the external and internal inputs. External inputs include silicate coming from land *via* rivers, ground water or the atmosphere and from the open ocean through advection of surface waters and upwelling and internal inputs of dissolved silicate through recycling in the water column, at the sediment-water interface and deeper in the sediments (Annadurai *et al.,* 2012). The growth of diatoms also depends on concentration of phosphate in coastal waters. Phosphate-phosphorus content in the present study ranged between 0.10 and 2.80μg-at PO_4-P/l. The limiting nutrient concentrations vary with season, location and phytoplankton community structure (Fisher *et al*., 1992) [6] and phosphate is one of the important organic nutrients that can limit the phytoplankton population in tropical waters.

In the present study, diatoms were dominant among all the phytoplankton community. Many studies indicated that the diatoms are most dominant phytoplankton in the west coast of India (Verlencar *et al.,* 2006) [38]. Total diatom abundance appears to be varied temporally and seasonally. Among diatoms, centrales were dominant by pennales in the coastal waters of Mangalore and Padubidri. Similar observations were also made by Karolina *et al*. (2009) [10], Kadam *et al*. (2011) [9], Sushanth and Rajashekhar (2012) [36] and Madhavi (2014) [15] in the same study area. The total of 55 species belonging to 27 genera of diatoms was recorded from six stations (Table 2). Total of 18 genera were observed in the centrales which includes *Chaetoceros* (9 species), *Coscinodiscus* (6 species), *Rhizosolenia* (6 species), *Biddulphia* (4 species), *Bacteriastrum* (3 species), *Triceratium* (2 species) and single species of *Ceratulina*, *Cocconeis*, *Cyclotella*, *Diatoma*, *Ditylum*, *Eucampia*, *Golenkinia*, *Lauderia*, *Leptocylindricus*, *Paralia*, *Planktoniella*, *Skeletonema* and 9 genera of pennales were observed which includes *Nitzschia* (3 species), *Pleurosigma* (2 species), *Thalassiosira* (2 species) and single species of *Asterionella*, *Fragilaria*, *Gyrosigma*, *Navicula*, *Thalassionema* and *Thalassiothrix*.Dominant species among centrales diatom were *Chaetoceros curvisetus followed by Chaetoceros decipiens* and *Chaetoceros compressus*. *Chaetoceros* species were recorded almost in all seasons and stations which indicate that these are tolerant to the fluctuation in wide range of physico-chemical parameters. Lathika *et al*. (2013) [12] reported the dominance of *Chaetoceros curvisetus* in the upwelling system of south-eastern Arabian sea, with a contribution of 60-90% of the total cell density and revealed that these species having high spore production and reseeding rates, which favours their occurrence in the upwelled waters. *Chaetoceros curvisetus* are suspended in the water column because their non-motile habit with valvular outgrowths (setae) which helps them to adapt the upwelling environment with continuous renewal of surface water (Margalef, 1978 and Margalef *et al*., 1979) [18, 19]. Dominant species among pennales diatom were *Nitzschia seriata* followed by *Nitzschia closterium*. The total density of *Nitzschia seriata* was 26490cells/m^3 during the study period. The high cell density (12995cells/m^3) was observed in station S4 during the month of December. The physico-chemical parameters in station S4 during the month of December were water temperature 28.9^{0}C, LEC 0.65, pH 8.23, DO 5.71mg/l, salinity 31.88PSU, total suspended solids 56mg/l, ammonia-nitrogen 3.11μg-at/land nutrients like nitrite-nitrogen 1.34μg-at/l, nitrate-nitrogen 3.48μg-at/l, silicate-silicon 31.19μg-at/l and phosphate-phosphorous 1.15μg-at/l. The dominance of *Nitzschia seriata* among pennales in the upwelling system of the south-eastern Arabian sea was also observed by Lathika *et al*. (2013) [12]. The richness (Margalef's) index varied from 0.5946 to 2.1215. The maximum index was observed in the month of December in station1 and minimum was observed in the month of April in station 5 (Figure 2).

