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Original Research Paper

The Effect of Sea Food Processing Discharge on the Nearby Wetlands in Cherthala-Aroor-Edakochi Coastal Belt of Kerala, India

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ABSTRACT

Effluents from the sea food processing plants discharged into the water bodies may cause eutrophication. This study has been carried out to assess the impact of effluent discharge on water quality and phytoplankton population in Vembanad-kol wetland adjacent to seafood processing industries. Five stations were selected in the Cherthala-Aroor-Edakochi coastal belt of Vembanad lake, four were near to the seafood processing facilities, and the fifth station was kept as a reference site, which is free from the direct seafood processing effluent discharge. Samples were collected on monthly for a period of one year (October 2011 to September 2012) for physico-chemical and biological analysis. The higher level of salinity, alkalinity, hardness, BOD, COD, nitrate, phosphate, ammonia, silicate and depleted level of dissolved oxygen indicated the pollution status of study stations (S_1-S_4) compared to reference site (S_5). Among the 137 genera of phytoplanktons, Bacillariophyceae was the major class followed by Chlorophyceae and Cyanophyceae. In addition to this, the class Rhodophyceae, Chrysophyceae, Haptophyceae, Eustigmatophyceae and Cryptophyceae were also reported. Percentage composition and biological indices of the phytoplanktons were assessed. The pollution tolerant genera like *Navicula, Nitzschia, Scenedesmus, Coscinodiscus, Ankistrodesmus, Chlorella, Oscillatoria, Phormidium,* etc. were dominant in the four stations (S_1-S_4) during the study period. This baseline information on the water quality status of Vembanad lake will be useful for future ecological assessment and monitoring to conserve this Ramsar site.

INTRODUCTION

India's fisheries sector contributes significantly to the national economy while providing livelihood to approximately 14.49 million peoples in this country. India is the second largest in aquaculture production in the world. The fish production during 2011-2012 is estimated to be 8.29 million tonnes (Ministry of Agriculture 2012). Kerala's share in the national fish production is about 20-25%. The Vembanad lake forms the largest water body in Kerala and the third largest in the country. Vembanad-kol wetland supports a rich diversity of life forms ranging from microscopic primary producer plankters to the tertiary consumer human beings. Wetlands provide a wide array of biological, social and economic benefits. Hence it is described as 'biological supermarkets (Mitsch & Gosselink 2000). The Vembanad lake and its connected backwater system around Cochin are well known for their role as a nursery ground for important fishery resources of this area (Pillai 1975) and was declared as a Ramsar site in November 2002. The fishing industry comprising of fish catching, processing, and marketing and processing of seafood produces a large bulk of by-products and wastes. Effluents from fish and crustacean processing plants are generally characterized by high concentration of nutrients, high levels of nitrogen as ammonia-N (29 to 35 mg/L), high total suspended solids (0.26 to 125,000 mg/L), increased BOD (10 to 110,000 mg/L) and COD (496 to 140,000 mg/L), and by the presence of sanitizers (AMEC Earth and Environmental Limited 2003). The direct discharge of waste from the seafood processing industries into the adjacent wetlands affects the aquatic life and thus may affect the whole food chain. Problems occur when the quantity of organic matter discharged exceeds the carrying capacity of the ecosystem and/or when its dispersion is constrained within coastal waters. Excessive discharge of organic nutrients into the marine environment can result in reduction of dissolved oxygen in the water leading to anoxia, increased ammonia concentrations, overloads of nitrogen (N) and phosphate (P) causing excessive plant growth, variation in pH, and increased water turbidity (Tchoukanova et al. 2003). The fish processing effluents detrimentally affect the quality of water bodies (Hamid et al. 2010). The water quality estimation can be done by determining physico-chemical quality (Hamid et al. 2010) or by making biological analysis (Hillerband & Somar 2000, Sharma & Bhardwaj 2011). Phytoplankton are characterized by their rapid responses to alterations in environmental conditions (Reynolds 1984) such as anthropogenically introduced eutrophication of coastal waters (Richardson 1997). The latter characteristic makes phytoplankton sensitive indicators of changes in aquatic ecosystems (Valdes-Weaver et. al. 2006). Their presence or absence from the community indicates changes in physico-chemical environment of the estuary (Rissik 2009). The negative impact of seafood processing effluent on water quality was investigated by Walden (1991) and Sagar & Naikwade (2012). Bonsdorff et al. (1997) reported the increase in phytoplankton biomass and decrease in species diversity of benthic and fish communities, with respect to the discharge of seafood processing wastes on aquatic bodies. Evidence suggests that serious shrimp farm production losses resulting from the outbreak of disease in Asia and Latin America are due to the environmental impacts of shrimp culture (Phillips et al. 1993). In addition to impacts on the aquaculture operation itself, shrimp farming has been linked to several cases of environmental degradation. Despite this type of evidence, there is still a lack of quantitative data on the ecological impacts to receiving waters (Phillips et al. 1993). Thus, it is obvious that, the seafood associated pollutants led to the destabilization of aquatic ecosystem. Due to the local, regional, national and international importance, Vembanad lake is an active research topic. Considerable amount of work has already been carried out on hydrography, productivity, nutrients, floral and faunal diversity of Vembanad wetlands (George 1958, Sankaranarayanan & Qasim 1969, Gopinathan 1972, Devassy & Bhattathiri 1974, Lakshmanan et al. 1987, Unnithan et al. 2001, Harikumar et al. 2007). Some other studies also explained the pollution status of Vembanad lake from various sources including domestic and municipal sewage, fertilizer and pesticide residues, heavy metals, coconut retting, industrial effluents from oil refineries, fertilizer plants and chemical industries (Rai et al. 1976, Remani et al. 1980, Saraladevi et al. 1979, Bijoy Nandan 2003, Mohan & Omana 2006, Priju & Narayana 2007). However, a detailed investigation on this perspective of pollution and its impact on the Vembanad lake have not been done earlier. Hence, the present study has been formulated to understand the preliminary effects of seafood processing waste discharge on the phytoplankton population of the Vembanad lake ecosystem.

