RESEARCH ARTICLE

Physico-chemical parameters and phytoplankton diversity of Netravathi - Gurupura Estuary, Mangalore, South west coast of India

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ABSTRACT

Water samples were collected from Netravathi estuary, Gurupura estuary and estuarine mouth with plankton collection net and different physico-chemical parameters were measured simultaneously to understand the Biophysicochemical conditions as they are important biological indicator of water quality. In the present study one-hundred and nineteen species in six divisions of phytoplankton were recorded. The maximum percentage of species were from division Bacillariophyta (77.31%), followed by Dinoflagellata (10.92%), Cyanobacteria (5.04%), Chlorophyta (4.20%), Ochrophyta (1.68%), Heterokontophyta (0.84%) respectively. The most diverse genus was Chaetoceros and Coscinodiscus (10 species each). The greatest number of phytoplankton diversity was found in Netravathi estuary (93) followed by estuarine mouth (77) and Gurupura estuary (61). Variations in physico-chemical parameters were observed at different study sites. The study infers that the phytoplankton diversity and distribution are subject to changes in physico-chemical conditions of the ecosystem. Therefore a frequent monitoring of these ecosystems with its physico-chemical conditions and biological diversity is crucial to know the health of such globally threatened ecosystem.

Keywords: Physico-chemical, Estuary, Ecosystem, Phytoplankton, Diversity

INTRODUCTION

Phytoplankton are normally unicellular microscopic wanderer with size ranging between 0.4 to 200 μm and are the autotrophies of plankton, as they get their energy through the process of photosynthesis and transfer to higher organisms by food chain (Tiwari and Chauhan, 2006; Saifullah *et al.*, 2014). These are about 1% in photosynthetic biomass of our earth but, 45% of annual primary production is through them (Field *et al.*, 1998). Several studies have illustrated the significance of diversity and distribution of the Phytoplankton (Dakshini and Soni, 1982; Brown, 1998; Geetha Madhav and Kondalarao, 2004; Sushanth *et al*., 2011), as they are biological indicators for level of eutrophication and water quality (Chaturvedi *et al*., 1999; Shashi Shekhar *et al*., 2008). Variations in the Phytoplankton abundance from selected estuaries of Karnataka Coast were reported by Karolina *et al*., (2009), Andrade *et al*., (2011) and Kaladharan *et al*., (2011). The qualitative and quantitative studies have been used in the assessment of phytoplanktonic diversity and quality of the ecosystem (Adoni *et al*., 1985 and Chaturvedi *et al*., 1999).

An estuary may be formed by conjunction of one or more river or stream that opens to the sea. These are vital aquatic ecosystem that are transition between terrestrial and aquatic system, where significant change in the physico-chemical properties and biological processes were observed due to the mixing of fresh and marine waters (Patterson and Ayyakkannu, 1991; Bardarudeen *et al*., 1996; Senthilkumar *et al*., 2002; Prasanna and Ranjan, 2010). Estuaries are influenced by various physical, chemical and biological factors, however the plankton being majorly primary producers and decomposers, can change physical and chemical properties of the water to a wide extent in any estuary (De Jonge *et al*., 2002). The health of any aquatic ecosystem majorly depends on the diversity and distribution of phytoplankton (Khattak *et al*., 2005) which is connected with the water quality of the ecosystem (Pattrick, 1977).

MATERIAL AND METHODS

Study area

The present study was carried out in Netravathi - Gurupura estuarine complex (12.90^{0}52'68", 74.82^{0}13'58" to 12.82^{0}81'36", 74.85^{0}89'45") along Mangalore on the South-West coast of India, which is open to Arabian sea throughout the year. The study area is divided into three sampling locations, the Gurupura estuary - site 1, the estuarine mouth - site 2 (connecting to Arabian Sea) and the Netravathi estuary - site 3 (Figure 1).

Sample collection and Analysis

The water samples were collected during June 2015 to May 2016 for analysis of different physico-chemical parameters. Atmospheric and surface water temperature was recorded using centigrade thermometer. The pH, salinity, turbidity and conductivity were measured using Systronics water analyzer 371. The dissolved oxygen, biological oxygen demand, nitrate and phosphate concentration of the sample were analyzed according to standard methods (APHA, 2012).