The evenness (Pielou's) index was varied from 0.0290 to 1.0000. The maximum index was observed in the month of April in station S5 and minimum was observed in the month of May at station 2 (Figure 3). The diversity (Shannon's) index varied from 0.0668 to 2.7483. The maximum was observed in the month of September at stationS3 and minimum was observed in the month May at stationS2 (Figure 4). In all the stations the richness index was found to be highest in the monsoon and post-monsoon seasons and lowest in pre-monsoon season, the diversity index was maximum in monsoon and post-monsoon seasons and minimum in pre-monsoon season. The present study agree well with physico-chemical parameters in coastal waters particularly in bar mouth region of Nethravathi and Gurupur estuary at station S1found increase in nutrients from domestic and sewage waters discharged into adjacent rivers causing the large influx of nutrients in the study area. Hence, high density of diatoms was observed in station S1 when compared with other five stations. Abundance and distribution of diatoms are also known to determine the water quality as indicators of nutrient rich environment (Yin *et al*., 2000) [39]. The high cell density of *Chaetoceros curvisetus* was observed in station S1 (2998800cells/m^3) during the month of February. During this month, physico-chemical parameters of station S1 were water temperature 28.8^{0}C, LEC 0.92, pH 8.21, DO 5.71mg/l, salinity 31.88PSU, total suspended solids 76mg/l, ammonia-nitrogen 16.08μg-at/l and nutrients like nitrite-nitrogen 0.29μg-at/l, nitrate-nitrogen 1.30μg-at/l, silicate-silicon 30.25μg-at/l and phosphate-phosphorous 0.35μg-at/l. This indicates that these physico-chemical parameters are favourable for the growth of *Chaetoceros curvisetus*. Diatom species has a specific optimum tolerance for some environmental parameters including pH, salinity, temperature, nutrients and light availability, thereby it makes them particularly useful indicators for biodiversity (Lim *et al.,* 2001). The species diversity of diatoms were high in station S1 in all the months and the single species dominated during pre-monsoon season/summer months could be due to deterioration of water quality. Similar observations were also revealed by Person, 1989 who reported that as water quality deteriorates, the total number of species decreases and a single species or only tolerant species dominate the community.

Table 1: Seasonal mean values of physico-chemical and biological parameters at coastal waters of Mangalore and Padubidri.

Seasons	Stations	Air temp. (⁰C)	Water temp. (⁰C)	Light Extinction Coefficient (m)	Total Suspended Solids (mg/l)	pH	Salinity (PSU)	Dissolved oxygen (mg/l)	Ammonia (µg-at NH_3-N/l)	Nitrite (µg-at NO_2-N/l)	Nitrate (µg-at NO_3-N/l)	Phosphate (µg-at PO_4-P/l)	Silicate (µg-at SiO_3-Si/l)	Diatom Species richness	Diatom Species Evenness	Diatom Species Diversity
Pre-monsoon	1	27.1	29.6	0.70	87	8.27	31.10	5.00	9.10	0.54	3.02	0.66	25.83	1.31	0.63	1.72
	2	27.1	30.1	0.84	79	8.31	32.66	5.81	9.90	0.59	2.78	0.81	23.59	1.14	0.50	1.37
	3	27.3	30.1	0.82	96	8.33	33.13	5.91	9.77	0.55	1.84	1.21	22.56	0.88	0.52	1.14
	4	27.3	30.2	0.79	78	8.40	33.13	5.91	11.84	0.41	1.42	0.91	21.04	1.18	0.84	2.07
	5	27.4	30.3	0.86	71	8.35	33.52	6.01	10.65	0.44	1.24	0.91	17.64	0.93	0.71	1.56
	6	27.5	30.5	0.72	76	8.33	33.63	5.91	7.85	0.33	1.34	0.69	11.46	1.17	0.78	1.91
Monsoon	1	26.8	27.4	1.18	58	7.64	16.25	5.71	3.68	1.14	5.27	0.83	48.44	1.45	0.81	2.29
	2	26.8	27.4	0.54	86	7.97	29.07	6.52	1.99	0.74	3.00	0.93	40.08	1.97	0.47	1.51
	3	27.0	27.8	0.48	92	8.07	30.01	6.73	2.68	0.22	1.58	0.80	38.59	1.97	0.88	2.73
	4	27.1	28.3	0.50	58	8.07	31.25	6.74	1.34	0.68	1.13	1.03	38.66	1.69	0.82	2.40
	5	27.0	28.0	0.43	100	7.96	29.07	6.32	2.90	0.28	3.89	0.78	37.85	1.73	0.72	2.13
	6	27.0	28.8	0.37	90	8.09	31.26	6.12	3.16	0.36	2.43	0.95	16.80	1.51	0.82	2.26
Post-monsoon	1	25.5	28.4	0.87	103	8.02	24.79	5.98	5.62	5.43	17.23	0.39	37.07	1.74	0.72	2.16
	2	25.5	28.7	0.80	72	8.24	30.42	6.25	7.38	2.00	11.66	0.60	34.76	1.47	0.65	1.88
	3	25.7	28.8	0.82	65	8.28	31.25	5.84	9.71	1.13	5.67	1.14	28.93	1.51	0.75	2.17
	4	25.8	28.6	0.76	73	8.34	30.84	6.25	5.82	1.67	4.64	0.90	35.13	1.47	0.74	2.10
	5	26.4	28.9	0.81	65	8.36	31.04	6.25	8.15	0.38	6.99	0.79	29.46	1.56	0.79	2.21
	6	26.6	29.1	0.75	85	8.37	31.25	5.98	5.33	1.06	5.16	0.62	16.47	1.43	0.63	1.69