MATERIALS AND METHODS

Study site: The Vembanad wetland extending between the 09°00'-10°40' N latitude and 76°00'-7°30' E longitude, is the most important tropical wetland in Kerala and supports several livelihood activities. This Ramsar site covers an area of 1,513 km^2 and stretch from Alappuzha to Cochin. The Vembanad lake borders Cherthala, Ambalapuzha and Kuttanad taluks of Alappuzha district. The present study was conducted in Cherthala-Aroor-Edakochi coastal belt, where large number of seafood processing plants are situated. Samples for the present study were collected from five different stations namely, Pattanakadu (S_1), Parayakadu (S_2), Edakochi (S_3), Aroormukkam (S_4) and Panavally (S_5) (Table 1). The sites (S_1-S_4) were closely associate the seafood processing discharge outlets and the site S_5 was kept as a reference site, which is free from the seafood processing discharge.

Water quality analysis: The water samples were collected from the five pre-selected sites of Vembanad wetlands for a period of one year from October 2011 to September 2012 on a monthly basis.

The Physico-chemical parameters such as water and atmospheric temperatures, pH, electrical conductivity and total dissolved solids were measured using microprocessor based portable water quality testing meters. Salinity and transparency were measured using refractometer and Secchi disc respectively. For the physico-chemical analysis, the water samples were collected in plastic bottles, taken to the laboratory and refrigerated at 4°C. The parameters like DO, alkalinity, hardness, COD and BOD were measured and analysed by titration as recommended by Adoni (1985) and APHA (2005). The nutrients like nitrate, phosphate, silicate, and ammonia were analysed using a portable multi parameter Bench Photometer (Hanna Instruments C 200 series).

Phytoplankton analysis: Phytoplankton samples were collected from the surface water using a conical net of mesh size 50µm, for a period of one year on a monthly basis. A known volume (25 litres) of water was passed through the net and collected in a 50mL plastic container. The labeled samples were preserved in 4% formalin solution at the site itself, labelled and brought to the laboratory.

Taxonomic identification of plankton up to genus level was done using standard keys (Adoni 1985, Newell & Newell 1986, Palmer 1980, Santhanam et al. 1987). Quantitative analysis of plankton was done by employing Sedgewick-Rafter cell counting chamber.

Statistical analysis: The water quality values were presented as mean ± standard error. Correlation analysis was employed to determine the relationship between physico-chemical parameters and phytoplankton. One way ANOVA was used to compare quality variance between stations. The diversity indices such as Shannon-Wiener species diversity index, Simpson dominance index and Margalef richness index were employed to assess the plankton diversity using the software PAST (2005).