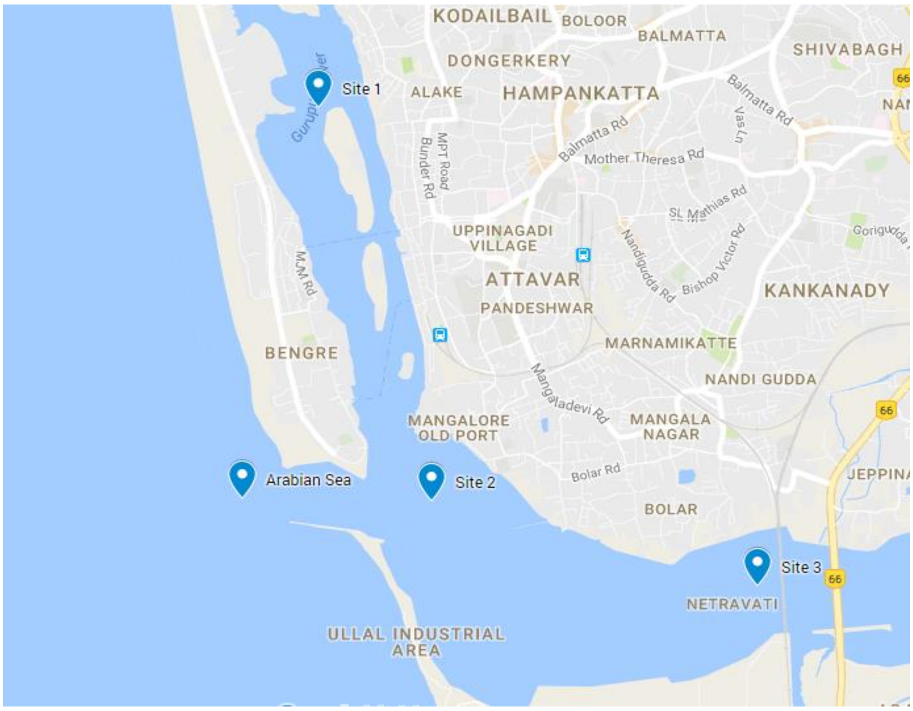

Figure 1: Map of Netravathi - Gurupura estuarine complex showing the sampling sites.

Simultaneously phytoplankton samples were collected by towing the plankton net of mesh size 30µm all along the stretch of each study area to filter the surface water. The sampling was done at morning hours of ebb tide to reduce diurnal tidal variation. The sample collected is transferred to a 2 liter opaque polyethylene bottles and were fixed immediately with 4% formalin (Parsons *et al.*, 1984) followed by addition of 20ml lugol's Iodine solution (Hällfors *et al.*, 1979; Köster *et al.*, 2008) and allowed to settle down. After half an hour the samples were transported to laboratory for further analysis. Plankton identification was carried out with standard manuals (Subrahmanyan, 1959; Egborge, 1973; Newell and Newell, 1977; Maosen, 1978; APHA, 1985; Desikachary, 1987; Tomas, 1997) using Lawrence and mayo microscope. The observed phytoplankton are photographed using Nikon coolpix digital camera.

Biodiversity indices such as Phytoplankton diversity index, species richness index and evenness index were calculated with the following standard formulae.

The diversity index was calculated using the Shannon - Wiener diversity index (H') (Shannon - Wiener, 1949).

$$H' = -\sum_{i=1}^{s}(P_i * Ln(P_i))$$

where $P_i = S / N$
S = number of individuals of one species
N = total number of all individuals in the sample
Ln = Natural logarithm

The species richnessindex was measured by using the Margalef's species richness index (d') (Margalef, 1958).

$$d' = \frac{(S - 1)}{Ln(N)}$$

where S = total number of species
N = total number of individuals in the sample
Ln = Natural logarithm

The evennessindex was analysed by adopting the Pielou's species evenness index (J') (Pielou, 1966).

$$J' = \frac{H'}{Ln(S)}$$

where H' = Shannon -Wiener diversity index
S = total nmber of species in the sample
Ln = Natural logarithm

RESULTS AND DISCUSSION

In the present study total 119 phytoplankton species were recorded (Table 1) in six divisions, 92 species were from Bacillariophyta (77.31%) followed by 13 Dinoflagellates (10.92%), 6 Cyanobacteria (5.04%), 5 Chlorophytes (4.20%), 2 Ochrophytes (1.68%) and1 Heterokontophyta (0.84%) in the Netravathi - Gurupura estuarine complex (Figure 2). The genus *Chaetoceros* and *Coscinodiscus* was found to be most diverse with 10 species each. The stability of an ecosystem could be assessed by analysing the diversity of phytoplankton in any particular system (Ptacnik *et al.*, 2008). Bacillariophytes were highly dominant followed by Dinoflagellates at all the study sites during the study period which co-relates that these adopts efficiently with the changes in the Physico-chemical conditions. Cyanobacteria, Chlorophytes, Ochrophytes and Heterokontophyta had very few species in all the study sites (Table 2).