Table 2: Seasonal mean values of diatoms (cells/m^3) at coastal waters of Mangalore and Padubidri.

Seasons	Pre-monsoon						Monsoon						Post-monsoon					
Stations	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
CENTRALES																		
Bacteriastrum comosum	3249	3749	1250	396	1083	708	-	-	-	-	-	-	333	-	-	-	-	-
Bacteriastrum hyalinum	6123	3665	-	7539	8247	6123	-	-	84	-	417	833	56	-	555	56	333	111
Bacteriastrum varians	167	-	-	-	-	-	-	-	-	-	-	417	-	-	56	111	-	-
Biddulphia aurita	-	-	-	-	-	-	-	-	667	-	-	-	-	-	-	-	-	-
Biddulphia mobiliensis	750	708	458	84	750	42	333	333	1000	333	1333	500	1888	1166	1777	2554	944	1055
Biddulphia regia	416	125	125	417	83	417	334	417	2248	500	2333	84	1722	1666	1222	889	611	1833
Biddulphia sinensis	2208	1958	3124	375	2458	3041	667	417	1000	-	667	167	3665	5109	7275	3943	1888	4221
Cerautilina pelagica	167	167	331	542	2416	458	-	-	-	-	-	-	-	-	-	-	-	222
Chaetoceros affinis	-	-	42	-	-	-	-	-	-	-	-	-	-	-	56	-	-	-
Chaetoceros compressus	200087	-	-	-	-	-	8330	1916	3499	6664	14578	28406	21991	37985	20658	11329	6553	34986
Chaetoceros curvisetus	1249500	7039	1458	1874	166600	2166	-	-	1250	333	667	3749	6331	5942	4831	12884	4831	239873
Chaetoceros decipiens	258563	212415	249900	9954	12495	4623	2916	2499	3166	9163	16327	16244	36097	43705	31598	12273	9163	30932
Chaetoceros densum	133280	-	-	833	250	-	-	167	-	-	833	4582	-	555	3887	79968	-	-
Chaetoceros diversus	-	-	-	-	-	2666	-	1166	1000	-	333	-	111	-	-	-	-	9441
Chaetoceros lorenzianus	160019	26156	4373	833	-	250	1333	2833	4082	667	1250	5831	1111	1444	444	-	-	1388
Chaetoceros peruvianus	-	-	-	-	-	-	-	833	833	833	-	-	-	-	-	-	-	-