RESULTS

The results of the physico-chemical analysis of the water

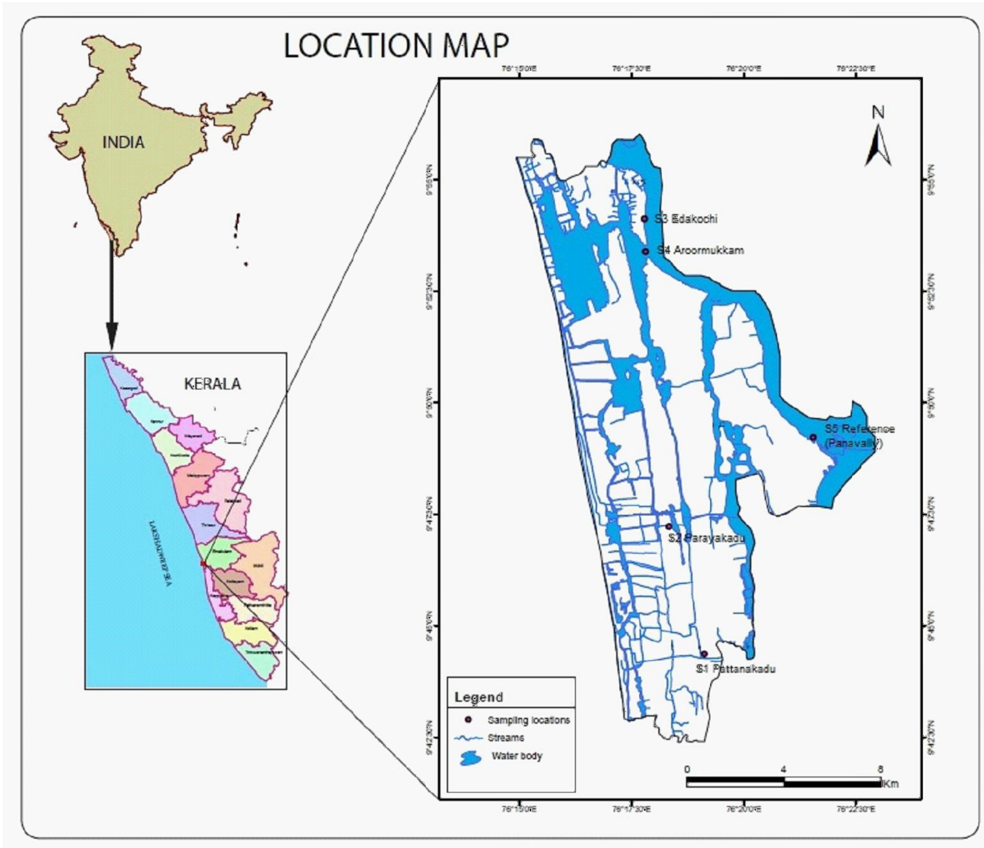

Fig. 1: Location and study sites in the Vembanad lake.

samples from different stations in Cherthala-Aroor-Edakochi coastal belt of Vembanad lake is given in Table 2. The interrelationships of physico-chemical parameters at different sites were analysed using correlation matrix. There was a negative correlation between atmospheric temperature and various other parameters like transparency at S_3 ($r = -0.663$, $p< 0.05$), alkalinity at S_4 and S_5 ($r = -0.616$; $r = -0.581$, $p< 0.05$) and COD at S_5 ($r = -0.624$, $p< 0.05$). The water temperature has significant positive correlation with COD ($r = 0.642$, $p< 0.05$ at S_3), nitrate ($r = 0.625$, $p< 0.05$ at S_4) and silicate ($r = 0.595$, $p< 0.05$ at S_5). A negative correlation was observed between water temperature with others such as pH ($r = -0.637$, $p< 0.05$ at S_1), salinity ($r = -0.601$, $p< 0.05$ at S_3) at S_2, S_5 and S_4 respectively). The pH was negatively correlated with various parameters including TDS ($r = -0.714$, $p< 0.01$ at S_1), EC ($r = -0.787$, $p<0.01$ at S_1), salinity ($r = -0.633$, $p< 0.05$ at S_1), alkalinity ($r = -0.605$, $p< 0.05$ at S_5) and total hardness ($r = -0.761$, $p< 0.01$ at S_1). Moreover, TDS related with total hardness in positive manner at S_1 and S_2 ($r = 0.649$ $p< 0.05$; $r = 0.757$, $p< 0.01$). There was a negative correlation between TDS and alkalinity ($r = -0.587$, $p< 0.05$ at S_2), DO ($r = -0.556$, $p< 0.05$ at S_2), silicate ($r = -0.710$, $p< 0.01$ at S_4). EC also showed a positive correlation with total hardness ($r = 0.746$; $r = 0.786$, $p< 0.01$ at S1 and S_2; $r = 0.594$, $p< 0.05$ at S_3) and show negative significant correlation with DO ($r = -0.700$, $p< 0.05$ at S_2) and silicate ($r = -0.659$, $p< 0.05$ S_4). There was a positive correlation between salinity and total hardness at S_1 and S_2 ($r = 0.695$ $p< 0.05$; $r = 0.780$ $p< 0.01$). Transparency was significantly correlated with hardness and DO in a positive way ($r = 0.606$, $p< 0.05$; $r = 0.667$, $p< 0.05$ at S_1) and related with COD, phosphate, nitrate and silicate in a negative way ($r = - 0.633$, $p< 0.05$ at S_3; $r = - 0.633$, $p< 0.05$ and $= - 0.635$, $p< 0.05$ at S_1; $r = -0.716$, $p< 0.01$ at S_4). Alkalinity and DO related negatively with ammonia ($r = - 0.612$, $p< 0.05$ at S_4; $r = - 0.664$, $p< 0.05$ at S_3), whereas the total hardness correlated positively with ammonia ($r = 0.668$, $p< 0.05$ at S_3). A positive correlation was obtained with BOD and nitrate with the r-value 0.611, $p< 0.05$ at S_2. Chemical oxygen demand was correlated to nitrate and silicate in a positive way ($r = 0.741$ and $r = 0.781$, $p< 0.01$ respectively at S_3). Phosphate exhibited positive correlation with other nutrients such as ammonia and silicate ($r = 0.868$, $p< 0.01$ and $r = 0.642$, $p< 0.05$ respectively at S_5). Moreover, ammonia also showed a positive correlation with silicate at

S_1 (r = 0. 620, p< 0.05).

In the current study, phytoplankton groups showed a few significant correlations with the physico-chemical parameters. The influence of water quality parameters (pH, alkalinity, hardness, BOD, COD) and nutrients (nitrate, phosphate, silicate) on phytoplankton are graphically represented in Figs. 1-4. In Pattanakadu (S_1), Class Bacillariophyceae was positively correlated with BOD (r = 0.615, p< 0.05) and Cyanophyceae with silicate (r = 0.655, p< 0.05).

