



Studies on physicochemical characteristics and distribution of diatoms associated with sediments at cuddalore industrial area lotic water bodies, Tamil Nadu

R Arulprakasam, K Sivakumar

Department of Botany, Division of Algal Biotechnology, Annamalai University, Annamalai Nagar, Tamil Nadu, India

Abstract

Temporal variations in the physicochemical parameters, density and diversity of intertidal diatom assemblages were investigated from July to December 2020 at two selected stations in the Sipcot Industrial area Lotic water bodies, Cuddalore District, Tamilnadu. The main physical and chemical parameters and the impact of industrial waste water waves which occurred prior to this study period and affected the species composition and currents density were studied. During this investigation, a total of 37 species of intertidal diatoms belonging to 21 genera were recorded from the two stations. A total number of 29 and 23 species were recorded at Station-I and II respectively. The result indicated that the distribution of diatoms taxa in the two stations were similar. The genera *Frgillaria*, *Mastogloia*, *Anomoeneis*, *Navicula*, *Diploneis* and *Pinnularia* were found dominant in terms of frequency and density. The physicochemical parameters showed spatial and temporal variations.

Keywords: physicochemical characteristics, diatoms, cuddalore industrial, lotic

Introduction

The natural environmental conditions are by no means constant, living organisms have developed adaptive mechanisms with which they are able to cope with natural variability. As a result, species composition often changes under stress, causing some species to increase in prominence and others to decline or disappear (Squires *et al.*, 1979) [31]. Phytoplankton are the major constituents of the food-webs in the freshwater ecosystems. Amongst phytoplankton occupy a unique place and are predominant in aquatic environments. The diatoms are planktonic and benthic. Of these, the benthic diatoms are important in the benthic food web as a vital constituent of the ecosystem and serves as good indicators of interstitial water quality including pollution. These diatoms are consequently an important carbon source for benthic heterotrophy and can significantly affect the exchange of oxygen and nutrients across the sediment-water Interface (Mitbavkar and Anil, 2002). [23] They inhabit the intertidal sand and mud flats. Analysis of such diatom population structure will provide an extremely sensitive indication of subtle changes taking place in the aquatic environment conditions (Bensen, 1972) [7]. The micro algal species found living firmly attached to the surfaces of sand grains are referred to as epismmon (Round, 1965) [28]. Epipelon refers to those species that are found on the surfaces of the sediments showing up and down movements in the industrial water.

The study of species composition of a community in environments will bring out the presence of the relative dominance of species (Mathevan Pillai, 1994) [19]. Structural aspects to the ecosystem such as the species composition of the population and species distribution are closely linked with the functional aspects such as metabolic rates and transfer of carbon through the food web (Jeyachandran, 1989) [16]. Intertidal diatoms associated with sediments predominantly consist of benthic diatoms and there is

increase interest in the study of relations of these benthic diatoms with their biotic and abiotic environment (Mathevan Pillai, 1994) [19]. The seasonal changes in the intertidal benthic diatom characteristics are directly controlled by primary ecological factors such as rainfall, temperature, salinity, dissolved oxygen, hydrogen ion concentration and nutrients (Prabhavathy *et al.*, 2010). Water quality assessment of Vellar river, Cuddalore District with special reference to phytoplankton was made (Aranganathan and Sivakumar, 2019) [4]. The industrial waste water currents battered along the freshwater ecosystem near Sipcot industries had showed great variability among the lotic water bodies communities affecting people largely and also the freshwater. It may be stated that the water currents have taken away large amount of sand from the confluence nearby area. Hence, an attempt was made to record the post effect of water current on the distribution of sediment inhabiting diatom community structure and the influence of prevailing selected physicochemical characteristics on the sediment inhabiting diatoms of Cuddalore Sipcot Lotic water environment.