Among the three different sites, the contribution of species at site 1, the maximum observed was Bacillariophyta 49 (80.33%) followed by Dinoflagellates 8 (13.11%), Cyanobacteria 3 (4.92%) and Chlorophytes 1 (1.64%)(Figure 3). At site 2 the maximum species was recorded in Bacillariophyta 59 (76.62%) followed by Dinoflagellates 11 (14.29%), Cyanobacteria 4 (5.19%), Chlorophytes 1 (1.30%), Ochrophytes 1 (1.30%) and Heterokontophyta 1 (1.30%)(Figure4). In site 3 the maximum species was recorded in Bacillariophyta 69 (74.19%) followed by Dinoflagellates 12 (12.90%), Cyanobacteria 6 (6.45%), Chlorophytes 4 (4.30%), Ochrophytes 1 (1.08%) and Heterokontophyta 1 (1.08%)(Figure5). These results indicated that the number of phytoplankton varied considerably with different study site which may be due to fluctuations in physico-chemical parameters and sheltered systems of estuarine waters (Table 3). The present results were in accordance with results as noticed by Perumal *et al.*, 2009. Similar findings on the phytoplankton were also recorded at off west coast of Arabian Sea (Subrahmanyan, 1959).

Among the study sites the highest species diversity, richness and evenness was observed in site 3 and lowest diversity, species richness was observed in site 1 (Table 4). This may be attributed to the dominance of Bacillariophytes and changes in the physico-chemical properties.

Table 1: List of Phytoplankton recorded in Netravathi - Gurupura estuarine complex ('+++' highly abundant (> 10000 cells/L), '++' moderately abundant (100 - 10000 cells/L), '+' present (1 - 100 cells/L) and '-' absent).

Phylum / Division / Species	Site - 1	Site - 2	Site - 3
BACILLARIOPHYTA			
Achnanthes linearis	-	-	++
Amphiprora alata	-	-	+
Amphiprora gigantea	-	+	+
Amphiprora paludosa	-	+	-
Amphora coastata	-	++	++
Amphora coffeaeformis	++	-	+
Amphora proteus	-	-	++
Asterionella japonica	-	-	+
Bacillaria paradoxa	+	+	++
Biddulphia aurita (Lyngb.) Breb.	-	++	-
Biddulphia longicuris Grev.	-	+	-
Biddulphia mobiliensis (Bail.) Grun.	++	++	+++
Biddulphia regia	+	-	+
Caloneis liber (Wm. Smith) Cl.	+	-	++
Chaetoceros compressus Lauder	-	+	-
Chaetoceros curvisetus	-	+	-
Chaetoceros danicus	-	++	+
Chaetoceros decipiensHust.	+	+	-
Chaetoceros diversus Cl.	+++	+++	++
Chaetoceros gracile	+++	+	-
Chaetoceros lorenzianus	-	-	+
Chaetoceros paradoxus Schutt	+	+	+
Chaetoceros peruvianus	-	++	-
Chaetoceros simplex	-	+	+
Coscinodiscus concinnus	-	+	++
Coscinodiscus curvatulus	-	-	+
Coscinodiscus gigasEhrenb.	+	+	++
Coscinodiscus granii Gough	+	++	+++
Coscinodiscus marginatusEhrenb	-	++	-
Coscinodiscus radiatusEhrenb.	+	+	++
Coscinodiscus rothii (Ehrenb.) Grun.	-	-	+
Coscinodiscus sp	++	-	+
Coscinodiscus stellaris Roper	++	+++	++
Coscinodiscus suspectus Jan	-	+	-
Cyclotella pelagica	-	-	+
Cylindrotheca closterium	+	+	+
Cymbella aspera	-	-	+
Cymbella tumida	+	-	+++

Dactyliosolen phuketensis	-	+	-
Diploneis sp.	++	+	++
Diploneis splendica	+	-	++
Ditylum brightwellii (West)	++	++	+++
Ditylum sol Grunow in Van Heurck	++	++	+++
Eucampia cornuta	-	-	+
Grammatophora marina	-	-	+
Guinardia striata	-	-	++
Gyrosigma balticum (Ehrenberg) Robenhorst	++	-	-
Hemiaulus sinensis Grev.	-	+	-
Hemidiscus hardmanianus (Grev.) Mann	++	+++	+++
Hemidiscus sp	+++	+++	+++
Hyalodiscus radiates Cl. and Grun.	-	-	+
Licmophora gracilis	+	-	++
Mastogloia paradoxa	++	+	++
Melosira sphaerica Pennates	-	+	++
Melosira sulcate	-	+	-
Navicula clavata	-	-	+
Navicula inflexa	+	-	++
Navicula lanceolata Grun.	-	-	+
Navicula longa	+	-	-
Navicula smithii	++	-	+
Navicula sp.	++	+++	+++
Nitzschia angularis	+	-	-
Nitzschia closterium	+	+	+++
Nitzschia frigid	-	+	+
Nitzschia longissima (Brebisson, in Kutzing) Ralfs in Pritchard	+	+	+++
Nitzschia panduriformis	+	++	+
Nitzschia sigma	++	+++	++
Odontella sinensis	+	++	+
Pinnularia viridis	+	+	+
Pleurosigma aestuarii (Breìbisson) W. Smith	+	-	-
Pleurosigma angulatum	++	++	+
Pleurosigma delicatum	+++	+++	++
Pleurosigma directum Grunow	-	+	-
Pleurosigma elongatum	-	-	++
Pseudonitzschia australis Frenguelli	+	+	+
Pseudonitzschia delicatissima (Cleve) Heiden in Heiden and Kolbe	++	+++	++
Rhizosolenia alata	+	++	++
Rhizosolenia castracanei Perag.	+++	+	++
Rhizosolenia cochlea Brun.	-	-	+
Rhizosolenia crassispina Schrod.	++	-	+++
Rhizosolenia hebetata Bail.	-	+	-