In Parayakadu (S_2), a negative correlation was reported between water temperature and Chlorophyceae (r = -0.660, p< 0.05). Electrical conductivity and salinity were positively correlated with Cyanophyceae having the values r = 0.766, p< 0.01 and r = 0.655, p< 0.05 respectively. Total hardness of water correlated with Cyanophyceae in positive manner (r = 0.700, p<0 .05). The nitrate was negatively correlated with Cyanophyceae (r = 0.579, p< 0.05).

A least relationship among physico-chemical variables and plankton was obtained in Edakochi (S_3).

In Aroormukkam (S_4), alkalinity was positively correlated with Bacillariophyceae and Chlorophyceae (r = 0.714 and r = 0.760, p< 0.01 respectively). Dissolved oxygen showed negative correlation with Cyanophyceae (r = -0.583, p< 0.05). Phosphate showed a positive correlation with both Bacillariophyceae and Chlorophyceae having the same r-value 0.641, p< 0.05.

To find out whether the variation in physico-chemical parameters and plankton groups from station to station was significant or not, the technique of analysis of variance was applied (Table 2). The results of (ANOVA-one way) revealed that there was no significant variation of atmospheric temperature between stations. Water temperature varied significantly between S_1 and S_3 at p<0.05. pH showed a significant variation between the stations S_1-S_3; S_1-S_4 at p< 0.01 and S_1-S_5 at p< 0.05 . TDS varied significantly between S_1-S_3 and S_1-S_4 at p< 0.01. It also varied among S_3-S_5 (p< 0.01) and S_4-S_5 (p< 0.05). Variation of electrical conductivity and salinity between stations S_1-S_3; S_1-S_4; S_3-S_5; S_4-S_5 were significant (p< 0.01). Values of salinity also differed significantly between S_2-S_3 (p< 0.05).

Transparency variation among the stations S_1-S_5; S_2-S_5; S_3-S_5; S_4-S_5 were significant (p< 0.01). Alkalinity differ in S_1-S_2; S_1-S_5; S_3-S_5 (p<0.05) and S_2-S_3; S_2-S_4; S_2-S_5 (p< 0.01). Stations S_3-S_5 (p< 0.05) and S_4-S_5 (p< 0.01) differ in total hardness also. Dissolved oxygen varied between S_1-S_5; S_2-S_5 (p< 0.01) and S_4-S_5 (p<0.05). Values of BOD varied among S_1-S_5; S_2-S_5; S_3-S_5 and S_4-S_5 (p< 0.01). A significant variation was obtained for COD between S_2-S_5 and that of (p<0.05) was for S_3-S_5. Phosphate showed variation between S_1-S_5; S_2-S_5; S_3-S_5 (p< 0.01) and S_4-S_5 (p< 0.05). Nitrate varied between S_1-S_5; S_2-S_5; S_3-S_5 and S_4-S_5 (p< 0.01). Ammonia values differ significantly with S_2-S_5; S_3-S_5 (p< 0.01) and S_3-S_4 (p< 0.05). Silicate varied only between S_1-S_5 (p< 0.05).

Phytoplankton: Variations in ecological conditions are reflected in both, the distribution and periodicity of plankters. A total of 137 phytoplankton genera representing 8 diverse taxonomic classes of Bacillariophyceae (53), Chlorophyceae (55), Cyanophyceae (19), Rhodophyceae (4), Chrysophyceae (2), Haptophyceae (2), Eustigmatophyceae (1), and Cryptophyceae (1) were reported during the study period. The total number of individuals quantified from the five stations during the investigation period was 9138, and they were classified up to the genus level. The phytoplankton diversity and their percentage composition are given in Table 3.

The Bacillariophyceae had a higher representation in all stations with maximum individuals of 1374 in S_1 and a minimum of 814 in S_5. Among them, representatives of 33 genera were present in all the stations which include *Achananthes, Amphora, Asterionella, Biddulphia, Ceratulina, Cheatoceros, Climacosphenia, Coscinodiscus, Cyclotella, Cymbella, Diatoma, Diploneis, Fragilaria, Frustulia, Gyrosigma, Grammatophora, Leptocylindrus, Licmophora, Navicula, Nitzschia, Pinnularia, Pleurosigma, Rhizosolenia, Skeletonema, Stauroneis, Streptotheca, Synedra, Tabellaria, Thalassionema, Thalassiosira, Thalassiothrix* and *Triceratium.* Of these, *Nitzschia, Navicula, Coscinodiscus* and *Fragilaria* showed higher dominance with varying number of individuals. The Class Bacillariophyceae occupied 62.57% of the total individuals reported during the study.

Table 1: Study sites.

