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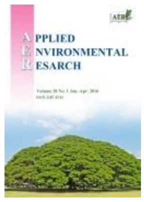

Phytoplankton-Water Quality Relationship in Water Bodies in the Mekong Delta, Vietnam

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Abstract

The study was conducted in March 2019 in three areas subject to impacts of agricultural production, residential areas and landfill in An Giang (Area 1), Kien Giang (Area 2) and Can Tho (Area 3), respectively, to assess relationship between water quality and diversity of phytoplankton. The results showed that water quality at 25 study sites is contaminated with organic matters, suspended solids and coliforms. The study found 422 species of phytoplankton belonging to five phyla of Bacillariophyta, Chlorophyta, Dinophyta, Cyanophyta and Euglenophyta. The density of phytoplankton in the three studied areas ranged from 13 to 77,328 individuals L^{-1}. Among the areas, Area 1 has the highest species composition and density, followed by Area 2 and then Area 3. Among the phytoplankton species occurrence, *Melosira granualata*, *Cyclotella meneghiniana*, *Cyclotella comta*, *Trachelomonas* sp., *Glenodinium beronense*, *Oscillatoria muticola* and *Skeletonema costatum* dominated and indicated the water environment with high organic matters, nutrient-rich and salty condition. Water quality index (WQI=57-88) indicated water quality ranged from good to medium whereas Shannon-Weiner diversity index (H'=0.71-3.89) showed water quality from medium to heavy pollution. Approximate 56% of the studied sites have similarities in water quality evaluated medium pollution using WQI and H' although the canonical correspondence analysis (CCA) results indicated that the distribution and abundance of phytoplankton was positively correlated with $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, BOD and TSS. It was suggested that H' is a good water quality indicator for uncontaminated freshwater, but not for saline water or highly complicated contaminating water. The findings revealed that H' only partially indicates water quality, thus examining physicochemical water quality variables for water quality monitoring is essential.

Keywords: Water quality; Shannon-Weiner diversity index; Phytoplankton; Pollution; Mekong Delta

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Introduction

The provinces of An Giang, Can Tho and Kien Giang are located in the upstream part of the Mekong Delta which is relatively flat, and inundated in flooding season. Agricultural, aquaculture, small manufacturing factories and service activities have a great influence on water quality in the water bodies of three provinces [1-2]. Any changes in water quality could lead to changes in the composition of aquatic organisms, especially phytoplankton, an important link in food chains or food webs of all water bodies in the Mekong Delta. Approximately 1,403 species were found in freshwater bodies in Vietnam including Chlorophyta with 530 species, Bacillariophyta 388, Cyanophyta 344, Euglenophyta 78, Pyrophyta 30, Chrysophyta 14, Xanthophyta 4 and Rhodophyta 4 [3]. In the Mekong Delta, five phyla of phytoplankton including Cyanophyta, Bacillariophyta, Chlorophyta, Dinophyta and Euglenophyta were detected on Hau River, Tien River and its tributaries [4]. Phytoplankton play a crucial role in water bodies since they could accumulate organic substances, generate biological productivity and clean up the water environment [4]. Thus, phytoplankton is considered as a good indicator for water quality environment. The distribution of phytoplankton species is closely related to the chemical characteristics of water quality [5], depth of water [6], and the interaction of aquatic organisms [7]. In recent years, the use of phytoplankton as an alternative indication for physical and chemical characteristics of water quality has been increasingly concerned in Vietnam. However, available publication on the relationship between physicochemical water quality and phytoplankton composition is limited. This study was carried out to examine the relationships between diversity index of phytoplankton and physicochemical water parameters in water bodies in the Mekong Delta, Vietnam. The findings from this study can be used as fundamental information for making decision on whether phytoplankton should be used to replace for physicochemical parameters in water monitoring.

Materials and methods

1) Description of sampling sites

The study was conducted in An Giang, Can Tho and Kien Giang Provinces in the Mekong Delta of Vietnam. The samples of phytoplankton and water quality were collected at 25 locations and divided into three areas, namely Area 1, Area 2, Area 3 as shown in Figure 1.

