Distribution Of Phytoplankton From The Vellar Estuary, Southeast Coast Of Tamil Nadu

R.Aruljothi and P.Sampathkumar*

Abstract: The distribution of phytoplankton and its communities in relation to physicochemical parameters from the surface waters of Vellar estuary were studied during the period from Apirl 2018 to March 2019. A total number of 86 phytoplankton species is recorded in the Vellar estuary, among them, 70 species of diatoms (Bacillariophyceae), 9 species of dinoflagellates (Dinophyceae) and 7 species of blue greens (Cyanophyceae) were recorded in the study area. The Statistical tools were carried out the measurement of correlation and species richness analyzed by using diversity index and "R" software respectively. The following phytoplankton species were abundant throughout the study period viz. *Coscinodiscus centralis, Nitzschia seriata (Pseudo-nitzschia seriata), Rhizosolenia styliformis, Tripos furca and Odontella aurita* amoung them. The percentage composition of phytoplankton is indicated in the order of as Diatom>Dinoflagellates>Blue green algae. Phytoplankton diversity is highly dynamic depending on the nutrient availability. The population increased during the post-monsoon season and less in summer season when compared with other seasons due to the inflow of freshwater. Thus the present study shows a good outline of the seasonal dynamic relationship between environmental parameters and phytoplankton distribution.

Keywords: Physico chemical parameter, phytoplankton diversity, evenness, richness, PCA and CCA analysis

1. INTRODUCTION

Estuaries are among the most diverse, economically important, productive and hydrologically variable environmental ecosystems on Earth [1]. Physico-chemical parameters, species composition and seasonal variation on the phytoplankton abundance have been studied in Indian coastal waters [2]. Variation in phytoplankton community are dependent on the temperature, light intensity, nutrients and on other limnological factors. Normally phytoplankton follows a fairly recognizable annual cycle of growth, but sometimes the synchrony in their normal annual cycle is disrupted by explosive growth of some species [3]. The phytoplankton act as an important component of the marine environment ecosystem, as they photosynthesize liberate oxygen and aid in the energy exchange process [4]. Temporal and spatial variations in the phytoplankton distribution are widely affected by the physicochemical factors such as temperature, salinity, dissolved oxygen, pH, nitrate, nitrite, ammonia, silicate and inorganic phosphate. The phytoplankton community factors which influence the species composition and their diversity in the marine environmental ecosystem [5] [6]. Generally, estuaries and shallow water showed seasonal fluctuation among the variables depending on the tidal inflow, regional rainfall, biotic and various abiotic processes. The substantial are major role in nutrient cycle in marine water [7]. Several factors such as upwelling, increase river inflow, substrate of remineralization and resuspension of particulate matter due to the eutrophication [8].

It might have both negative and positive impact on phytoplankton diversity depending on the environment ecosystem [9] [10]. A marine phytoplankton is mostly dependent on physical parameters and nutrients in a coastal environment. The nutrients are frequently considered as a key factor of the regulating growth and metabolism, phytoplankton abundance. Many similar works has been done on seasonal variation in phytoplankton species composition in different coastal environmental ecosystem of India [11] [12] [13]. The present study aims to find out the seasonal variation on phytoplankton diversity, evenness and richness in response to the various environmental parameters.

2. MATERIALS AND METHODS

The water samples were collected from the Vellar estuary, southeast coast of Tamilnadu, India during April 2018 - March 2019. Monthly sampling of seawater was collected at different depths using Niskin water sampler. The samples were collected from the stored 1L poly- propylene bottles and filtered through Whatman GF/F filters for further analysis. Physical parameters such as temperature, salinity, dissolved oxygen and pH were analyzed by the following standard methodology [14] and seasonal phytoplankton diversity was recorded.

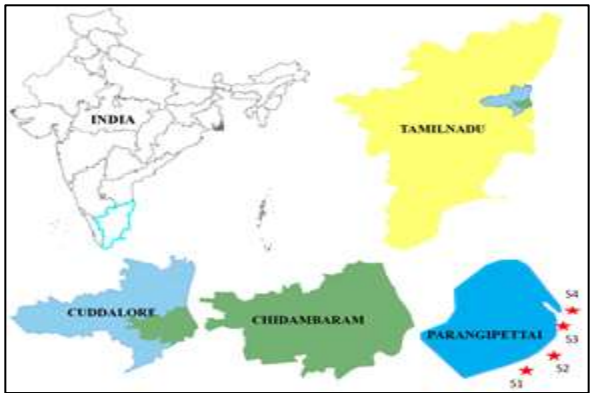

Fig 1. *Study area from the Vellar estuary*

Chlorophyll-a concentration was estimated by pigment extraction used in acetone (90%). Extraction was incubated in refrigerator under dark condition. The concentration pigment were obtained through UV-VIS spectrometer (Shimadzu-UV) used in 5 cm cells at 630 nm, 645 nm and

- *P.Sampathkumar, Professor, Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai 608 502, Tamil Nadu, India. Mail id: sampathcas@gmail.com*

665nm [14]. For total Suspended Solid (TSS) analysis, glass bottles were used (Whatmann GF/C, 0.45mm) before filtration. After filtration, the filtered paper were kept on oven in 24h at 75°C and then further weighted to find out the total suspended solids. Nutrients such as Nitrite (NO2), Nitrate (NO3), Ammonia (NH4), Total nitrogen (TN), Total Phosphate (TP) and Reactive Silicate (SiO4) were analyzed following the standard method described by [14].The phytoplankton sample was collected at monthly intervals in surface water by using towing plankton net (mouth diameter- 50 cm). The flow meter (Hydro-Bios, Germany) was attached at the center point of the plankton net to calculate the volume of seawater passed through the plankton net. The phytoplankton samples were preserved in 4% buffered formalin for further analysis. The phytoplankton qualitative and quantitative analysis were executed using by inverted microscope. The quantification of phytoplankton samples were using Sedgwick counting chamber and then the phytoplankton species were identified by the following phytoplankton identification manual [15] [16] [17] [18] [19] [20] [21] [22] [23].