Sl.No	Name	Geographic Position	Land Utilisation	Remarks
1	Pattanakadu (S_1)	9°44'22N,76°19'07E	Panchayat area	Interconnected canal
2	Parayakadu (S_2)	9°47'13N,76°18'20E	Aquaculture farm	Interconnected canal
3	Edakochi (S_3)	9°54'07N,76°17'42E	Boat building yard	Main water body
4	Aroormukkam (S_4)	9°53'23N,76°17'49E	Fallow land	Main water body
5	Panavally (S_5)	9°49'13N,76°21'33E	Agriculture and aquaculture area	Main water body

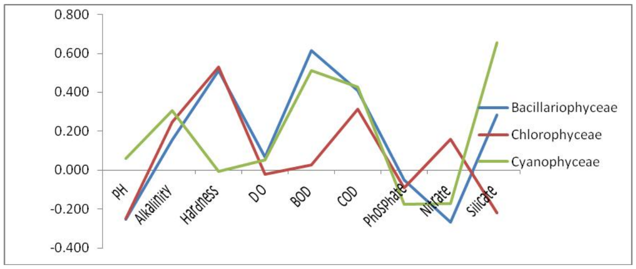

Fig. 1: Correlation matrix relating phytoplankton class with physico-chemical parameters at Pattanakadu (S_1).

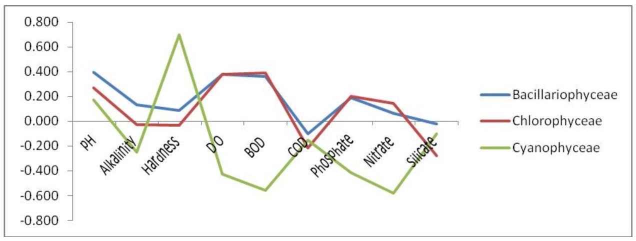

Fig. 2: Correlation matrix relating phytoplankton class with physico-chemical parameters at Parayakadu (S_2).

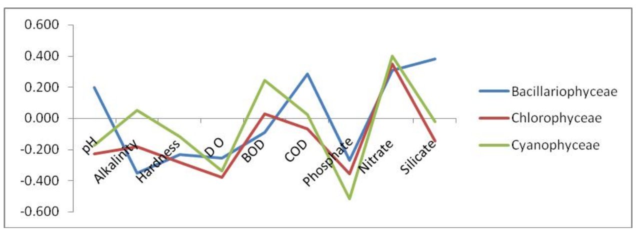

Fig. 3: Correlation matrix relating phytoplankton class with physico-chemical parameters at Edakochi (S_3).

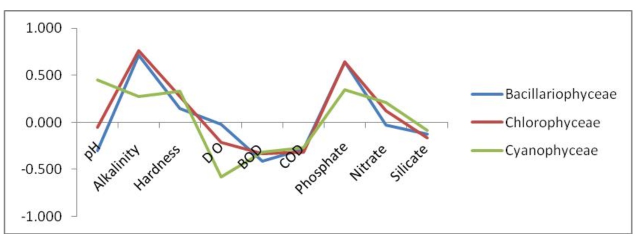

Fig. 4: Correlation matrix relating phytoplankton class with physico-chemical parameters at Aroormukkam (S_4).

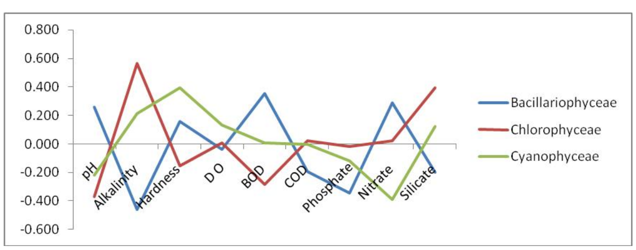

Fig. 5: Correlation matrix relating phytoplankton class with physico-chemical parameters at Panavally (S_5).

The second dominant class obtained in the study was Chlorophyceae (19.52 %). The highest number of individuals were reported in S_2 (690) and lower in S_4 and S_5 (234). Twenty genera were present in all the stations and they were, *Actinastrum, Ankistrodesmus, Characium, Chlamydomonas, Chlorella, Cladophora, Clostridium, Closterium, Cosmarium, Elakatothrix, Microspora, Oedogonium, Scenedesmus, Spirogyra, Spirotaenia, Staurastrum, Tetraedon, Ulothrix* and *Zygnema*. The Genus *Ankistrodesmus, Scenedesmus, Chlorella* and *Spirogyra* showed dominance.

The Class Cyanophyceae was represented by 16.95% of total phytoplankton identified during the study period. More number of individuals were reported from S_2 (651) and less from S_4 (128). The genera represented in all stations were *Agmenellum, Anabaenopsis, Anabaena, Lyngbya, Oscillatoria, Phormidium, Spirulina* and *Trichodesmium.* Out of these, *Oscillatoria* and *Phormidium* were dominant.

The members of Rhodophyceae (0.18%), Chrysophyceae (0.16%), Eustigmatophyceae (0.14%), Cryptophyceae (0.11%) and Haptophyceae (0.07%) were also obtained. They did not show any dominance during the study period.

Out of the 8 taxonomic classes of phytoplankton obtained, 7 were present in Pattanakadu (S_1). Among Bacillarophyceae, *Nitzschia* (301), *Navicula* (221), *Fragilaria* (96), and *Coscinodiscus* (92) were dominant. *Ankistrodesmus* (65), *Scenedesmus* (47) and *Chlorella* (47) were predominant among Chlorophyceae. *Oscillatoria* (208) and *Phormidium* (95) represented the leading genera among Cyanophyceae.