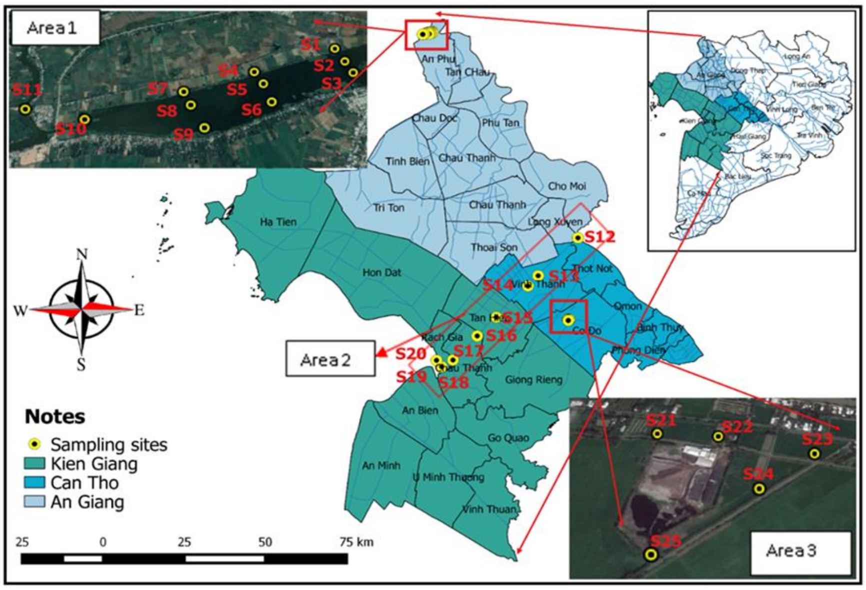

Figure 1 Sampling locations in the water bodies in the three provinces.

Area 1 (Bung Binh Thien, An Giang) is a wetland area where is regularly affected by domestic activities. Area 2 is along Cai San River, which flows through all three provinces of An Giang, Can Tho and Kien Giang, plays an important role in waterway transport and affected by the transport, agriculture and daily life activites. In addition, the end of Cai San River in Kien Giang Province is salty and influenced by fishing activities. Meanwhile, Area 3 is located far in the paddy field, mainly affected by agricultural production and operation of the open landfill in Co Do District, Can Tho City.

2) Sample collection and analysis

Water samples were collected in March 2019. In Area 1, 11 water samples and 11 phytoplankton samples were collected and symbolized from S1 to S11. In Area 2, 9 samples of phytoplankton (denoted from S12 to S20) were collected along the Cai San River. In Can San River, five water samples were simultaneously collected with the samples of phytoplankton at the sites S12, S15, S17, S19 and S20. In Area 3, five samples of phytoplankton were collected and labeled from S21 to S25. Four samples of water were simultaneously collected at the same locations with phytoplankton samples at S21, S22, S23 and S25 in canals around the landfill. The water quality parameters including pH, turbidity (NTU), dissolved oxygen (DO, mg L^{-1}), total suspended solids (TSS, mg L^{-1}), biochemical oxygen demand (BOD, mg L^{-1}), chemical oxygen demand (COD, mg L^{-1}), coliforms (MPN 100 mL^{-1}) and nutrients ($N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$, mg L^{-1}) were analyzed at the Environmental Analysis Lab, College of Environment and Natural Resources, Can Tho University following Standard Methods for Examination of Water and Wastewater [8].

The samples of phytoplankton were collected by filtering 200 L of water through 25 µm mesh size net. The samples were placed in a 110 mL vials and fixed with formaldehyde 2-4%. Qualitative analysis was performed using a microscope at the magnitude of 10X-40X to identify the species of phytoplankton using the handbooks which describes the species of phytoplankton in details to the species level [3-4, 9-11]. The frequency of phytoplankton species occurrence was also recorded in the qualitative analysis. Quantitative analysis of the recognized phytoplankton was performed using Sedgewick Rafter counting chamber under microscope following the methods of Fernando [10]. The density of phytoplankton was calculated by Eq. 1.

$$Y = \frac{X * V_c * 1000}{N * A * V_t} \quad \text{(Eq. 1)}$$

where Y is phytoplankton density (individuals L^{-1}); X is the number of individual phytoplankton in the counted cells; V_c is the concentrated sample volume (mL); N is the number of counted cells; A is area of counted cells (1 mm^2) and V_t is water volume collected (mL).