Rhizosolenia hyaline	-	+	-
Rhizosolenia imbricata	-	+	++
Rhizosolenia styliformis	-	++	-
Skeletonema costatum	+++	+++	+++
Synedraacus	+	+	-
Synedra tabulate	+	+	-
Thalasseonema sp.	++	+	+++
Thalassionema nitzschioides	-	-	++
Thalassiosira anguste	++	+	+
Thalassiothrix longissima	-	-	++
Triceratium robertsianum	-	+	++
DINOFLAGELLATA			
Alexandrium sp.	+	-	+
Ceratium breve (Ostenfeld et Schmidt) Schroder	-	+++	++
Ceratium declinatum (Karsten) Jörgensen	++	++	+++
Ceratium falcatum (Kofoid) Jorgensen	+++	-	+++
Ceratium furca	++	+++	++
Ceratium macroceros (Kofoid) Schiller	-	++	++
Ceratium minutum	+++	++	++
Ceratium trichoceros (Ehrenberg) Kofoid	-	+++	++
Dinophysis caudata	++	+++	+++
Prorocentrum micans	-	+	+++
Protoperidinium elegans Cleve	+++	+	+++
Protoperidinium obtusum	-	+	-
Pyrophacus horologium Stein	+	+	+
CYANOBACTERIA			
Microcystis aeruginosa	-	-	+
Merismopedia sp.	+	+	+
Oscillatoria cortiana	-	-	+
Oscillatoria limosa	+	++	++
Oscillatoria tenius	+	+	+
Phormidium lucidum	-	++	++
CHLOROPHYTA			
Chlamydomonas reticulate	-	+	-
Chlorella sp.	-	-	+
Closterium intermedium	+	-	+
Scenedesmus quadricauda	-	-	+
Schroederia sp	-	-	+
OCHROPHYTA			
Asteromphalus sp	-	-	+
Dictyocha fibula	-	+	-
HETEROKONTOPHYTA			
Bacteriastrum delicatulum Cl.	-	+	++

Table 2: Phytoplankton taxonomic distribution in the Netravathi-Gurupura estuarine complex.

Group	Bacillariophyta	Dinoflagellata	Cyanobacteria	Chlorophyta	Ochrophyta	Heterokontophyta	Total
Class	3	1	1	3	2	1	11
Order	20	4	3	5	2	1	35
Family	28	5	3	5	2	1	44
Genera	38	5	4	5	2	1	55
Species	92	13	6	5	2	1	119

Table 3: Phytoplankton count in the Netravathi-Gurupura estuarine complex during the study period.

Phylum/Division	Site - 1	Site - 2	Site - 3
Bacillariophyta	49	59	69
Dinoflagellata	08	11	12
Cyanobacteria	03	04	06
Chlorophyta	01	01	04
Ochrophyta	00	01	01
Heterokontophyta	00	01	01
Total number of species	61	77	93

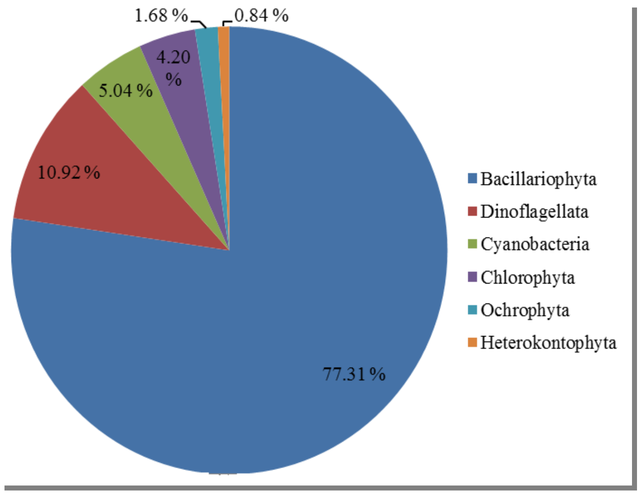

Fig. 2: Percentage of Phytoplankton of different Phylum / Division during the study period