A total of 97 genera were reported in Parayakadu (S_2). The dominant genera of Bacillariophyceae were *Nitzschia* (306), *Navicula* (229), and *Fragilaria* (104). *Scenedesmus* (182), *Ankistrodesmus* (59) and *Chlorella* (54) were dominant among Chlorophyceae, and *Anabaenopsis* (152), *Phormidium* (130) and *Oscillatoria* (106) were dominant among the Cyanophyceae.

All the 8 phytoplankton groups with 101 genera were present in Edakochi (S_3). Dominant genera among Bacillariophyceae were *Nitzschia* (261), *Navicula* (206), *Coscinodiscus* (76) and *Fragilaria* (52). Among Chlorophyceae, *Ulothrix* (51), *Microspora* (35), *Ankistrodesmus* (28) and in Cyanophyceae, *Oscillatoria* (80) and *Phormidium* (29) were dominant.

A total of 101 genera belonging to 7 phytoplankton taxonomic classes were reported in Aroormukkam (S_4). Among Bacillariophyceae (1153 members) *Navicula* (214), *Nitzschia* (155) and *Coscinodiscus* (86) were dominant. Chlorophyceae had 37 genera (234 members) with predominance of *Spirogyra* (31), *Uronema* (19), *Microspora* (16) and *Ankistrodesmus* (16). Cyanophyceae with 14 genera (128 members) were dominated by *Phormidium* (39) and *Oscillatoria* (29).

In the reference site Panavally (S_5), 92 genera from 4 classes were reported, which included Bacillariophyceae (43 genera with 814 individuals), Chlorophyceae (35 genera with 257 individuals), Cyanophyceae (11 genera with 136 individuals) and Rhodophyceae (3 genera with 9 individuals). *Navicula* (214), *Nitzschia* (155), and *Pleurosigma* (75) of Bacillariophyceae, *Gonatozygon* (34) and *Spirogyra* (32) of Chlorophyceae, *Phormidium* (32) and *Oscillatoria* (26) of Cyanophyceae were the dominant genera in S_5.

The values of Simpson dominance index (1-D) were in the range of 0.95-0.97. Its minimum value (0.95) was observed in S_1, S_3 and S_4, whereas the maximum in S_5. The Shannon Wiener diversity index (H') ranged between 3.58 to 3.87. The lowest H' value (3.58) was obtained in Pattanakadu (S_1) and that of higher value (3.87) in Panavally (S_5). Margalef richness index (d) was ranged between 12.19-13.64. The lowest and highest values were noticed in S_2 and S_4 respectively (Table 4).

Correlation study was done between phytoplankters in all the five sites to understand their interrelationship. In S_1, the correlation analysis of plankton with each other revealed that there was a significant positive correlation between Bacillariophyceae and Cyanophyceae ($r = 0.668$, $p< 0.05$). In S_2 and S_4 Chlorophyceae showed a significant positive correlation to Bacillariophyceae. In S_3 and S_5 the plankton groups did not show any significant relationship with each other.

DISCUSSION

The higher value of pH indicates higher productivity of water (Senthilkumar & Sivakumar 2008). The highest value of pH recorded in this study was 9.6 from S_1 indicating the increased rate of productivity in this area. Lower pH values at S_3, S_4 and S_5 may have resulted from decaying of the domestic and industrial waste litter in the lake contributing to the acidic nature of the water. Variation in pH values of effluent can affect the rate of biological reactions and survival of various microorganisms (Sagar & Naikwade 2012). Total dissolved solids in four study stations (S_1-S_4) were high compared to the reference site, S_5. In this study, TDS showed a strong positive relation with electrical conductivity. The maximum value of conductivity was from S_3 (19.7mS) and the minimum of 0.1mS in S_5. A high value of EC designates pollution status of the lake (Kadam & Tiwari 1990). In the current study, significant high salinity values were observed at all the stations except the reference site (S_5). The most remarkable observation of our study was the strong positive correlation of TDS, EC and salinity. All these three parameters showed the same relation in all the five study stations. Transparency, a measure of light penetration, mainly depends on the turbidity of water. High transparency values at Panavally (S_5) showed that the amount of suspended solids was less as compared to the other sites. A positive correlation of transparency with dissolved oxygen was obtained in our study and it is negatively related with silicate, nitrate and phosphate. It was reported that the total alkalinity value of 60 mg/L or more indicates hard water (Vass et al. 1977) . In the current study, mean value of alkalinity above 100 mg/L was observed in S_2, and that of S_1, S_3 and S_4 was above 50 mg/L. Contradictory to this, Panavally (S_5) showed a mean alkalinity value less than 50mg/L. Thus, it is obvious that the Station 5 was devoid of any organic pollution. In our study it is noted that alkalinity was negatively correlated with the concentration of ammonia. And it was also noted that, alkalinity values varied significantly between stations. Total hardness of the samples from four study sites (S_1-S_4) was remarkably high when compared with the reference site, Panavally (S_5). Thus, it is assumed that the hardness is due to the dissolution of minerals present in waste load discharged into the water body. Junshum et al. (2007) observed a high value of water hardness in wastewater treatment plant, as compared with natural reservoirs. We also found a positive correlation between total hardness of water with TDS, EC and salinity. The lower values of DO obtained in Pattanakadu (S_1), Parayakadu (S_2), Edakochi (S_3) and Aroormukkam (S_4) was an indicative of the presence of considerable amount of biodegradable organic matter in the water body. In contrast to this, a high value of DO was recorded in Panavally (S_5). The accumulation of organic matter from seafood waste will lead to the depletion of dissolved oxygen in the water column (Mazik et al. 2005). High mean BOD values of stations 1-4 of the current study pointed out the significant entry of organic pollution load to the lake, whereas that of lower value in reference site, indicated that the area is free from pollution.