Materials and Methods

Present study was carried out Sipcot Industrial area lotic water bodies Cuddalore District of Tamil Nadu (Fig. 1). Two stations were fixed for the study. Station-I was located near the area and the Station-II, three kilometers away north from the first station near the Chemplast Industry. Samples were collected at monthly intervals for a total period of six months from July to December 2020 for the estimation of various physico-chemical parameters. Rainfall data were obtained from the Climatology Section of the Meteorological Department at Cuddalore. Temperature (air, water and sediment) were measured using a standard centigrade thermometer. Industrial water samples were suctioned out of the sediment following the procedure

outlined by Hackney and Delacruz (1978) [13]. Salinity was recorded using the salinometer (Erma, Japan). Water and sediment pH were determined using a pH meter (Elico). For the estimation of dissolved oxygen, dissolved phosphate, nitrite and nitrate, the standard methods described by Strickland and Parson (1972) [33] were adopted. For analysis of organic carbon, the sediment samples were collected, air dried and pulverized through 85 mm mesh. These fine powders were used for analyses following method described by Wakeel and Riley (1956) [36], total nitrogen (Barnes, 1959), total phosphorous (Murphy and Riley, 1962) [24] and potassium (Culkin and Cox, 1966) [8].

diatoms, all the cells in the slide were counted and multiplying it by aliquot factor (Sridharan, 1979) [33]. The sediment inhabiting diatom taxa were identified using classical works of Hustedt (1930- 1966) [15], Cupp (1943) [9], Hendey (1964) [14], Desikachary (1986, 1987, 1988) [10] among others. Species diversity index (H'), Species richness (SR), Evenness index (J') and Dominance index (5) were calculated using the formulas of Shannon and Weaver (1949) [29], Gleason (1922) [12], Pielou (1966) [26] and McNaughton (1967) [22] respectively. The simple correlation co-efficient (r) analyses have been employed for the statistical interpretation of data obtained in the present study period.

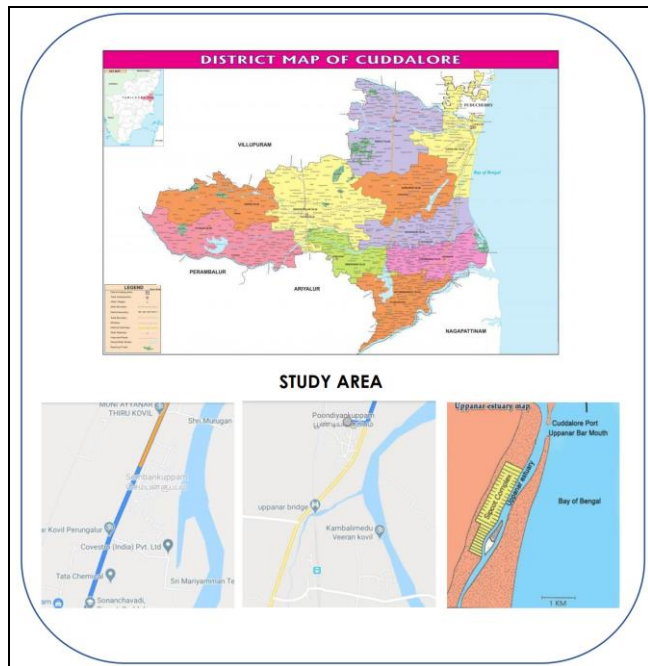


Fig 1

Sediment samples, containing diatoms were collected from the Sipcot and chemplast industrial water outlet connected with lotic water bodies following the method described by Amspoker and McIntire (1978). For enumerating the

Results and Discussion

Seasonal variation and simple correlation co-efficient (r) analysis between population density and physicochemical parameters (minimum and maximum values) are presented in Table 1 and Fig.1a,b,c,d,e. The rainfall recorded during the study period was generally very low. Maximum rainfall (217 mm) was recorded during November and minimum (13.21 mm) during July. During the study period rainfall ($r = -0.509$, $P < 0.05$) showed negative significant correlation with the population density of studied regions. There was uniformity in the temperature (Air, water and soil temperature) range at Stations-I and II with values generally 28 to 33°C. This uniformity was also observed in their means, which showed slight variations of $\pm 1^\circ\text{C}$. Air, sediment and water temperature play a key role in the distribution and establishment of sediment inhabiting diatom communities (Prabavathy *et al.*, 2010) [27]. The high temperature observed in this study was due to the intensity of sunlight and general shallowness of the river water, which exposed the water body and sediment to the heat of the sun. This is in support of the findings of Sukumaran (2009) [34] and Mathavan Pillai *et al.* (2011) [21]. During the study period air ($r=0.502$, $P < 0.05$), water ($r=0.514$, $P < 0.05$) and sediment ($r=0.640$, $P < 0.05$) temperature showed positive significant correlation with the population density of studied regions.