2.1 STATISTICAL ANALYSIS

The diversity index was calculated by [24]. Pielou's Evenness Indexes (e) were calculated to be used as an evenness of species[25]. Margalef's indexes were used as a measure the species richness [26]. The statistical analysis of Canonical Correspondence Analysis (CCA) and Principal Component Analysis (PCA) were performed used by R (Version 3.4.0, 2016) statistical software [27]. The ggplot2 software package were used by line diagrams and Box plot [28].

3. RESULTS

Physico-chemical and biological parameters such as Temperature, Salinity, pH, Dissolved Oxygen (DO), Chlorophyll-a (chl), Total suspended solids (TSS), Nitrate (NO_2), Nitrite (NO_3), Total Phosphate (IP), Total nitrogen (TN) and Silicate (SiO_3) were assessed. Nutrients concentration were fluctuated depends on the seasonal variation. The maximum temperature (32.4°C) was recorded during summer season and the minimum temperature (23.9°C) was noted during monsoon season with the mean value of 28.62±2.62. The Salinity values varied from 33.3 to 32.00 ppt. The maximum value was recorded at summer season and the minimum was recorded at monsoon season with the mean of 28.33±3.11. The pH values was ranged from 8.3 to 7.1, the maximum pH value was pH 8.3 observed during summer season and minimum of pH 7.1 was recorded in monsoon season with the mean value of 7.9±0.35. Dissolved oxygen is a most important component in water environment and the water quality are supported in water environment. The investigated dissolved oxygen values was varied from 5.64 mg/L to 4.04 mg/L, the maximum DO values recorded during post monsoon season and the minimum value was (4.04 mg/L) recorded during summer season with the mean of 4.70± 0.58. Chlorophyll-a, the most important pigment is responsible for primary production in marine ecosystem. The maximum concentration of chlorophyll-a (2.29 µg L^{-1}) was observed during post monsoon season and minimum concentration of 0.4 µg L^{-1} was noted in summer season with the mean of 1.45±0.94. Total suspended solids values varied from 55.32 mg/L to 28.45 mg/L. the maximum value was observed (55.32 mg L^{-1}) during monsoon season and the minimum values was recorded (28.45 mg/L) in post monsoon with the mean of 38.21±9.56.

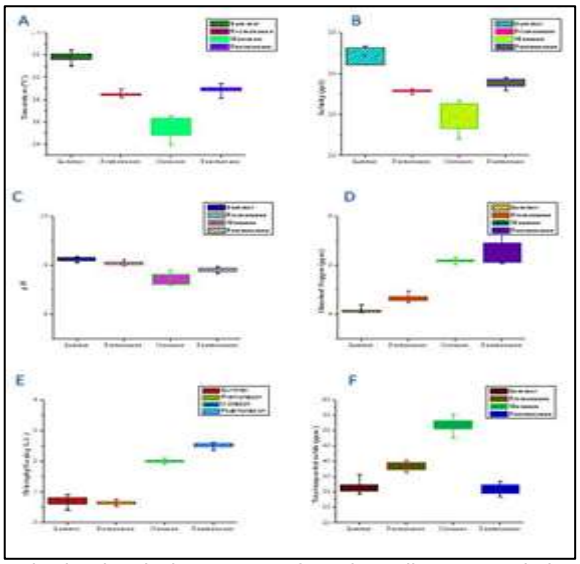

***Fig 2**. Physicochemical parameters from the Vellar estuary during April 2018 - March 2019. A-Temperature, B-Salinity, C- pH, D-Dissolved Oxygen (DO), E- Chlorophyll-a and F- Total Suspended Solids*

3.1 NUTRIENT DYNAMICS

Nutrients such as nitrate, nitrite, inorganic phosphate, ammonia, total nitrogen, inorganic phosphate and silicate were assessed in the coastal environment. The seasonal variations are depending on the rainfall, ingress in tidal, freshwater input and consumption of nutrient by autotrophic. The nitrate is a stable from of combined nitrogen in natural waters. The nitrate range in the present study varied from 0.73/ µmol^{-} to 0.26/ µmol^{-1}. The maximum nitrate concentration was observed (0.73/ µmol^{-1}) during monsoon season and minimum concentration (0.26 /µmol^{-1}) was recorded in pre-monsoon season with the mean of 0.42±0.13. Nitrite is the intermediate product of oxidation of ammonia to nitrate and the values was ranged from 4.02 /µmol^{-1} to 0.26/ µmol^{-1}. The maximum nitrite concentration was observed (4.02/ µmol^{-1}) during monsoon season and the minimum of was recorded (0.26/ µmol^{-1}) in pre monsoon with the mean of 2.82±0.76. The assessment of Ammonia values varied from 1.36 to 0.17/ µmol/L. The maximum concentration of ammonia (1.36/ µmol^{-1}) was observed during monsoon season and the minimum value (0.17/ µmol^{-1}) was recorded in pre monsoon with the mean of 0.58±0.49. The observed nitrogen values varied from 16.97 to 8.42 / µmol/L. The maximum value was recorded (16.97 /µmol^{-1}) during monsoon season and the minimum value was (8.42/ µmol^{-1}) recorded in post monsoon with the mean of 11.35±2.33. The total inorganic phosphate values was recorded in the range of 1.78 to 0.8 /µmol^{-1}. The maximum concentration of total phosphate (1.78 /µmol^{-1}) was observed during monsoon season and the minimum concentration was (0.8 / µmol^{-1}) recorded in post monsoon with the mean of 0.75±0.63. The assessed silicate value was ranged from 2.42 to 0.89 /µmol^{-1}. The maximum concentration (2.42 /µmol) was observed during pre-