3) Data analysis

Water quality was evaluated using a set of water quality paremeters as water quality index (WQI). WQI is calculated following Eq. 2 [12]:

$$WQI = \frac{WQI_{pH}}{100}\left[\frac{1}{5}\sum_{a=1}^{5} WQI_a . \frac{1}{2}\sum_{b=1}^{2} WQI_b . WQI_C\right]^{1/3} \quad \text{(Eq. 2)}$$

where WQI_a is the WQI value of five parameters (DO, BOD_5, COD, $N\text{-}NH_4^+$, and $P\text{-}PO_4^{3-}$); WQI_b is the WQI value of TSS; WQI_c is the WQI value of coliforms; WQI_{pH} is the WQI value of pH parameters (ranging from 6 to 8.5).

The WQI ranges from 0 to 100 dividing water quality into five levels. Level 1 (100> WQI>91) is good water quality that could be used for purposes of water supply. Level 2 (90>WQI>76) is also used for water supply for domestic uses but suitable treatment measures are required. Level 3 is for irrigation and other similar purposes (75>WQI>51). Level 4 (50> WQI>26) is the water suitable for transport and equivalent purposes while Level 5 (25>WQI>0) is considered to be heavily polluted water that proper treatment measures are urgently needed.

The diversity of phytoplankton was examined using Shannon-Wiener diversity index (H') following Eq. 3 [13]:

$$H' = -\sum p_i \,.\, ln(p_i) \qquad \text{(Eq. 3)}$$

where $p_i=n_i/N$; n_i is the numbers of it individual; N is total amount of individuals in the samples. Water quality is divided at three levels of pollution based on H' values. H' is greater than 3 indicates good water quality or water is not polluted. H' ranges from 1 to 3 showed moderate water pollution. Finally, H'<1 revealed that water is highly polluted [13].

Cluster analysis (CA) was used to determine spatial distribution of phytoplankton and SIMPER (Similarity Percentages) was used to examine dominant species in each study area. CA and SIMPER were performed using PRIMER software V5.2.9 [14].

Canonical Correspondence Analysis (CCA) was used to find the main water quality parameters affecting phytoplankton species. The direction of the arrows indicated positive and negative correlation and their length corresponds to the importance of the explanatory variable in the graph [15-16]. For statistical analysis of data, the composition of phyto-plankton is the dominant species with a contribution level of over 5% through the SIMPER analysis [17]. The relationship between water quality variables and the abundance of phytoplankton (CCA) in this study was determined by the PAST (Paleontological Statistics) version 3.06.

Results and discussion

1) Water quality assessment using individual water quality parameters

Table 1 presents a summary of surface water quality indicators at 25 study sites. Temperature ranged from 28 to 30^{o}C, suitable for living of aquatic life [18]. pH in the range of 7.27-7.92, was within the allowable limits for surface water quality [19]. Turbidity was relatively low ranging from 3.37 to 11.43 NTU at S1-S11 but it was high at S12, S15, S17, S19 and S20 (21.77-59.17 NTU). The DO value varied from 1.20 to 9.17 mg L^{-1}; DO in the Area 1 was higher than that of the other areas due to low presence of organic matters and abundant presence of aquatic plants as oxygen supplier [20]. The lowest DO value was found in Area 2 (Cai San River) where being influenced by diversity of anthropogenic polluting sources, for example domestic wastes, water transportation and small-scale production villages (S12-S20). BOD in the three study areas ranged from 2.44-11.67 mg L^{-1}, higher than the permissible level regulating in QCVN 08-MT: 2015/BTNMT (except the site S20), indicating that surface water in the Mekong Delta was organically polluted. COD highly fluctuated from 7.95 to 37.97 mg L^{-1}, indicating 60% of the sampling sites were contaminated by organic matters. The concentrations of TSS were relatively high, ranging from 15 to 78.5 mg L^{-1}, higher than the permitted level of QCVN 08-MT: 2015/BTNMT. Concentrations of $N\text{-}NH_4^+$ were low ranging from 0 to 0.94 mg L^{-1}. As could be seen that $N\text{-}NH_4^+$ at the sites of S17, S19, S20, S21, S22 and S25 were relatively high, exceeding QCVN 08-MT: 2015/BTNMT which could result in affecting aquatic life. The concentrations of $P\text{-}PO_4^{3-}$ were 0-0.09 mg L^{-1} which was in the appropriate range for growth of phytoplankton

(0.018-0.098 mg L^{-1}) [21]. Coliforms density ranged from 1,900 to 9,300 MPN 100 mL^{-1}. In all surveyed locations, coliforms at S10 and S11 exceeded the permitted level of QCVN 08-MT: 2015/BTNMT; The high coliform at these sites could be because the improper release of fecal materials from human activities and animals. The current study showed that surface water in all study sites was organic pollution (high BOD, COD and TSS) and this finding was in line with the previous reports [1-2, 22]. Area 1 suffered additional microbial contamination (high coliforms) while Areas 2 and Area 3 were additionally affected by high levels of nutrients (N-NH_4^+ and P-PO_4^{3-}), and seriously low DO. Previous study showed that the Area 3 is also contaminated by heavy metals from landfill leachate [23].