Table 1: Seasonal variation and simple correlation co-efficient analysis between population density and physicochemical parameters

Parameters	Station I		Station II		Correlation coefficient
	PM	M	PM	M	
Rainfall	13.21-135	102-217	13.21-135	102-217	-0.509*
Air temperature	32-33	29.5-30.5	32-33	29.5-30	0.502*
Soil temperature	32-32.5	29-30	32-32.5	29-30	0.514*
Water temperature	32-33	28-30	32.5-33	28-30	0.640**
Salinity	3.4-3.6	3.1-3.3	3.5-3.6	3.1-3.2	0.616**
Water pH	8.2-8.58	7.95-8.5	7.95-8.62	8.0-85	-0.143
Soil pH	7.94-8.60	8.5-8.68	8.36-8.64	8.12-8.68	0.776**
Dissolved oxygen	3.2-4.92	4.2-4.7	3.0-3.6	4.15-4.68	-0.354
Phosphate	0.15-0.62	0.70-1.52	0.15-1.53	0.68-1.49	-0.765**
Nitrate	0.34-0.83	0.40-1.12	0.44-1.79	0.43-2.03	-0.975
Nitrite	0.05-0.97	0.64-0.78	0.05-1.35	0.68-1.03	-0.712**
Total nitrogen	32-79	52-127	32-39	78-127	-0.387
Phosphorus	0.15-0.24	0.13-1.36	0.18-0.26	0.13-1.36	-0.979
Organic carbon	0.03-0.82	0.02-0.25	0.05-0.20	0.02-0.32	0.346
Potassium	9.41-18.57	13.5-15.23	9.52-18.5	13-15.23	-0.361
Population density	2500-4062	1875-3562	1875-3312	1500-1937	1.000
Species diversity	2.34-3.27	2.75-3.53	3.42-3.53	2.21-3.46	0.490*
Species richness	1.41-1.56	1.23-1.96	1.46-1.85	0.66-1.21	0.917
Species evenness	1.01-1.41	1.18-1.52	1.47-1.52	0.95-1.49	0.485*
Dominance Index	31.25-42.5	30.35-40.0	30.0-32.07	21-66-51.6	0.349

PM-Premonsoon (July-September); M – Monsoon (October-December); PD-Population density; * $P < 0.02$; ** $p < 0.001$