monsoon and minimum concentration was (0.89/ µmol^{-1}) recorded in summer season with the mean of 1.49±0.55.

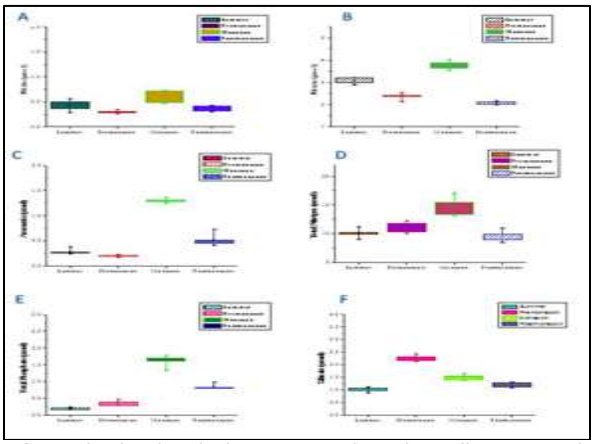

Fig 3*. Physicochemical parameters from the Vellar estuary during April 2018 - March 2019. A- Nitrite, B- Nitrate, C- Ammonia D- Total nitrogen, E-- Total phosphate and F- Silicate*

3.2 PHYTOPLANKTON COMPOSITION, DIVERSITY INDICES AND POPULATION DENSITY

Phytoplankton species composition, development, proliferation and quantification were majorly influenced by physico-chemical parameters. The phytoplankton species recorded during the study period is presented in Table 1. The total number of 86 phytoplankton species was recorded in Vellar estuary. Among them, 70 species of diatoms (Bacillariophyceae), 9 species of dinoflagellates (Dinophyceae), 7 species of blue greens (Cyanophyceae) was recorded in the study area. The following phytoplankton species were abundant throughout the study period viz. Coscinodiscus centralis, Nitzschia seriata (Pseudo-nitzschia seriata), Rhizosolenia styliformis, Tripos furca and Odontella sinensis.

Table 1 *List of phytoplankton diversity from the Vellar estuary during April 2018 - March 2019*

Phytoplankton Bacillariophyceae (Diatoms)	*Summer*	*Pre monsoon*	*Monsoon*	*Post monsoon*
Amphora sp.	+	+	+	+
A. marina	.	.	.	.
Asterionella sp.	-	+	-	+
Asterionellopsis glacialis	-	-	+	+
Bacillaria sp.	+	+	+	+
B. paxillifera	+	+	+	+
B. paradoxa	+	-	-	+
Bacteriastrum sp.	+	-	+	+
B. furcatum	+	+	+	+
B. hyalinum	+	-	+	-
B. comosum	+	+	+	+
B. delicatulum	+	+	-	+
Cerataulina sp.	+	+	+	+
Chaetoceros sp.	+	+	+	+
C.indicus	-	+	+	+
C.lorenzianus	+	-	+	+
C. curvisetus	+	+	+	+
C.affinis	+	+	+	+
C.diversus	+	-	-	-
C.furcatus	-	+	+	+
C.impressus	+	+	+	+
C.messanensis	+	+	+	+
Coscinodiscus granii	+	+	+	+
C. centralis	-	+	+	-
C. gigas	-	+	+	-
C. radiatus	-	-	+	-
Cyclotella sp.	+	+	+	+
Ditylum sp.	+	+	+	+
D. brightwelli	+	+	+	+
Guinardia sp.	+	+	+	+
Hemiaulus sp	+	+	+	+
Lauderia annulata	+	+	+	+
Leptocylindrus sp.	+	+	+	+
L. danicus	+	+	+	+
Lithodesmium undulatum	-	+	+	+