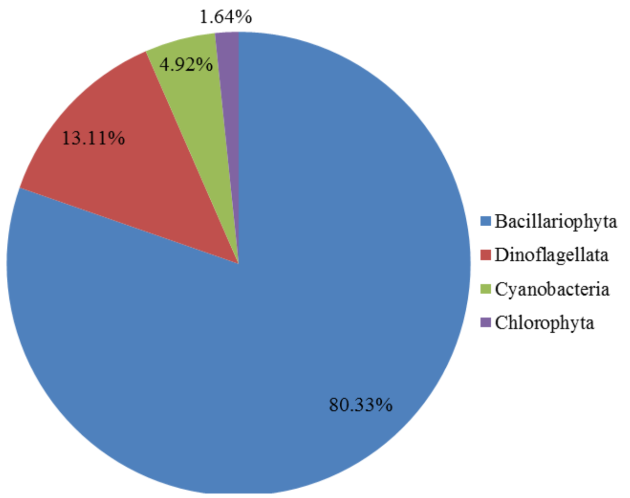

Fig. 3: Phytoplankton percentage of different Phylum / Divisionat site 1

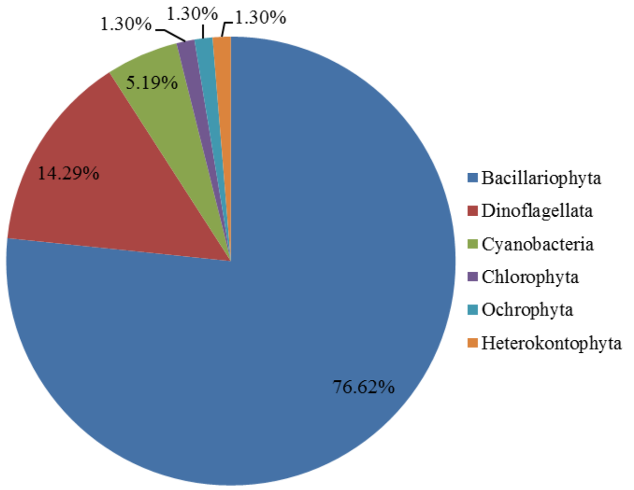

Fig. 4: Phytoplankton percentage of different Phylum / Divisionat site 2

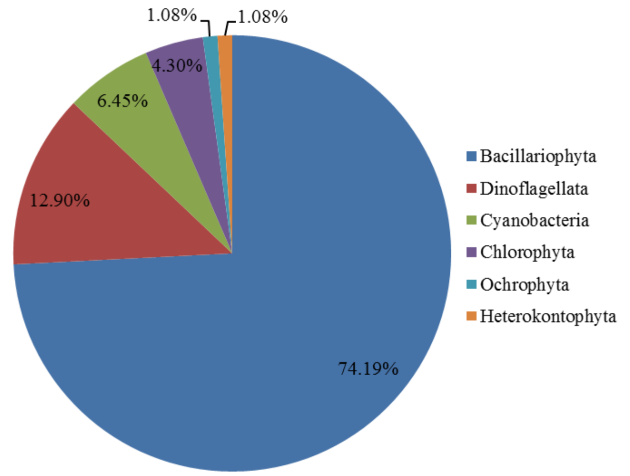

Fig. 5: Phytoplankton percentage of different Phylum / Division at site 3

The physico-chemical parameters are the important control for the diversity of phytoplankton in any aquatic ecosystem (Hulyal and Kaliwal, 2009). Plankton diversity changes could be observed when few groups dominate in a community, more common group replace a rare group or few groups rapidly reproduce (Robinetal., 2010). In the present study, the Bacillariophytes like *Biddulphia mobiliensis, Chaetoceros diversus, Coscinodiscus granii, C. stellaris, Ditylum brightwellii, D. sol, Hemidiscus hardmanianus, Navicula sp., Nitzschia sigma, Pleurosigma delicatum, Pseudonitzschia delicatissima, Rhizosolenia castracanei, Skeletonema costatum* and *Thalasseonema sp.* and the Dinoflagellates like *Ceratium sp.,* and *Dinophysis caudata*were dominant which might be due to their resistance to the changes in the physico-chemical conditions. The diversity of phyto-plankton varied with levels of stability of physico-chemical parameters which was also observed by Rajesh *et al.* (2002). Hence these organisms could flourish and dominate the phytoplankton community in this ecosystem. The highest phytoplankton diversity and richness are found in Karnataka coastal water as reported by Robin *et al.* (2010).

Table 4: Diversity index, richness index and evenness index of phytoplankton sampling sites during the study period. (H' = Shannon-Wiener diversity index; d = Margalef's species richness index; J = Pielou's evenness index)

Biodiversity indices	Site - 1	Site - 2	Site - 3
Diversity index (H')	4.017	4.231	4.442
Richness index (d)	13.03	15.79	18.04
Evenness index (J')	0.978	0.974	0.979

Atmospheric Temperature

The Atmospheric Temperature maximum was recorded as 32.35°C and 32.07°C during post-monsoon season at site 2 and pre-monsoon season at site 3 and was recorded minimum as 27.50°C and 28.00°C during the winter season at site 2 and site 1 (Figure 6).