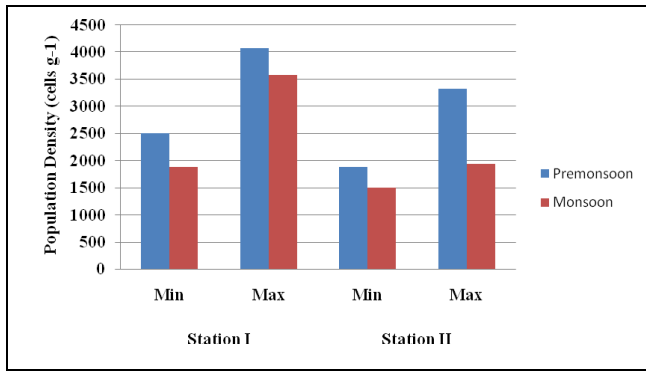


Fig 2: Population density of phytoplankton

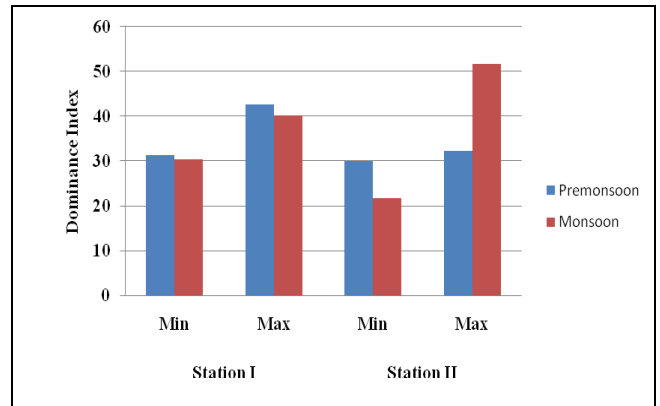


Fig 6: Dominance index of phytoplankton

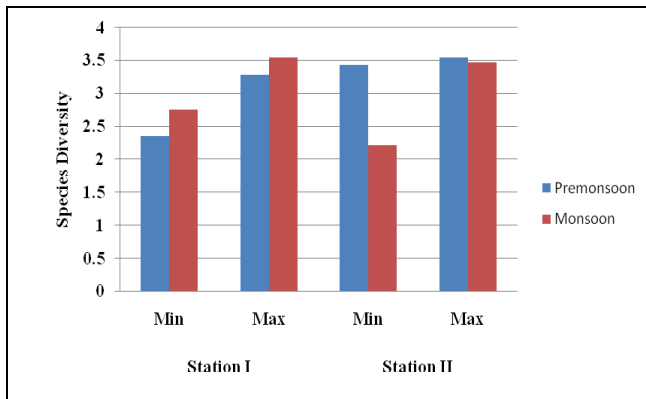


Fig 3: Species diversity of phytoplankton

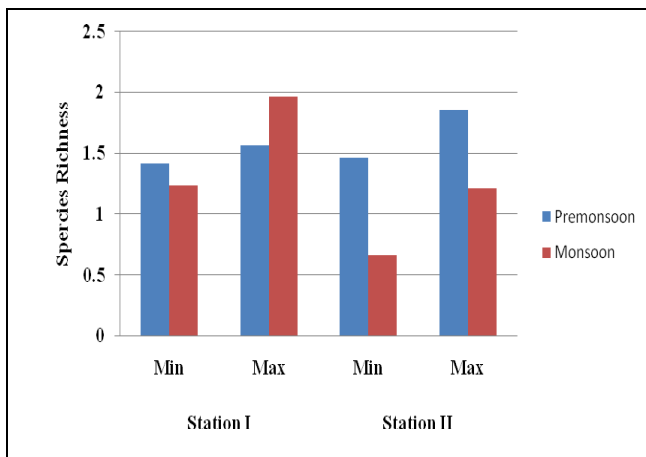


Fig 4: Species richness of phytoplankton

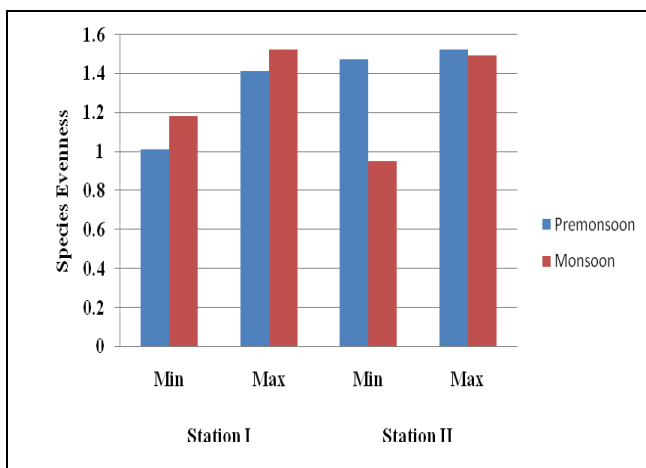


Fig 5: Species evenness of phytoplankton

There was a narrow range of variation in salinity in the industrial water during the study period between the stations. It ranged from 3.1 to 3.6‰. The maximum (3.6‰) value was recorded during July at Station-I and the Station-I and II recorded minimum (3.1‰) value during December. During the study period the minimum salinity was recorded during monsoon and the maximum during pre-monsoon season at both stations and positively correlated with the population density ($r=0.616, P<0.05$). This agrees well with the finding of Sin *et al.* (2000) [30]. Kukina *et al.* (2005) [18] proved that majority of sediment inhabiting diatoms were found distributed over a wide range of salinities. pH of water and sediment during the study period at the two stations varied from 7.94 to 8.68. In general, the pH values of water and sediment were lower at monsoon and higher at pre monsoon seasons. The higher pH value was perhaps due to the substantial evaporation of water and redox changes in the sediments and water colour. pH value obtained during the present study period were lower in the water when compared to the sediment at both stations. The pH of sediment positively correlated with the population density ($r=0.776, P<0.05$) during the study period. Similar findings were made by Fathima Suba (2004) [11] and Mathevan Pillai *et al.* (2011b) [21].

Dissolved oxygen content at the stations varied between 3.0 to 4.9 ml⁻¹. The maximum (4.92 ml l⁻¹) dissolved oxygen content was recorded during November at Station I and the minimum (3.0 ml l⁻¹) at Station-II during pre monsoon season. The dissolved oxygen content in the stations was highly variable and dependent on a number of factors. In addition, the study areas were badly affected by the Anthropogenic activities, which locked oxygen due to the huge amount of microalgae and dead remains on the surface. Concentration of phosphate in the industrial water showed narrow range of fluctuation during the study period except the month of July at Stations-II and-I. It varied from 0.15 to 1.53µM. The maximum (1.53 µM) and minimum value (0.15 µM) were recorded during July and November at Stations-II and I respectively. The nitrate (0.34 to 2.03 µM) and nitrite (0.05 to 1.35 µM) values of stations showed slight variations during the study period. The concentration of nutrients (dissolved inorganic phosphate, nitrite and nitrate) in the industrial water showed marked variations between stations. In the present study, dissolved nutrient concentration was maximum during monsoon and minimum during pre-monsoon seasons and vice versa. This variable is dependent on a multitude of factors (Ault *et al.*, 2000; Mathevan Pillai, 2011) [5, 21]. In addition, this was probably