Navicula sp.	+	+	+	+
N. longa	-	+	+	+
N.indica	+	+	-	+
Nitzschia sp.	+	+	+	+
N. longissima	-	-	-	+
N.seriata	+	+	+	+
N.angustata	+	+	+	+
Odontella sp.	+	+	+	+
O. aurita	+	-	-	+
O. reticulata	+	+	+	+
O. sinensis	+	+	+	+
Platessa salinarum	+	-	-	+
Planktoniella sol	-	-	+	+
Pleurosigma sp.	+	+	-	+
P. angulatum	+	+	+	+
P. elongatum	+	+	+	+
P. normanii	+	+	+	+
Proboscia sp.	+	+	+	+
P. alata	+	+	+	+
Rhizosolenia sp.	+	+	+	+
R. hebetata	+	-	+	+
R.styliformis	+	+	-	+
R.alata	-	+	-	+
R.imbricata	+	-	-	+
R.setigera	+	-	-	+
Skeletonema sp.	+	+	+	+
S. marinoi	+	+	+	+
S. costatum	-	-	-	+
Stephanopyxis palmeriana	+	+	+	+
Thalassiosira sp.,	-	-	-	+
T. subtilis	+	+	+	+
Thalassiothrix longissima	+	-	-	+
T. frauenfeldii	-	-	-	+
Thalassionema nitzschioides	+	-	+	+
Triceratium sp.	+	+	+	+
T. favus	+	+	+	+
	Dinophyceae (Dinoflagellates)			
Tripos sp.	+	+	+	+
T.lineatum	+	+	-	+
T.macroceros	-	-	-	+
T. furca	+	+	+	+
T.trichoceros	+	+	+	+
T.tripos	-	-	-	+
Dinophysis sp.	+	+	-	+
D. caudata	-	-	-	+
Protoperidinium Oceaniucum	-	-	-	+
	Blue greens Cyanophyta			
Anabaena sp.	+	+	+	+
Oscillatoria sp.	+	+	+	+
O. indica	-	+	-	+
Planktothrix agardhii	+	+	+	+
Spirulina sp.	-	-	+	+
Trichodesmium sp.	+	+	+	+
Volvox sp.	-	-	-	+

The Shannon diversity (H') index calculated for faunal data showed minimum (2.893) value during monsoon and maximum (4.095) value during summer season; Margalef species richness (d) showed lower (3.189) value at summer and higher (6.062) value in pre-monsoon; Pielou's species evenness (J') varied between 0.895 and 0.998 with higher value at Vellar estuary during pre monsoon and lower value in monsoon.

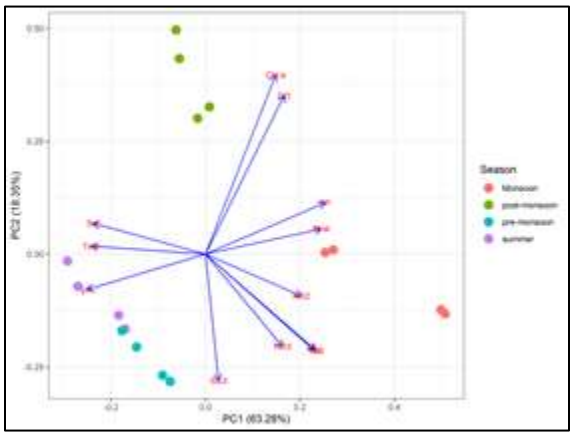

Fig 4. *Diversity indices A- Shannon diversity (H'); B- Margalef richness (d) and C- Pielou's evenness (J') calculated for the Phytoplankton species abundance collected from the Vellar estuary during April 2018 - March 2019.*

3.3 PCA (Principal Component Analysis)

The first two component of PCA explained between 63.28% and 18.35% variation. Environmental variables such as dissolved oxygen, chlorophyll, total nitrogen, total phosphate, total suspended solids, ammonia, nitrate, nitrite, silicate showed positively correlation with monsoon season, whereas temperature, pH, salinity negatively correlated with monsoon, pre-monsoon and post-monsoon seasons

.

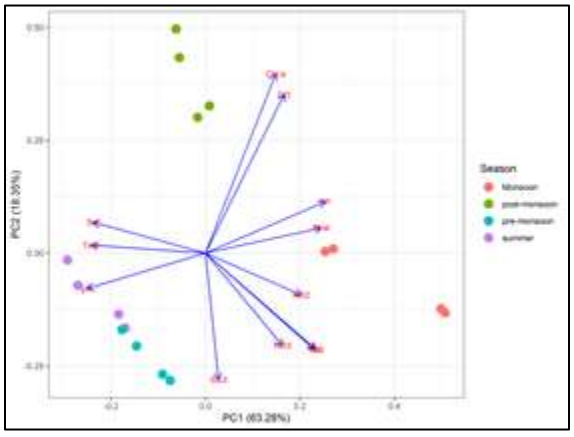

Fig 5*. Principal Component Analysis drawn for the environmental parameters with phytoplankton density recorded during April 2018 - March 2019 from the Vellar estuary.*

3.4 CCA (Canonical Correspondence Analysis)

CCA observed correlation between phytoplankton diversity and physico chemical parameters. CCA explained totally 96% of species variation in both axis 1 and 2. Environmental parameter such as dissolved oxygen, Chlorophyll, , total phosphate, ammoniasilicate showed positive correlation with evenness and diversity whereas other parameters negatively correlated with richness.

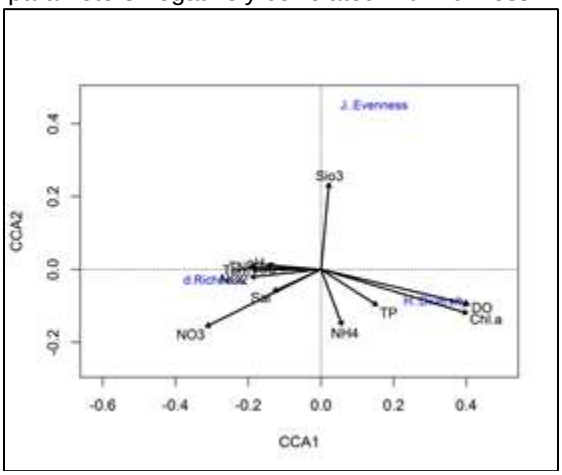

Fig 6*. Canonical Correspondence Analysis drawn for the environmental parameters with phytoplankton diversity in the Vellar estuary during April 2018 - March 2019.*