Increasing trend of BOD and the decreasing trend of DO clearly indicate the addition of pollution load (Mulani et al. 2009). The same results reflected in our study also. Lowest values of COD were found in Panavally while higher values were obtained in all other study sites, which indicate the probability of organic pollution in study sites except Panavally. High value of COD strongly confirmed the presence of industrial effluent discharge as well as organic pollution (Nandan & Aher 2005). The S_4 was found to be more polluted with an increased level of nitrate, and the least value

Table 2: Physico-chemical characteristics (October 2011- September 2012).

Parameters	Pattanakadu (S_1)		Parayakadu (S_2)		Edakochi (S_3)		Aroormukkam (S_4)		Panavally (S_5)	
	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE
Atmospheric temperature (°C)	27.5-36	32.66±0.69	28-38	33.33±0.86	27.5-36	33.75±0.67	28-36	33.58±0.79	28-36	32.33±0.82
Water temperature (°C)	26.5-31	29.20±0.37	26-34	31.08±0.68	28-33.5	33.75±0.54a*	28-32.5	30.41±0.44	28-32	29.83±0.29
pH	7.60-9.60	8.60±0.26	7.20-8.70	7.93±0.13	6.20-8	7.25±0.19a**	6.00-8.40	7.21±0.21a**	6.90-8.80	7.77±0.16a*
TDS (ppt)	0.20-4.10	1.64±0.45	0.80-6.50	3.25±0.56	0.40-7.50	5.22±0.68 a**	1.00-7.30	4.78±0.58 a**	0.10-4.90	2.40±0.53 c**d*
EC (ms)	0.5-13.2	4.76±1.43	2-17.6	8.10±1.57	0.8-19.9	13.00±1.70 a**	0.5-19.7	12.93±1.91 a**	0.1-12.2	5.20±1.13 c**d**
Salinity (ppt)	0-10	3.91±1.09	0-13	6.16±1.37	3-20	11.83±1.41a* *b*	2-18	11.00±1.48 a**	0-8	2.91±0.87 c**d**
Transparency (sdd)	12.6-73	48.63±4.17	23-85.5	47.25±5.14	12-62	36.33±5.06	37.5-79.5	55.20±4.59	41.5-112.5	83.06±5.58 a**b**c** d**
Free CO_2 (mg/L)	22-280	78.70±21.47	16-356	102.83±26.86	10-120	45.25±11.09	6-100	47.41±9.34	8-48	22.91±3.04b*
Alkalinity (mg/L)	14-160	77.50±13.23	63-220	122.50±13.95 a*	35-130	75.58±6.93 b**	21-100	60.25±5.33b**	6-70	33.41±5.06 a*b**c*
Hardness (mg/L)	114-2360	667.83±192.30	206-2900	1188.00±266.07	210-4540	1494.33±418.29	120-4300	1632.33±372.28	30-250	119.41±18.37 c*d**
D O (mg/L)	3.23-8.05	6.59±0.37	4.56-8.48	6.64±0.36	4.85-9.70	7.20±0.39	5.25-8.08	6.96±0.22	7.68-10.91	8.43±0.29.a**b**d*
BOD (mg/L)	12.10-60.6	29.34±4.26	14.10-72.70	38.98±5.36	18.10-68.60	35.07±4.57	11.56-58.50	28.13±4.17	3.54-9.87	6.75±0.53 a**b**c**d**
COD (mg/L)	8.40-32.96	20.26±2.38	11.20-171.20	45.60±12.62	11.20-81.60	33.49±6.81	12.60-64	24.63±4.30	3.20-7.60	4.97±0.45 b**c*
Phosphate (mg/L)	0.50-5.70	2.41±0.42	1.16-2.89	2.28±0.17	0.40-4.80	2.176±0.38	0.28-3.70	1.62±0.26	0.10-0.50	0.29±0.09 a**b**c**d*
Nitrate (mg/L)	6.60-12.56	8.85±0.50	4.66-10.91	8.58±0.47	6.97-11.96	9.47±0.47	4.43-16.36	9.26±1.04	0.86-3.99	1.82±0.28 a**b**c**d**
Ammonia (mg/L)	3.50-9.97	5.82±0.53	1.57-28.91	9.06±2.24	2.58-35.12	10.32±2.56	1.29-6.32	3.22±0.40c*	0.35-2.800	1.13±0.20 b**c**
Silicate (mg/L)	1.2-10.50	4.02±0.74	1.60-5.50	2.87±0.36	1.80-7.20	3.33±0.51	1.40-4.90	2.33±0.33	0.05-5.10	1.69±0.47a**

a-Pattanakadu, b-Parayakadu, c-Edakochi, d-Aroormukkam. *5 % level significant ($p < 0.05$); **1 level significant ($p < 0.01$)

Table 3: Percentage composition of phytoplankton.