due to the impact of industrial waste water which completely altered the condition of nutrients in the industrial water. During the study period phosphate ($r=0 - 0.765$, $P<0.05$) and nitrate ($r=0 - 0.712$, $P<0.05$) showed negative significant correlation with the population density of studied regions.

The concentration of nitrogen (N), phosphorous (P) and organic carbon (OC) content of sediment between stations varied from 32.0 to 127.0mg g⁻¹, 0.13 to 1.36mgg⁻¹ and 0.02 to 0.82 mg g⁻¹ respectively. The Station-I and II recorded maximum (N- 127.0, P- 1.36, OC- 0.82mg g⁻¹) and minimum (N-32, P-0.13, OC-0.02 mg g⁻¹) nitrogen, phosphorous and organic carbon content during the month of August and October and December respectively. The concentrations of nitrogen, phosphorous and organic carbon in the sediments showed narrow range of variations and were lower in the study stations due to the nature of sand and lesser discharge of domestic wastes, anthropogenic waste and the impact of the industrial waste water currents that alter the sand nature in the study area. Phosphorous content of sediments indicates that concentration and distribution of phosphorous are related to the amount of available organic matter in the sediments (Mathevan Pillai and Sukumaran, 2004) [20].

The monthly variation of population density of industrial waste water. River showed wide range of variations from 1500 to 4062 cells g⁻¹. The maximum (4062 cells g⁻¹) value

was recorded at Station-I and the Station-II showed minimum (1500 cells g⁻¹) population density. The monthly values of species diversity varied from 2.34 to 3.53. The maximum (3.53) and minimum (2.34) was recorded at Station-I during the study period. Species richness of sediment inhabiting diatoms varied from 1.20 to 1.96. The maximum (1.96) was recorded at Station-I and Station-II recorded the minimum (1.20) species richness. Species evenness values varied from 0.95 to 1.52. The Station-I recorded the maximum (1.52) species evenness and the Station-I recorded minimum (0.95) values. Dominance index values ranged from 21.66 to 42.30. Station-I recorded the maximum (42.50) and the Station-II showed the minimum (21.66) index values. During the study period, species diversity ($r=0.490$, $P<0.05$) and species richness ($r=0.485$, $P<0.05$) showed positive significant correlation with the population density of studied regions. Dominance index value showed higher in the pre-monsoon season and lower in the monsoon season at Station-I and vice versa in Station-II. Sediment inhabiting diatom population density was lower during the monsoon season and higher during the pre-monsoon at stations during the study period. The minimum population density recorded during the monsoon season may be attributed to the heavy fresh water flow, high turbidity due to land run-off, decreased temperature and high pH. Similar results were reported earlier by Jeyachandran (1989) [16] and Sunitha (2005).