4. DISCUSSION

The observed water quality parameter such as temperature, salinity, dissolved oxygen, pH and nutrients exposed seasonal variations. Temperature is an important factor for marine environment as it influences the life of organisms and physicochemical parameters [29]. The high temperature during summer could be attributed to high solar radiation. The low temperature during monsoon could be due to strong rainfall received from monsoon season. Recent studies also showed that the higher temperature was observed at summer season and lower temperature recorded in monsoon season [30]. Similarly it was found that the higher temperature observed at summer and low temperature observed monsoon season. The salinity acts as a limiting factor for the distribution of living organisms and its variation caused by dilution and evaporation is most likely to influence the fauna in the coastal ecosystems [31] [12]. The high salinity values recorded during summer season could be due to the intrusion of neritic water and high intensity of solar radiation during summer and minimum values recorded during monsoon season might be due to the freshwater influence and fluctuation in tides [32]. The recent study also showed that the higher salinity recorded in summer and reduced salinity recorded in monsoon season at Parangipettai coastal region [30]. The higher pH noticed during summer season whereas lower pH noticed during monsoon season. The higher pH in summer could be characterised by high photosynthetic activity of phytoplankton and the lowered pH value in monsoon was due to freshwater influx by Vellar estuary. Correspondingly, [30] reported that the higher pH value noticed during the post-monsoon season and lower pH value are recorded in monsoon season. Dissolved oxygen showed marked seasonal variation throughout the study period. During summer and pre-monsoon , less dissolved oxygen content was recorded, which could be due to the high temperature, salinity and biological activity [33] [34].High concentration of dissolved oxygen observed during monsoon and post-monsoon is attributed to high fresh water input and evidenced by the maximum

occurrence of phytoplankton species [35]. Chlorophyll-a is the standard photosynthetic pigment liable for the primary production in marine and coastal waters. The maximum concentration of chlorophyll-a would result in maximum standards of productivity and redirect on high phytoplankton biomass. In the present study, chlorophyll-a concentration was low during summer season and higher concentration was noted during post monsoon season. In contrast, [36] reported that the higher concertation of chlorophyll-a reported during summer season and low concentration recorded during monsoon season. Nitrate is one of the most important indicators of water pollution which shows the topmost oxidized form of nitrogen. Nitrogen is an important role in strengthening the aquatic life in coastal ecosystem. The maximum nitrate concentration noticed during the monsoon and minimum was observed during pre-monsoon season. The maximum nitrate concentration in monsoon season is due to the fresh water influx and terrestrial overflow. The minimum concentration was during pre-monsoon season which could be due to the lower usage of nitrogen fertilizers and less disposal of wastes in the Vellar estuary. The similar results also found in the earlier research works reported by [37] in Arasalar estuary.. The higher concentration of nitrate during monsoon and summer could be due to the terrestrial runoff, fresh water inflow, biological production, reduction of nitrate, oxidation of ammonia by recycling of nitrogen and also by biodegradation of planktonic detritus present in the marine environment ecosystem [38]. The lower concentration of nitrate during post monsoon and pre-monsoon period due to high consumption of nitrate by incursion of neritic water and the photosynthetic organisms which constitute the small amount of nitrate are present in marine ecosystem [38] [39] [40]. The high concentration of nitrite could be due to the increased oxidation of ammonia, phytoplankton excretion and reduction of nitrate and by recycling of the nitrogen and also due to bacterial decomposition of the planktonic detritus present in the marine environment [38]. The low concentration nitrite values are present during summer season due to the high salinity and less freshwater inflow [41] [42]. The ammonia concentration level was increased during monsoon season due to incursion of decomposition of phytoplankton and terrestrial runoff [43] [43]. Decreased low value of ammonia concentration during summer and premonsoon may be attributed to consumption of phytoplankton community as they preferred ammonia more than nitrate at certain marine environment ecosystem [44]. The recorded high level concentration of inorganic phosphates during monsoon season might possibly due to upwelling into the creek, so increased the level of phosphate. Low summer values could be attributed to the utilization of phosphate by phytoplankton, high salinity and limited flow of freshwater [45]. Phosphate plays are important role in primary productivity in an aquatic environment ecosystem as it promotes or limits the phytoplankton production and growth for organisms by [46]. Higher value concentration of inorganic phosphate is attributed to the monsoon season due to rainfall along with terrestrial runoff [47] and the low value are present in summer could be due to utilization of the phosphate by photoautotrophs and sediment under varying environmental conditions [48]. High value of silicate are recorded higher than the other nutrients (NO_2, NO_3 and PO_4) and higher value was noticed during monsoon season when the salinity was very low which might be due to heavy fresh water inflow [49]. The low value of silicate are recorded during the post monsoon season could be attributed to uptake of the silicate using biological activity of phytoplankton. Low primary productivity is recorded during monsoon due to the phytoplankton in the neritic region by the monsoonal flood besides reduction of the salinity, which could have been affected by the phytoplankton population [50]. Monsoon season effects such us upwelling and land runoff which favors the growth and proliferation of diatoms [51] [52]. Low monsoon season values could be due to freshwater discharges recorded from the causing turbidity and less availability of light [53] [54]. Phytoplankton is recorded in the present study period consisted of 86 species from the stations. During the study, diatom was found to be the dominant group followed by dinoflagellates and green algae in all the stations. Percentage contribution of each group of phytoplankton was thus in the decreasing order as follows Diatoms> dinoflagellates> green algae. Generally the diatoms were found to be dominant in the estuarine environment, which could be due to the diatoms can be tolerating widely depending on the hydrographical environment [45] [50] [55] [56]. The phenomenon has been reported earlier with the other different species during premonsoon season [45] [54].The observed high density during summer season might have been attributed to more than stable hydrographical parameters [57]. However, species compositions were moderately higher in postmonsoon and summer than the premonsoon. Phytoplankton abundance is present in low during monsoon season and this could be due to the heavy rainfall, low temperature, decreased salinity, pH and high turbidity [57].
The highest value in post-monsoon was due to high species composition observed during the study period. Environmental condition promotes the growth of diatoms during the postmonsoon season by [52]. [50] Diversity indices and low species richness in monsoon might have associated with lower temperature and salinity was also reported earlier by [58] southeast coast of India. Species richness was minimum (3.348) during monsoon and maximum (6.454) during summer season. High values was recorded during summer and low species richness recorded during monsoon season could be correlated with nutrients influx as suggested earlier by [50]. Species evenness index ranged between 0.847 and 0.974 with maximum during the postmonsoon and minimum recorded during monsoon season. Similar findings was reported earlier by [28] in Muthupetai coastal region waters.