2) Phytoplankton composition

In the study area, 422 species of algae belonged to five phyla were identified, including 56 species of Cyanophyta, 94 species of Euglenophyta, 38 species of Dinophyta, 116 species of Chlorophyta and 118 species of Bacillariophyta. The phytoplankton density of each phylum was between 13-77,328 individuals L^{-1} (Figure 2). High density of phytoplankton was found in the Area 1, Bung Binh Thien in An Giang Province. This finding was consistent with the results of the measurements of physicochemical water quality parameters such as low N-NO_3^- and P-PO_4^{3-} due to algal uptake, and high DO because of algal photosynthesis. In this area, Chlorophyta, Cyanophyta, and Bacilariophyta were more dominant than Dinophyta and Euglenophyta. For the Area 2, Cai San River, density of algae was lower than those in the Area 1. This could be because the water environment is more polluted with organic matters, nutrients and deficiency of DO. In the Area 2, Cyanobacteria and Chlorophyta were less abundant than Euglenophyta (Figure 2).

Table 1 Summary of water quality at the study sites

Site	Temp	pH	DO	Turb.	BOD	COD	TSS	N-NH_4^+	P-PO_4^{3-}	Coliforms
S1	29.20	7.64	8.83	4.67	11.33(+)	17.33(+)	46.33(+)	0.00	0.00	1,900
S2	29.00	7.79	8.93	3.53	11.67(+)	17.67(+)	46.67(+)	0.20	0.00	2,400
S3	30.30	7.85	7.73	3.28	11.00(+)	17.00(+)	44.00(+)	0.00	0.00	2,200
S4	29.50	7.81	9.03	4.33	11.67(+)	17.67(+)	50.33(+)	0.00	0.00	4,300
S5	29.23	7.56	8.10	6.25	10.00(+)	15.33(+)	48.00(+)	0.00	0.00	2,300
S6	30.10	7.55	9.17	3.27	10.00(+)	15.00	47.67(+)	0.04	0.00	2,300
S7	29.37	7.71	8.00	5.33	10.00(+)	16.00(+)	47.33(+)	0.00	0.00	2,200
S8	30.33	7.74	7.57	6.00	9.33(+)	14.33	48.33(+)	0.00	0.00	4,600
S9	29.60	7.56	8.03	4.90	10.00(+)	15.33(+)	49.67(+)	0.00	0.00	2,300
S10	29.27	7.70	6.10	11.43	11.33(+)	17.33(+)	53.00(+)	0.10	0.00	9,300(+)
S11	28.07	7.75	5.33(+)	9.03	10.00(+)	15.33(+)	53.33(+)	0.22	0.05	9,300(+)
S12	29.10	7.35	3.00(+)	33.10	6.73(+)	13.01	29.20	0.29(+)	0.07	1,900
S15	30.00	7.27	1.40(+)	59.17	10.43(+)	12.48	45.25(+)	0.76(+)	0.07	2,400
S17	29.20	7.27	1.20(+)	46.07	10.71(+)	37.97(+)	42.00(+)	0.82(+)	0.04	2,200
S19	28.80	7.30	2.95(+)	21.77	9.93(+)	28.48(+)	15.00	0.90(+)	0.07	4,300
S20	28.90	7.92	4.30(+)	26.50	2.44	7.95	33.75(+)	0.38(+)	0.05	2,300
S21	-	-	-	-	9.00(+)	16.00(+)	47.00(+)	0.87(+)	0.02	-
S22	-	-	-	-	9.00(+)	15.00	53.50(+)	0.94(+)	0.02	-
S23	-	-	-	-	10.00(+)	15.00	78.50(+)	0.19	0.09	-
S25	-	-	-	-	8.00(+)	12.00	43.00(+)	0.69(+)	0.00	-
QCVN*	-	6-8.5	≥6	-	6	15	30	0.3	0.2	5,000

Note: Sign (+) denoted the water parameters over National technical regulation on surface water quality (* denotes QCVN 08-MT:2015/BTNMT)