Table 2: Distribution of sediment inhabiting diatom species

Sl. No.	Name of the Species	Station-I	Station-II	Occurrence
Centrales				
1	<i>Cyclotella meneghiniana</i> Kuetzing	+	-	Common
2	<i>C. stelligera</i> c. l u. Grun	+	+	Rare
3	<i>Skeletonema costatum</i> (Grey.) Cleve	+	+	Common
4	<i>haetoceros orientalis</i> Schiller	-	+	Very rare
5	<i>Thalassiosira marginata</i> Sp. Nov.	+	-	Common
Pennales				
6	<i>Fragiilaria brevistriata</i> Grun	+	+	Rare
7	<i>F. ratonensis</i> Grun	-	+	Common
8	<i>F. intermedia</i> Grun	+	-	Common
9	<i>Synedra ulna</i> (Nitz)	+	-	Rare
10	<i>Mastogioia exigua</i> Lewis	+	+	Rare
11	<i>M. dolosa</i> Venkataraman	+	+	Common
12	<i>M.brauni</i> Grun	-	+	Common
13	<i>M. smithii</i> Thwaites	+	-	Rare
14	<i>M. apiculata</i> Wm. Sm.	-	+	Rare
15	<i>Achmanthes hauckiana</i> Grun	+	-	Rare
16	<i>A. inflata</i> Kuetz.	+	+	Common
17	<i>Cocconeis placentula</i> Cleve	+	+	Common
18	<i>Dipioneis subo vaiis</i> Cleve	-	+	Very rare
19	<i>D. ovalis</i> (Hilse)	+	+	Common
20	<i>D. interrupta</i> (Kuetz.)	+	-	Rare
21	<i>Anomoeneis sphaerophora</i> (Kuetz.)	+	+	Rare
22	<i>A. serians</i> (Breb.) Celve	+	-	Rare
23	<i>Stauroneis anceps</i> Ehr.	+	+	Common
24	<i>Navicula cuspidate</i> Kuetz.	+	+	Common
25	<i>N. peregrina</i> Kuetz.	-	+	Rare
26	<i>N. lacustris</i> Greg	+	+	Rare
27	<i>N. cincta</i> Kuetz.	+	-	Rare
28	<i>N. rostellata</i> Kuetz.	+	-	Common
29	<i>N. laterostrata</i> Hust	+	-	Common
30	<i>N. radiosa</i> Kuetz.	-	+	Common
31	<i>N. pycmae</i> Kuetz.	+	+	Common
32	<i>N. rectangularis</i> Kuetz.	+	-	Common
33	<i>N. acicularis</i> Kuetz.	+	+	Common
34	<i>N. capitatoradiata</i> Kuetz.	+	-	Rare

35	<i>N. mutica</i> Kuetz.	+	-	Common
36	<i>N. hasta</i> Pant.	-	+	Rare
37	<i>Pinnularia gibba</i> Ehr.	+	+	Common
	Total	29	23	