5. CONCLUSION

Present investigation summarizes the station with seasonal fluctuations in the physicochemical parameters and phytoplankton diversity from the Vellar estuary. Parangipettai waters are highly riverine, freshwater inflow influence the high level nutrient in the Vellar estuary, Bay of Bengal. The addition of nutrient such as nitrate and silicate present in the waters are mainly during the monsoon season. The high organic load are present during monsoon season containing silcate, phosphate, and nitrate plays the substantial role in phytoplankton growth in the forthcoming

seasons, which helps the phytoplankton to avail the nutrients and proliferate. It is clearly evidenced from R software that the nutrients have positive and negative correlation between seasons and phytoplankton diversity. The phytoplankton diversity is dynamic depending on nutrient availability. Thus, the study gives a good quality outline of the seasonal dynamic relationship between environmental parameters and phytoplankton diversity. The phytoplankton populations are increased during the post monsoon season due to positive presence of nutrient abundance and environmental condition, but in summer season is less inflow of water to compare with other seasons. The phytoplankton concentration level are low during monsoon season due to the dilution factor and sudden changes of the water quality parameters, which leads to the less amount of photosynthetic activity by the primary producers.

6. ACKNOWLEDGEMENT

The authors thankful to the Dean and Director and other authorities of CAS in Marine Biology, Annamalai University, Parangipettai for providing the facilities.

7. REFERENCES

[1] Hobbie, J.E. ed., 2000 “Estuarine science: a synthetic approach to research and practice”. Island Press.

[2] Saravanakumar, A., Rajkumar, M., Serebiah, J.S. and Thivakaran, G.A., 2008 “Seasonal variations in physico-chemical characteristics of water, sediment and soil texture in arid zone mangroves of Kachchh-Gujarat” .J. Environ. Biol, 29(5), pp.725-732.

[3] Vaulot, D., 2001 “Phytoplankton. Encyclopedia of life sciences” Nature Publishing Group. London

[4] Khan, T.A., 2003 “Limnology of four saline lakes in western Victoria, Australia: I. Physico-chemical parameters” Limnologica, 33(4), pp.316-326.

[5] Duarte, P., Macedo, M.F. and Da Fonseca, L.C., 2006 “The relationship between phytoplankton diversity and community function in a coastal lagoon In Marine Biodiversity” (pp. 3-18). Springer, Dordrecht.183, 3—18.

[6] Madhu, N.V., Jyothibabu, R., Balachandran, K.K., Honey, U.K., Martin, G.D., Vijay, J.G., Shiyas, C.A., Gupta, G.V.M. and Achuthankutty, C.T., 2007 “Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin backwaters–India)” Estuarine, Coastal and Shelf Science, 73(1-2), pp.54-64.

[7] Choudhury, S.B. and Panigrahy, R.C., 1991 “Seasonal destribution and behaviour of nutrients in the creek and coastal waters of Gopalpur, East Coast of India. Mahasagar” 24(2), pp.81-88.

[8] Guinder, V.A., López-Abbate, M.C., Berasategui, A.A., Negrin, V.L., Zapperi, G., Pratolongo, P.D., Severini, M.D.F. and Popovich, C.A., 2015 “Influence of the winter phytoplankton bloom on the settled material in a temperate shallow estuary” Oceanologia, 57(1), pp.50-60.

[9] Crossetti, L.O., Bicudo, D.D.C., Bicudo, C.E.D.M. and Bini, L.M., 2008 “Phytoplankton biodiversity changes in a shallow tropical reservoir during the hypertrophication process” Brazilian Journal of Biology, 68(4), pp.1061-1067.

[10] Skejić, S., Bojanić, N., Matijević, S., Vidjak, O., Grbec, B., NINČEVIĆ, Ž.G., Šestanović, S. and Šantić, D., 2014 “Analysis of phytoplankton community in the vicinity of domestic sewage outflow during stratified conditions” Mediterranean Marine Science, 15(3), pp.574-586.

[11] Menon, N.N., Balchand, A.N. and Menon, N.R., 2000 “Hydrobiology of the Cochin backwater system–a review” Hydrobiologia, 430(1-3), pp.149-183.