Chaetoceros teres	216580	12329	2083	833	1666	-	-	-	-	-	-	-	444	19714	2221	722	2499	-
Cocconeis littoralis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	56	-	-
Coscinodiscus excentricus	1833	666	457	208	1125	4040	10163	7585	5334	3918	7667	2834	6775	1222	888	1499	555	500
Coscinodiscus jonesianus	-	-	-	-	-	-	-	1667	-	-	-	-	-	-	-	-	-	-
Coscinodiscus lineatus	750	375	792	292	83	333	5331	13003	3167	2501	3584	1000	1333	555	2832	1000	722	1111
Coscinodiscus oculus iridis	500	1041	417	208	916	333	6498	9247	2916	1834	4001	417	278	2332	1333	444	222	111
Coscinodiscus peruvianus	1500	-	-	-	-	-	-	-	-	-	-	2916	-	-	-	-	-	-
Coscinodiscus radiatus	-	-	-	-	-	-	-	1334	250	167	84	-	-	-	-	-	-	-
Cyclotella stelligera	417	125	42	-	84	-	416	500	833	333	1916	167	833	167	722	24824	222	111
Diatoma vulgare	-	-	-	-	-	-	-	167	-	167	-	-	-	56	-	-	-	-
Ditylum brightwellii	4082	2999	1000	3540	4667	875	333	583	833	167	-	-	4054	6609	12051	31987	3054	2055
Eucampia zodiacus	-	333	-	375	1666	667	-	-	-	-	-	-	56	-	-	-	-	-
Golenkinia sp.	-	-	-	-	-	-	-	-	-	-	-	-	222	-	-	-	-	-
Lauderia annulata	13578	3332	1749	3582	3415	583	-	417	-	-	-	1250	944	2499	-	444	666	777
Leptocylindricus danicus	83	-	-	-	-	417	-	-	-	-	-	-	-	-	-	-	-	-
Paralia sulcata	-	-	-	-	-	-	-	-	84	-	-	-	-	-	-	-	-	-
Planktoniella sol	1000	250	-	84	42	167	167	417	833	333	334	917	2499	1555	3110	666	611	222
Rhizosolenia alata	1583	292	375	42	125	83	-	-	333	84	84	833	-	-	-	3222	111	1333
Rhizosolenia crassispina	83	83	-	-	-	42	417	667	1666	1000	833	833	-	222	-	-	-	-
Rhizosolenia setigera	-	83	-	-	-	-	-	333	417	333	84	-	-	-	-	-	-	-
Rhizosolenia shrubsolei	-	-	-	-	-	83	-	-	-	5165	2916	4998	333	-	-	-	-	222
Rhizosolenia stolterfothii	12828	4457	208	2832	666	583	1666	1000	4165	1000	833	2083	111	1111	222	56	56	1277
Rhizosolenia styliformis	250	-	-	208	-	167	-	250	167	-	84	-	444	-	1833	389	167	-
Skeletonema costatum	1833	-	-	-	-	-	4165	95462	5248	2582	69139	26656	13661	10551	3276	12162	3110	4887
Triceratium favus	83	833	-	-	83	-	-	-	-	-	167	-	56	-	56	-	111	333
Triceratium reticulate	1666	1583	250	2707	1166	417	-	84	-	-	-	417	1666	1666	777	444	333	3998
Total Centrales	2273173	284760	268431	37757	210085	29281	43065	143291	45068	38072	130457	106127	107012	145830	101682	201920	36764	340999
% contribution	99.84	99.51	99.88	91.24	99.53	95.64	83.52	88.16	79.33	85.10	92.83	95.86	92.87	93.62	90.73	95.53	96.78	96.80
PENNALES																		
Asterionella japonica	83	-	-	-	-	-	-	-	-	-	-	417	-	-	-	-	56	-
Fragilaria oceanica	833	208	-	2291	667	83	-	1501	334	-	-	-	56	4667	1611	278	222	8552
Gyrosigma balticum	83	83	42	-	-	-	-	-	-	-	-	-	1222	111	-	-	-	-
Navicula longa	208	417	208	-	-	-	917	500	1416	-	667	333	111	167	111	-	222	-
Nitzschia closterium	2000	83	-	-	83	791	417	9580	3832	2166	3999	1583	666	555	777	1444	-	722
Nitzschia longissima	167	-	-	625	83	-	-	2499	583	167	-	-	-	-	-	-	111	-
Nitzschia seriata	42	-	-	708	167	-	2499	167	-	2000	2416	833	4331	3332	7330	6553	333	944
Pleurosigma elongatum	250	417	-	-	-	-	417	-	1250	333	417	417	-	-	-	-	-	-
Pleurosigma normanii	83	167	83	-	-	458	4248	4832	4165	2000	2249	1000	278	555	222	888	278	611
Thalassionema nitzchiodes	-	-	-	-	-	-	-	167	-	-	-	-	-	555	-	-	-	-
Thalassiosira decipiens	-	-	-	-	-	-	-	-	-	-	333	-	1555	-	333	278	-	333
Thallasiosira gravida	-	42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassiothrix longissima	-	-	-	-	-	-	-	-	167	-	-	-	-	-	-	-	-	111
Total Pennales	3749	1416	333	3624	1000	1333	8497	19244	11746	6665	10079	4581	8219	9943	10385	9441	1222	11273
% contribution	0.16	0.49	0.12	8.76	0.47	4.35	16.48	11.84	20.67	14.90	7.17	4.14	7.13	6.38	9.27	4.47	3.22	3.20
Total Diatoms	2276922	286176	268764	41381	211085	30614	51562	162535	56814	44736	140537	110708	115231	155773	112067	211361	37986	352272