+ Present; - Absent

During the study period, 37 species 15 genera of sediment inhabiting diatoms were recorded from the two stations. Species numbering 29 and 23 were recorded at Stations-I and II respectively (Table 2). The study showed a clear dominance of pennate over centric diatoms at the two stations. This may be attributed to their elongated nature with which they can attach themselves better on other materials (Kannan *et al.*, 1997 and Mathevan Pillai *et al.*, 2011a) [21]. Nine species are recorded common to the two stations namely *C. stelligera* c. l u. Grun, *Skeletonema costatum* (Grey.) Cleve, *Fragililaria brevistriata* Grun, *Mastogioia exigua* Lewis, *M. dolosa* Venkataraman, *A. inflata* Kuetz, *Cocconeis placentula* Cleve, *D. ovalis* (Hilse), *Anomoeneis sphaerophora* (Kuetz.), *Stauroneis anceps* Ehr., *Nayicula cuspidate* Kuetz., *N. lacustris* Greg and *N. pycmae* Kuetz.. The environmental changes from industrial waste water, the sand and debris deposited over the river areas will eventually choke off fresh water species, endangering the delicate ecological balance. Leading to change in the occurrence and distribution patterns of diatom species. Ecology of phytoplankton in Palaman river, Chidambaram Town, Cuddalore district of Tamil Nadu was made (Aranganathan and Sivakumar, 2019). Proper sanitation measures and environmental education to public care are essential to keep these lotic type of water bodies in clean and safe. A few efforts like diversion of sewage, presentation of leaching of nutrients from catchment area through plantations would definitely yield healthy hygienic and sustainable environment.

The study concluded that industrial waste water had its own effect on changing the distribution of intertidal diatoms of lotic water bodies. The large quantity of sediment deposited during outlet of waste water from industry had telling effect on the biodiversity of the river area. However, continuous monitoring of the lotic environment of the study area and in-depth physicochemical and biological studies are necessary. The present baseline information of the intertidal diatoms distribution and ecological characters would form a useful tool for further ecological assessment and monitoring of these industrial waste water outlet confluent the lotic water bodies in Cuddalore District of Tamil Nadu.

Acknowledgement

The authors express their gratitude to the Professor and Head, Department of Botany, Annamalai University for providing laboratory facilities and encouragement to carry out this research work.

References

- Ambili K. Distribution of epipelagic diatoms on the intertidal sediments of Kanyakumari Coast, Tamil Nadu. *Seaweed Res. Utilin.*, 2011b:33(1&2) 201-212.
- Amspoker MC, McIntire CD. Distribution of intertidal diatoms associated with sediments in Yaguina estuary, Oregon. *J. Phycol.*, 1978:14:387-395.
- Aranganathan A, Sivakumar K. Ecology of phytoplankton in Palamar River, Chidambaram Town, Cuddalore District of Tamil Nadu. *Indian Hydrobiology*, 2019:18(132):90-102.
- Aranganathan A, Sivakumar K. Water quality assessment of Vellar river Cuddalore District with special reference to phytoplankton. *Journal of the Gujarat Research Society*, 2019, 21(15).
- Ault T, Velzeboore R, Zammit R. Influence of nutrient availability phytoplankton growth and community structure in the port Adeaide River, Australia: Bioassay assessment of potential nutrient limitation. *Hydrobiologia*, 2000:429(1-3):89-103.
- Barnes H. *Apparatus and Methods of Oceanography*, Part I. Chemical. O. Allen and Uwin Ltd., London, 1959, 341.
- Bensen S. Proc. *Fourth Symp. Recent and Fossil Marine Diatoms*. R. Simonsen (ed). Novo Hedwigia, Germany, 1972.
- Culkin F, Cox RA. Sodium, potassium, magnesium, calcium and strontium in seawater. *Deep Sea Res*, 1996:13:789-804.
- Cupp EE. Marine diatoms of the West coast of North America. *Bull. Scripps. Inst. Oceanogr*, 1943:5(1):1-237.
- Desikachary TV. Atlas of diatoms. Monographs phases I, II, III and IV. Madras Science Foundation, Madras, 1986-88.
- Fathima Suba J. *Studies on the physico chemical parameters and pelagic diatoms of Manakudy estuary Kanyakumari District*. M.Sc dissertation, M.S. University, 2004, 99.
- Gleason HA. On the relation between species and area. *Ecology*, 1922:3:156-162.
- Hackney CT, Delacruz. Changes in interstitial water salinity of a Mississippitidal marsh. *Estuaries*, 1978:1:185-188.
- Hendey NT. A revised check list Of British marine diatoms. *J Mar Biol Ass*, 1964:54:277-300.
- Hustedt F. Die Kiesalger Duetschland Osterreichs under Schweiz, In: *Robenthorst Kryptogamy Flora* (1, 2, 3), 1930-1966.
- Jeyachandran S. *Studies on the intertidal diatoms from the Pitchavaran mangroves*. Ph.D. thesis, Annamalai University, 1989, 169.
- Kannan L, Anantharaman P, Mathevan Pillai M. Microphytobenthic diatom of Tamil Nadu coast. *Phykos*, 1997:36(1&2):103-113.
- Kukina SE, Sadovinkova LK, Calafatfraw A, Palerud P, Hummel H. Forms of metals in bottom sediments from some estuaries of the basin of the White and Barents Sea. *Russ. Acad. Sci. Ocenology*, 2005:37(12):1197-1202.
- Mathevan Pillai, M. *Hydrobiological investigations on the intertidal diatoms of the Cuddalore Uppanar estuary, India*. Ph.D. thesis, Annamalai University, 1994, 159.
- Mathevan Pillai M, Sukumaran M. A preliminary report on the distribution of intertidal diatoms associated with sediments of Chotthavilai beach, Kanyakumari district. *Proc. Nat. Sem. Mar Res*, 2004, 15-20.
- Mathevan Pillai M, Prabavathy H, Brinda M. Epiphytic