[12] Sridhar, R., Thangaradjou, T., Kumar, S.S. and Kannan, L., 2006 “Water quality and phytoplankton characteristics in the Palk Bay, southeast coast of India” Journal of environmental biology, 27(3), pp.561-566.

[13] Sahu, G., Satpathy, K.K., Mohanty, A.K. and Sarkar, S.K., 2012 ‘Variations in community structure of phytoplankton in relation to physicochemical properties of coastal waters, southeast coast of India” Indian Journal of Geo-Marine Sciences 41 (3), 223—241.

[14] Strickland, J.D. and Parsons, T.R., 1972 “A practical handbook of seawater analysis., 2nd ed. Fish. Res. Board Canada, Ottawa” 310 pp.

[15] Venkataraman, G., 1939 “A systematic account of some south Indian diatoms” Proceedings: Plant Sciences, 10(6), pp.293-368.

[16] Subrahmanyan, R., 1946 “A systematic account of the marine plankton diatoms of the Madras coast” In Proceedings of the Indian Academy of Sciences-Section B (Vol. 24, No. 4, pp. 85-197). Springer India.

[17] Smith, D.L., 1977 “A guide to marine coastal plankton and marine invertebrate larvae “Kendal/Hunt Publ. Co., Dubuque, 16 pp.

[18] Santhanam, R., Ramanathan, N., Venkataramanuja, K.V., Jegatheesan, G., 1987 “Phytoplankton of the Indian Seas: An Aspect of Marine Botany. Daya Publ., House, Delhi” 127 pp.

[19] Battish, S.K., 1992 “Freshwater zooplankton of India Oxford & IBH Publishing Co. Pvt Ltd., New Delhi, India

[20] Ward H.B. and Whipple, G.C., 1992 “Fresh water biology (Edmondson, WT) Int. Books Periodicals supply service, New Delhi”

[21] Sampathkumar, P. and Perumal, P., 2002. Manual on Identification of Phytoplankton. All India Coordinated Project on Survey and Inventorization of Coastal and Marine Biodiversity (East coast), CAS in Marine Biology, Annamalai University, India. 56pp.

[22] Al-Kandari, M., Al-Yamani, F. and Al-Rifaie, K., 2009 “Marine phytoplankton atlas of Kuwait’s waters” (p. 351).

[23] Shannon, C.E. and Weaver, W., 1949 “The mathematical theory of communication–Univ” Illinois press, Urbana, I, 11, p.117.

[24] Pielou, E.C., 1966 “Species-diversity and pattern-diversity in the study of ecological succession” Journal of theoretical biology, 10(2), pp.370-383.

[25] Margalef, R., 1958 “Temporal succession and spatial heterogeneity in phytoplankton” Perspectives in marine biology, pp.323-349.

[26] Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P. and Stevens, M.H.H., 2016 “R Package Version 2.4-0. Vegan: Community Ecology Package"

[27] Wickham, H., 2009 “Elegant graphics for data analysis (ggplot2)” Springer-Verlag, New York, 213 pp.,

[28] Sukumaran, M., Muthukumaravel, K. and Sivakami, R., 2013 “Seasonal variation in physico-chemical characteristics of Agniar Estuary, Southeast Coast of India” Asia Pac. J. Res, 2(8), pp.108-120.

[29] Vajravelu, M., Martin, Y., Ayyappan, S. and Mayakrishnan, M., 2018 “Seasonal influence of physico-chemical parameters on phytoplankton diversity, community

structure and abundance at Parangipettai coastal waters, Bay of Bengal, South East Coast of India" Oceanologia, 60(2), pp.114-127.

[30] Balasubramanian, R. and Kannan, L., 2005 'Physico-chemical characteristics of the coral reef environs of the Gulf of Mannar Biosphere Reserve, India" Int. J. Ecol. Environ. Sci, 31(3), pp.273-278.

[31] Jyothibabu, R., Madhu, N.V., Maheswaran, P.A., Jayalakshmy, K.V., Nair, K.K.C. and Achuthankutty, C.T., 2008 "Seasonal variation of microzooplankton (20–200 µm) and its possible implications on the vertical carbon flux in the western Bay of Bengal" Continental Shelf Research, 28(6), pp.737-755.

[32] Davis, J.C., 1975 "Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review" Journal of the Fisheries Board of Canada, 32(12), pp.2295-2332.

[33] Levinton, J.S., 2001 "Marine biology. Chapter 4–The Chemical and Physical Environment. Oxford Univ. Press, New York" 560 pp.

[34] Morgan, A.M., Royer, T.V., David, M.B. and Gentry, L.E., 2006 "Relationships among nutrients, chlorophyll-a, and dissolved oxygen in agricultural streams in Illinois" Journal of environmental quality, 35(4), pp.1110-1117.

[35] Satyanarayana, D., Rao, I.M. and Prasada Reddy, B.R., 1990 "Primary productivity, plants pigments and particular organic carbon of Visakhapatnam Harbour–A seasonal study" In Proceeding of International Symposium of Marine Pollution (pp. 287-300).

[36] Bragadeeswaran, S., Rajasegar, M., Srinivasan, M. and Rajan, U.K., 2007 "Sediment texture and nutrients of Arasalar estuary, Karaikkal, south-east coast of India" Journal of Environmental Biology, 28(2), pp.237-240.

[37] Govindasamy, C., Kannan, L. and Azariah, J., 2000 "Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel coast, India" Journal of Environmental Biology, 21(1), pp.1-7.