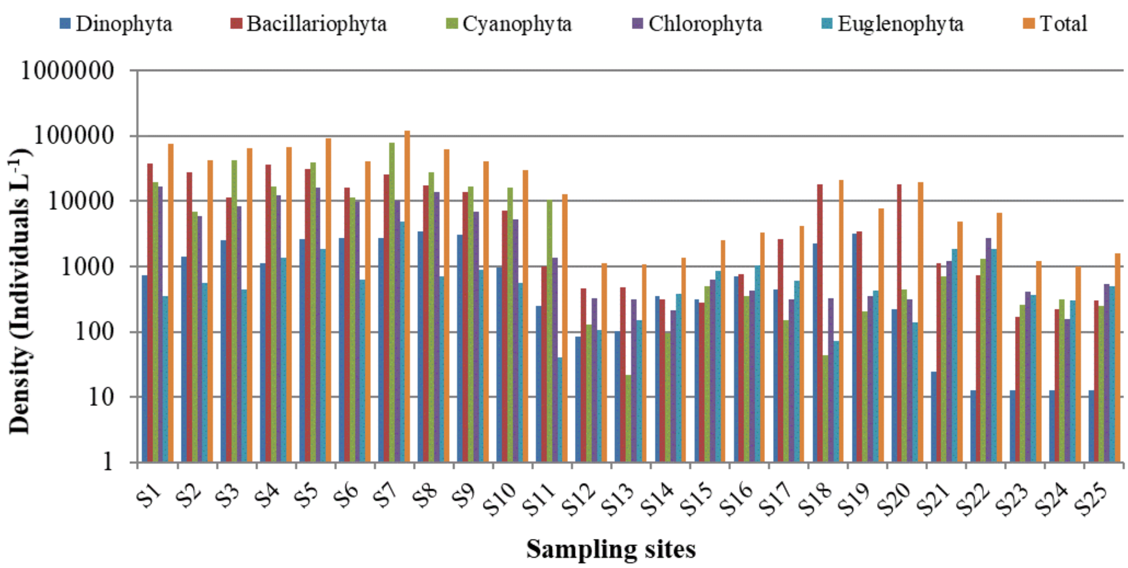

Figure 2 Density of phytoplankton at sampling sites.

The results indicated Euglenophyta tended to occur in more polluted water environment. Toward to the seaside, where salinity was high, Dinophyta and Bacillariophyta become dominant while Cyanobacteria and Chlorophyta significantly decreased. It could be observed that the salinity caused shift of phytoplankton structure. In the Area 3, which was affected by agricultural activities and operation of landfill, the density of algae was lower than that of the Area 1 and Area 2. Here, Euglenophyta and Chlorophyta were dominating species contrasting phytoplankton composition found in the Area 1. The predominance of Euglenophyta and Chlorophyta in the area affected by landfill was also found in the previous study [24]. Dinophyta was the lowest in density in the Area 3 compared to those at the other areas. All in all, composition of phytoplankton was greatly influenced by water quality.

SIMPER analysis indicated that the variation of algae species in the study areas was mainly due to change in density of *Oscillatoria muticola* (Area 1 and Area 3). *Trachelomonas sp.*, and *Cyclotella comta* also contributed to the change density of phytoplankton in the Area 1. Area 3, the change also contributed by *Melosira granulata*, *Nitzschia longissima* and *Chodatella chodatii*. For the Area 2, the denisity changed mainly by the presence of *Skeletonema costatum* and *Glenodinium berolinense*. Frequent occurrence of *Oscillatoria muticola* (Cyanophyta) at all study sites indicated that surface is facing with organic pollution [25-26] characterized by high BOD and COD as discussed in the previous section. In addition, toxin-producing algae and highly polluted water tolerant species in water bodies such as *Anabaena circinalis*, *Microcystis aeruginosa*, and *Ocillatoria limosa* in the Area 1; *Scenedesmus obliquus*; *Cyclotella meneghiniana*, and *Skeletonema costatum* in the Area 2; *Euglena acus*, *Trachelomonas sp.*, *Trachelomonas subverrucosa*, *Scenedesmus quadricauda* in the Area 3 were also detected in the current study. These species could be highly bloomed when the water environment become highly polluted with organic matters and nutrients [27-30].