Table 3: Correlation (significant at 99% and 95%) coefficients between physico-chemical and biological parameters.

Parameters	AT	WT	LEC	pH	DO	NH_3	NO_2	NO_3	SiO_3	Sal	TSS	TS	TI	R	E
LEC	-.740* (S4) -.728* (S6)	-.821**(S1)													
pH		.723* (S3) .709* (S4) .727* (S5)													
DO		-.815**(S2) -.724* (S3) -.832**(S4) -.764* (S5)													
NH_3			.749* (S5)												
NO_2	-.711* (S4)	-.666* (S4)	.780* (S3)												
NO_3							.975**(S1) .968**(S2) .915**(S4)								
Sal		.669* (S2) .678* (S4) .710* (S5)		.710* (S2)			-.689* (S4)		.891**(S1)						
TSS				.738* (S4)	.671* (S6)		-.746* (S2)	-.728* (S2) -.719* (S3)							
TS		-.812**(S2) -.678* (S5)		-.743* (S4) -.697* (S5)						-.692* (S2) -.873**(S5)	-.738* (S4)				
TI					-.679* (S2) -.720* (S6)	.672* (S1)									
R		-.826**(S2) -.764* (S5)		-.670* (S4)	.716* (S2)		.798**(S1)	.776* (S2)	-.716* (S1)	-.907**(S5)		.788* (S1) .980**(S2) .975**(S3) .884**(S4) .934**(S5) .964**(S6)			
E		-.728* (S3)			.779* (S6)							-.691* (S1) -.676* (S6)	-.879**(S1) -.802**(S2) -.875**(S3) -.872**(S4) -.926**(S5) -.891**(S6)		
D		-.809**(S3)			.697* (S2)							.724* (S3)	-.912**(S1) -.748* (S2) -.737* (S3) -.821**(S5)	.833**(S3)	.928**(S1) .980**(S2) .914**(S3) .769* (S5)

**.Correlation is significant at the 0.01 level (2-tailed).

*.Correlation is significant at the 0.05 level (2-tailed).

Conclusion

The species diversity of diatoms in the coastal waters of Mangalore and Padubidri showed clear seasonal patterns. The study showed that the stations S2, S3, S4, S5 and S6 are in a good state of health as they reflected water quality is in normal condition and diatom species were evenly distributed compared to station S1. The species diversity of diatoms were high in bar mouth region of Nethravathi and Gurupur estuary (station S1) in all the months and the single species dominated during pre-monsoon season/summer months could be due to deterioration of water quality. Regular assessment of spatio-temporal variation in physico-chemical parameters is necessary to understand the correlation between physico-chemical parameters on diatom diversity thereby it gives early detection of coastal water quality.

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