[38] Gouda, R. and Panigrahy, R.C., 1995 "Seasonal distribution and behaviour of nitrate and phosphate in Rushikulya estuary, east coast of India" Indian Journal of Geo-Marine Sciences, 24 (4), 233—235;

[39] Das, J., Das, S.N. and Sahoo, R.K., 1997 "Semidiurnal variation of some physico-chemical parameters in the Mahanadi estuary, east coast of India" Indian Journal of Geo-Marine Science, 26 (3), 323—326.

[40] Krishnamurthy, K., Mani, P. and Krishnamurthy, K., 1989 "Variation of phytoplankton in a tropical estuary (Vellar estuary, Bay of Bengal, India)" Internationale Revue der gesamten Hydrobiologie und Hydrographie, 74(1), pp.109-115.

[41] Murugan, A. and Ayyakkannu, K., 1991. Ecology of Uppanar Backwaters, Cuddalore: 2. Nutrients. Mahasagar, 24(2), pp.103-108.

[42] Senthilkumar, B., Purvaja, R. and Ramesh, R., 2008 "Seasonal and tidal dynamics of nutrients and chlorophyll a in a tropical mangrove estuary, southeast coast of India" Indian Journal of Geo-Marine Sciences. 37 (2), 132—140.

[43] Thangaradjou, T., Sarangi, R.K., Shanthi, R., Poornima, D., Raja, K., Saravanakumar, A. and Balasubramanian, S.T., 2014 "Changes in nutrients ratio along the central Bay of Bengal coast and its influence on chlorophyll distribution" Journal of environmental biology, 35(3), p.467.

[44] Dugdale, R.C., Wilkerson, F.P., Hogue, V.E. and Marchi, A., 2007 "The role of ammonium and nitrate in spring bloom development in San Francisco Bay" Estuarine, Coastal and Shelf Science, 73(1-2), pp.17-29.

[45] Senthilkumar, S., Santhanam, P. and Perumal, P., 2002 "Diversity of phytoplankton in Vellar estuary, southeast coast of India" In The 5th Indian Fisheries Forum Proceedings (Eds.: S. Ayyappan, JK Jena and M. Mohan Joseph). Published by AFSIB, Mangalore and AeA, Bhubanewar, India (pp. 245-248).

[46] Cole, C.V. and Sanford, R.L., 1989 "Biological aspects of the Phosphorus cycle" In Proc. Symp. on phosphorous requirements for sustainable agriculture in Asia and Oceania (Vol. 610).

[47] Satpathy, K.K., Sahu, G., Mohanty, A.K., Prasad, M.V.R., Panigrahy, R. C., 2009 "Phytoplankton community structure and its variability during southwest to northeast monsoon transition in the coastal waters of Kalpakkam, east coast of India" International Journal of Oceans and Oceanography. 3 (1), 43—74.

[48] Perumal, N.V., Rajkumar, M., Perumal, P. and Rajasekar, K.T., 2009 "Seasonal variations of plankton diversity in the Kaduviyar estuary, Nagapattinam, southeast coast of India" J. Environ. Biol, 30(6), pp.1035-1046.

[49] Rajasegar, M., 2003. Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. Journal of Environmental Biology, 24(1), pp.95-101.

[50] Rajasegar, M., Srinivasan, M. and Rajaram, R., 2000 "Phytoplankton diversity associated with the shrimp farm development in Vellar estuary, south India" Seaweed Res. Utiln, 22(1-2), pp.125-213.

[51] Dehadrai, P.V. and Bhargava, R.M.S., 1972 "Distribution of chlorophyll, carotenoids and phytoplankton in relation to certain environmental factors along the central west coast of India. Marine Biology, 17(1), pp.30-37.

[52] Dupuis, A.P. and Hann, B.J., 2009 "Warm spring and summer water temperatures in small eutrophic lakes of the Canadian prairies: potential implications for phytoplankton and zooplankton" Journal of Plankton Research, 31(5), pp.489-502.

[53] Godhantaraman, N., 2002 "Seasonal variations in species composition, abundance, biomass and estimated production rates of tintinnids at tropical estuarine and mangrove waters, Parangipettai, southeast coast of India" Journal of Marine Systems, 36(3-4), pp.161-171.

[54] Thillai Rajsekar, K., Perumal, P., Santhanam, P., 2005. Phytoplankton diversity in the Coleroon estuary, southeast coast of India. J. Mar. Biol. Assoc. India 47 (2), 127—132.

[55] Kannan, L. and Vasantha, K., 1992 "Microphytoplankton of the Pitchavaram mangals, southeast coast of India: species composition and population density" In The Ecology of Mangrove and Related Ecosystems (pp. 77-86). Springer, Dordrecht.

[56] Mani, P., 1992 "Natural phytoplankton communities in Pichavaram mangroves" Indian Journal of Geo-Marine Sciences,21 (4), 278—280.

[57] Babu, A., Varadharajan, D., Vengadesh, P.N., Thilagavathi, B., Manikandarajan, T., Sampathkumar, P. and Balasubramanian, T., 2013 "Diversity of phytoplankton in different stations from Muthupettai, South east coast of India" J Marine Sci Res Dev, 3(128), p.2.

[58] Akpan, E.R. and Offem, J.O., 1993 "Comparison of chlorophyll a and carotenoids as predictors of phytoplankton biomass in the cross river system of Nigeria"