Class	S_1	S_2	S_3	S_4	S_5	Total	% composition
Bacillariophyceae	1374	1288	1089	1153	814	5718	62.57
Chlorophyceae	340	690	313	234	234	1811	19.82
Cyanophyceae	426	651	208	128	136	1549	16.95
Rhodophyceae	2	0	3	2	9	16	0.18
Chrysophyceae	0	0	11	4	0	15	0.16
Haptophyceae	1	2	2	1	0	6	0.07
Eustigmatophyceae	7	3	3	0	0	13	0.14
Cryptophyceae	4	0	4	2	0	10	0.11
Total	2154	2634	1633	1524	1193	9138	100.00

Table 4: Biodiversity indices.

	Pattanakadu (S_1)	Parayakadu (S_2)	Edakochi (S_3)	Aroormukkam (S_4)	Panavally (S_5)
Taxa	98	97	101	101	92
Individuals	2154	2634	1633	1524	1193
Palmer pollution index	30	25	26	27	24
Simpson dominance index (1-D)	0.95	0.96	0.95	0.95	0.97
Shannon Wiener diversity index (H')	3.58	3.66	3.67	3.73	3.87
Margalef Richness index (d)	12.64	12.19	13.52	13.64	12.85

of nitrate was recorded in S_5. According to Osibanjo et al. (2011) nitrate level rises with increased sources of industrial wastes and addition of domestic sewage. The high nitrate values were recorded in S_1-S_4 compared to the S_5. Present results indicated that S_1-S_4 had a higher value of phosphate content as compared to that of S_5 and showed a positive correlation with ammonia and silicate. Higher concentration of ammonia was observed in S_1-S_4 and lower value was found in reference site Panavally. The mean values of silicate content in study sites (S_1-S_4) were higher than that of reference site (S_5). The higher level of salinity, alkalinity, hardness, BOD, COD, nitrate, phosphate, ammonia, silicate and depleted level of dissolved oxygen indicates the pollution status of the study stations as compared to the reference site.

The analysis of phytoplankton communities was carried out in support of the interpretation of the results obtained from the physico-chemical analysis of the water. Although, Bacillariophyceae (diatoms) were the dominant group in all stations, their highest numbers of occurrence was reported in the study sites S_1-S_4. The reference site Panavally had only a limited number of individuals as compared to other sites. Bellinger & Siegee (2010) reported that abundance of Bacillariophyceae is a characteristic feature of a eutrophic environment. Nandan & Aher (2005) showed that the diatoms like *Nitzschia, Navicula,* etc. are the species found in organically polluted water. Our results enumerated a higher number of these genera from S_1-S_4, as compared to that of reference site, S_5. In this study, the epiphytic algae *Gomphonema* were present in S_1 and S_4 as an indication of water pollution (Round 1965, Shekar et al. 2008). The second dominant class of phytoplankton in the study was Chlorophyceae. The presence of genera *Ankistrodesmus* and *Scenedesmus* was considered as the eutrophicated environment (Jose & Kumar 2011). More number of these genera was reported from S_1 and S_2. The presence of Cyanophyceae indicated that the water is not potable. Cyanophyceae dominance and its blooms are the most visible symptom of accelerated eutrophication of lakes and reservoirs (Moss et al. 1995). According to Round (1965), epilithic algae such as *Oscillatoria* and *Phormidium* are excellent indicators of water pollution. They were reported in higher number in S_1, S_2 and S_3, which indicate the presence of pollutants of biological origin. In the study we recorded a positive correlation between Bacillariophyceae and Chlorophyceae with phosphate. Not only there was abundance of phytoplankton in the study sites, but also there was a greater diversity of taxa. High mean value of Shannon Wiener diversity index (H') was observed in Panavally (S_5), as compared to other sites. According to Dash (1996), higher the value of Shannon index, greater the planktonic diversity, hence a healthier ecosystem. Lower value of H' index is an indication of pollution load in environment. In the present study, the pollution tolerant genera showed dominance in S_1-S_4. Thus, we can substantiate that Panavally supported greater diversity and has lesser pollution with respect to other sites. The values of Simpson dominance index (1-D) were in the range of 0.95-0.97. Its minimum value (0.95) was observed in S_1, S_3 and S_4 whereas the maximum in S_5. Margalef richness index (d) ranged between 12.19-13.64. The lowest and highest values were noticed in S_2 and S_4 respectively.

The study on pollution using the physico-chemical parameters together with phytoplankton monitoring showed that the water quality of the four sites (Pattanakadu, Parayakadu, Edakochi, Aroormukkam) is deteriorating as compared to the reference site (Panavally). The waste discharge from the sea food processing industry is one of the factors contributing to the alarming rate of water pollution. Hence, appropriate measures should be taken by the legal bodies before the complete destruction and loss of this national treasure otherwise the Vembanad wetland becomes a wasteland for ever. The deteriorated water quality will negatively affect the sea food production, its export and our foreign exchange reserve. This baseline information on the water quality status of Vembanad Lake will be useful for future ecological assessment and monitoring to conserve this Ramsar site.

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