- diatoms associated with mangrove (*Rhizophora mucronata*) prop roots in Manakudy estuary, southwest coast of India. *Seaweed Res. Utin*, 2011a:33(1&2):213-220.
22. McNaughton SJ. Relationship among functional properties of California glass land. *Nature (London)*, 1967:216:168-169.
 23. Mitbavakar S, Anil AC. Diatoms of the microphytobenthic community; Population structure in tropical intertidal sand flat. *Mar. Biol*, 2002:140:4-57.
 24. Murphy J, Riley. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chem. Acta*, 1962:27:3:1-36.
 25. Nichol SL, Lian OB, Carter CH. Sheet-gravel evidence for a late Holocene tsunami run-up on beach dunes, Great Barrier island, New Zealand. *Sedimentary Geology*, 2003:155:129-145.
 26. Pielou EC. The measurement of diversity in different types of biological collection. *Theoret. Biol*, 1966:13:144.
 27. Prabavathy H, Mathevan Pillai M, Mohan VR. Benthic diatoms of Manakudy mangroves. *J. Theor. Exp. Biol*, 2010:7(1-2):35-41.
 28. Round FE. Studies on the bottom living algae in some lakes of the English Lake District II: The distribution of Bacillariophyceae on the sediments. *J. Ecol*, 1965:45:434-360.
 29. Shannon CE, Weaver W. The Mathematical Theory of Communication. *Univ. of Illionis Press, Urban*, 1949, 117.
 30. Sin Y, Wezel RL, Anderson YC. Seasonal variation of size fractionated phytoplankton along the salinity gradient in the yark River estuary, Virginia (USA), *I Plankton Res*, 2000:22(10):1945-1960.
 31. Squires LE, Rushforth SR, Brotherson DJ. Algal response to a thermal effluent: Study of power station on the Provo River, Utah, USA. *Hydrobiology*, 1979:63:1011-1017.
 32. Sridharan VT. *Studies on marine diatoms of the Indian coast*. Ph.D. thesis, University of Madras. 213 p.
 33. Strickland, J.D.H. and T.R. Parson 1972. A practical hand book of seawater analysis. *Bull. Fish. Res. Bd. Canada*, 1979:167:310.
 34. Sukumaran M. Bacteriological water quality of Manakudy estuary in K.K. District, Tamil Nadu, India. *Indian I Bot. Res*, 2009:5(1-2):91-98.
 35. Sunitha N. *Changes of sediment inhabiting diatom distribution in Manakudy estuary with special reference to south Asian Tsunami*. M.Sc dissertation., M.S.University, 2005, 104.
 36. Wakeel SK, Riley JP. The determination of organic carbon in marine mud. *J. Cons. Int. Explor Mar*, 1956:22:180-183.