Water Temperature

The water temperature is a critical parameter that control aquatic biota (Wetzel, 1983). Maximum water tempera-ture was recorded as 32.80°C and 32.30°C during post-monsoon season at site 2 and site 3 and was recorded minimum 28.90°C and 29.00°C during the Monsoon and winter season at site 1 (Figure 7).

Salinity

The Salinity maximum was recorded as 35.50ppt and 33.83ppt during pre-monsoon season at site 2 and site 3 and was recorded minimum 9.33ppt and 14.77ppt during the Post monsoon season at site 3 and site 1 (Figure 8). These variations in salinity between stations could also be due to tidal influence. Madhavi *et al*, (2014), has reported that the plankton diversity vary with the change in salinity gradient.

Electrical Conductivity (EC)

The electrical conductivity highly depends on the amount of dissolved solids in water and it varies with season. The maximum electrical conductivity was recorded 60.78mS and 58.45mS during monsoon and pre-monsoon season at site 2 and was recorded

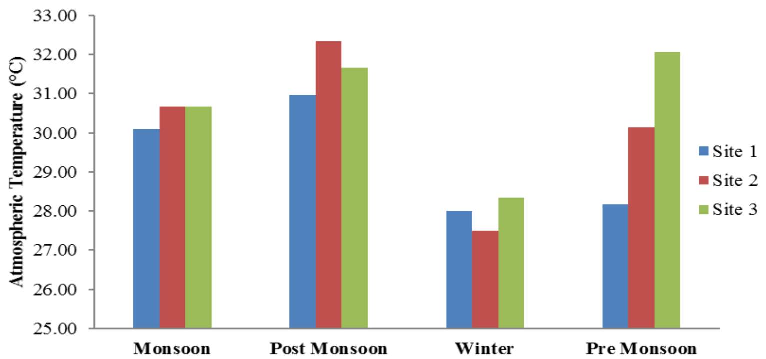

Fig 6: Atmospheric Temperature (°C) at different study sites in different seasons

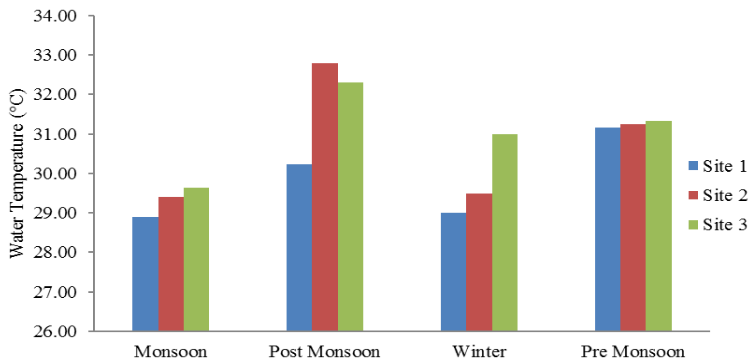

Fig 7: Water Temperature (°C) at different study sites in different seasons

minimum 13.25mS and 20.78mS during the Post monsoon season at site 3 and site 1 (Figure9).

Hydrogen ion concentration (pH)

The Hydrogen ion concentration between the sampling sites was slightly alkaline during the study period with maximum record 8.23 and 7.85 during post-monsoon season at site 2 and site 3 and minimum record 7.16 and 7.31 during the winter season at site 1 and site 3 (Figure 10). This variation might be due to buffering effect of tidal sea water. In general pH values are high when the temperature found to be high which could be due to planktonic consumption of Carbon-di-oxide and increased rate of evaporation in the monsoon period. Such change was also been noticed in Netravathi estuary by Rajesh *et al.*, 2001 and in Pazhayakayal estuary by Rani *et al.*, 2012.

Turbidity

The turbidity maximum was recorded 4.83NTU and 4.41NTU during winter season at site 3 and site 1 and was recorded minimum 0.59NTU and 0.91NTU during the pre monsoon season at site 2 and site 3 (Figure 11). The turbidity of the surface water may be due to the presence of Clay, silt, organic matter and plankton, which in other way become a limiting factor for biological productivity (Kishore *et al.*, 2005).

Dissolved Oxygen (DO)

Dissolved oxygen is avital environmental parameter to decide ecological health of aquatic ecosystem (Chang, 2002). It is known that the temperature and salinity alters the dissolved oxygen content in any water body (Vijayakumar *et al.*, 2000). The maximum dissolved oxygen was recorded as 7.75mg L^{-1} and 7.43mg L^{-1} during pre-monsoon season at site 2, site 1 and site 3 and was recorded minimum 4.37mg L^{-1} and 4.80mg L^{-1} during the post monsoon season at site 1 and site 2 (Figure 12).

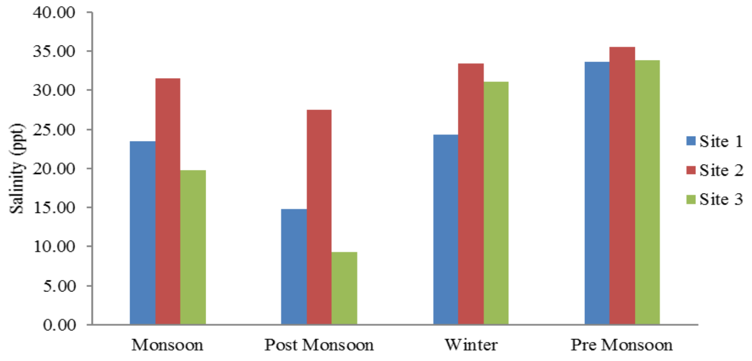

Fig 8: Salinity (ppt) at different study sites in different seasons

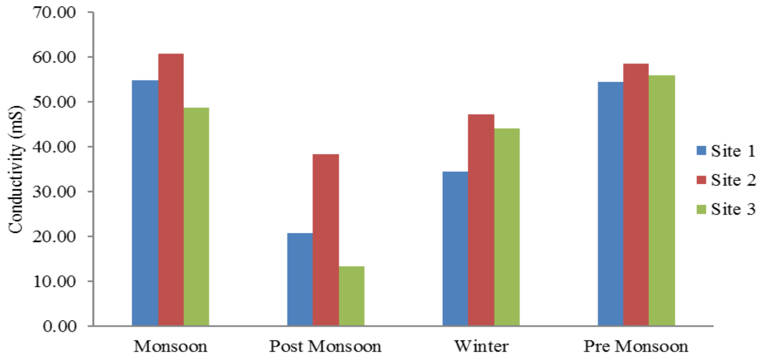

Fig.9: Conductivity (mS) at different study sites in different seasons

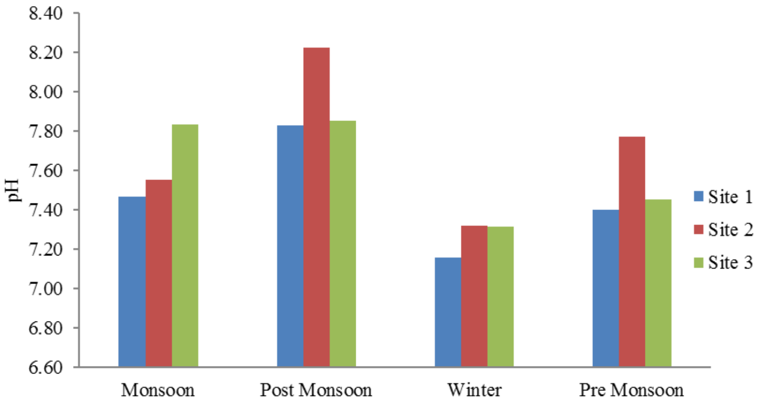

Fig 10: Hydrogen ion concentration (pH) at different study sites in different seasons.

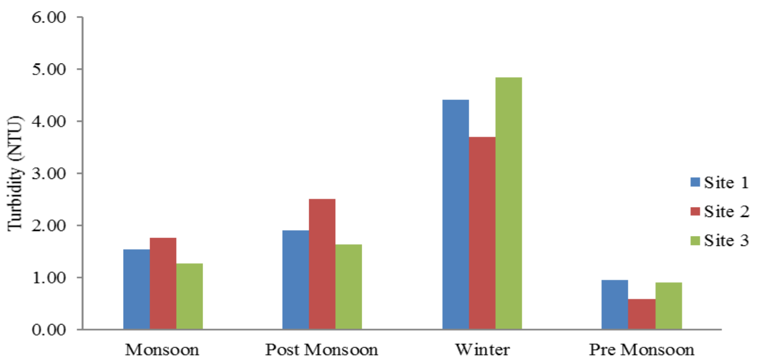

Fig 11: Turbidity (NTU) at different study sites in different seasons

Biological Oxygen Demand (BOD)

The Biological oxygen demand maximum was recorded as 31.00 mg L^{-1} and 23.80mg L^{-1} during winter and pre-monsoon season at site 1 and was recorded minimum 6.50mg L^{-1} and 8.15mg L^{-1} during the post monsoon and pre monsoon season at site 2 (Figure 13).

Nitrate

In oxygenated water the nitrate in the form of inorganic nitrogen becomes most stable which is evident in the present study with the maximum nitrate recording 12.00mg L^{-1} and 10.44mg L^{-1} during winter season at site 2 and site 3 and minimum recording 2.23mg L^{-1} and 2.86mg L^{-1} during the pre monsoon season at site 2 and site 1 (Figure 14).

Phosphate

As the inorganic phosphate becomes an important nutrient for phytoplankton, the maximum phosphate was recorded 0.65mg L^{-1} and 0.62mg L^{-1} during pre-monsoon at site 1 and winter season at site 2 and was recorded minimum 0.01mg L^{-1} and 0.11mg L^{-1} during the pre-monsoon and monsoon season at site 2 (Figure 15). The source for nitrate and phosphate in this ecosystem is mainly from fresh water influx and organic matter input to the system (Santhanam and Perumal, 2003)

CONCLUSION

The diversity of phytoplankton are subject to changes in the physico-chemical parameters of the estuarine ecosystem, such studies would help in assessing health of these ecosystems. Hence monitoring such ecologically important ecosystem is crucial to understand the physico-chemical and biological conditions. The present study provides a baseline data on the diversity of phytoplankton with varied physico-chemical parameters. A further

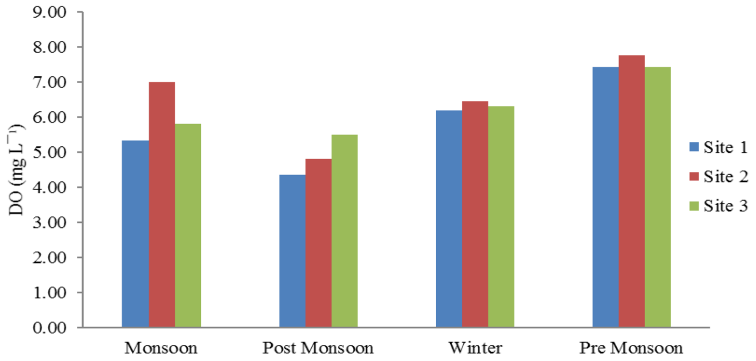

Fig. 12: Dissolved Oxygen (mg L^{-1}) at different study sites in different seasons

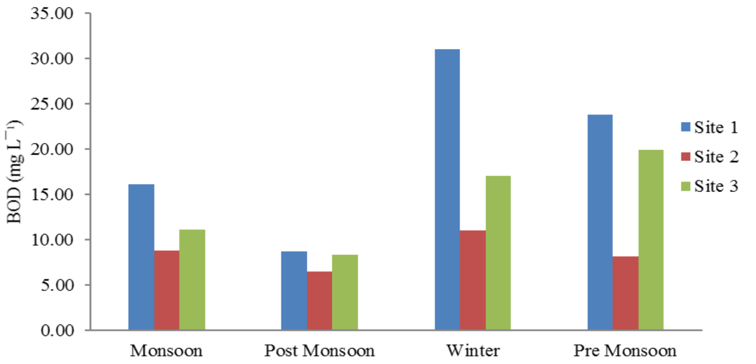

Fig 13: Biological oxygen demand (mg L^{-1}) at different study sites in different seasons.

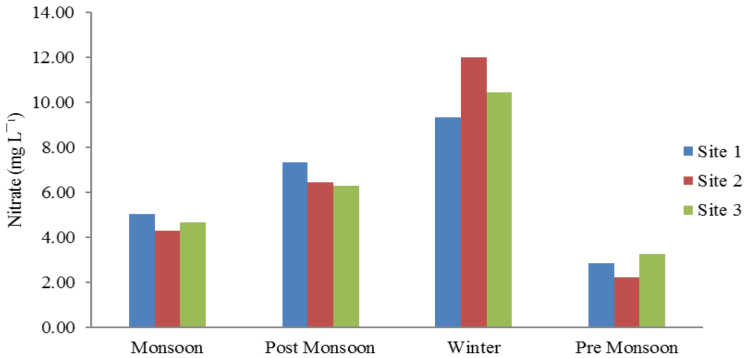

Fig 14: Nitrate (mg L^{-1}) at different study sites in different seasons

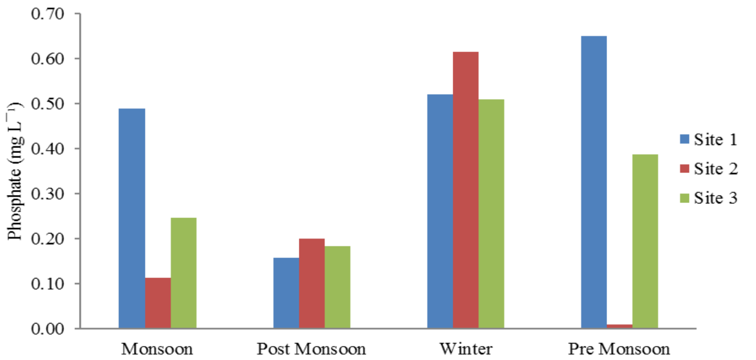

Fig.15: Phosphate (mg L^{-1}) at different study sites in different seasons

continuous monitoring of physico-chemical parameters and assessment of phytoplankton could provide useful information in understanding such eco-sensitive zones.

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