3) Water quality assessment using WQI and H'

The average WQI values in the survey areas ranged from 57 to 88 (Figure 3). In the Area 1, WQI ranged from 80 to 88, classified as good water quality (S1-S9, inside Bung Binh Thien Lake, An Giang). For S10 and S11, WQI was from 67 to 58, categorized as medium water quality (used for irrigation). WQI on the Cai San River in the Area 2 (S12-S20) was highly varied (62-82) that could be due to the impact of various sources of pollution along the river. The water quality in the Area 2 was classified from good to medium quality. However, WQI in the Area 3 ranged from 62 to 70 classified as medium water quality. The WQI clearly showed that water quality in the studied areas was polluted.

Shannon-Wiener diversity index (H’) at survey sites ranged from 0.71 to 3.89 (Figure 3). According to the evaluation scale [13] of water quality at study sites ranged from clean to heavy pollution. In the Area 1, WQI and H’ showed the similar results in the quality of water evaluation which was moderate pollution. Irregular fluctuations of H’ relatively compared to WQI from the site S19 to S20 (at the end sites toward the sea of the Area 2, salinity from 1‰ to 15‰) and from S21 to S25 (the Area 3 impacted by landfill and agriculture) was due to salinity and various compositions of pollutants, respectively. The water quality in the Area 3 was seriously polluted by organic matters, nutrients and heavy metal, however, H’ showed high values of 3.0-4.0 indicating the water environment was not yet polluted. This revealed the weakness of using H’ as indication for water quality status. The contrasting results of water quality assessment were found because the value of H’ was calculated mainly based on the diversity of species, but not species abundance. In the canals around the landfill, the numbers of individual species (abundance) were low whereas the number of species (diversity) were high leading to high H’ and this could result in misinterpretation of actual water quality. For example, the values of H’ at site S21 and S25 were estimated to be high at 3.87 and 3.88, respectively because these sites found 94 species with 4,914 individuals L^{-1} (S21) and 89 species with 1,588 individuals L^{-1} (S25). In contrast, the values of H’ at the site S11 and S20 were calculated low at 1.12 and 0.71, respectively since the site S11 found 36 species with 13,082 individuals L^{-1} and the site S20 found 59 species with 19,375 individuals L^{-1}. Previous study also found that values of H’ were high (2.52-3.52) at the water environment sourrounding landfill [24]. The more diversity of phytoplankton at the landfill due to the occurrence of more species of Euglena, Phacus and Trachelomonous belonging to Euglenophyta. The findings of the current study revealed that H’ only partially reflects water quality status, especially in the heavy contaminated areas. In that case, H’ should be used in combining with examination of physical and chemical characteristics of water environment.

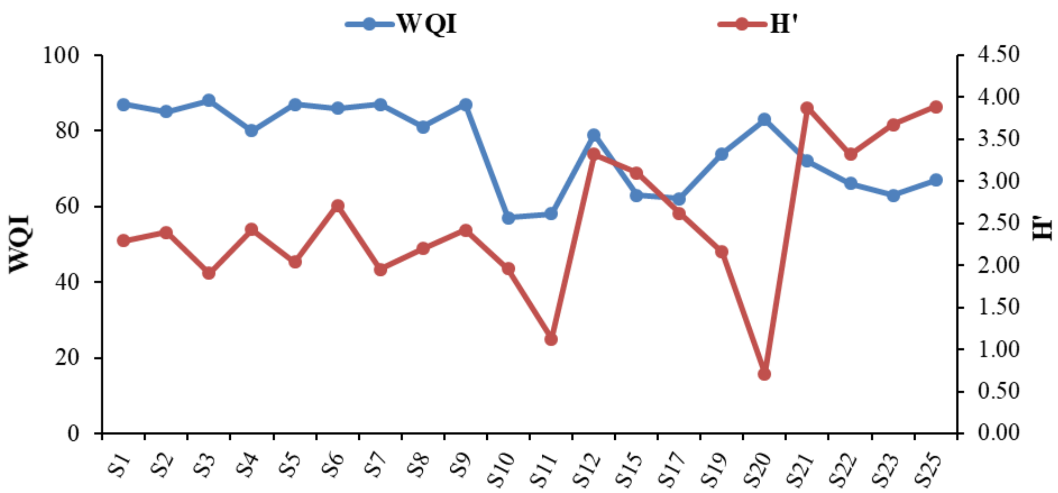

Figure 3 Variation of WQI and H’ at sampling sites.

4) Spatial distribution of phytoplankton

Cluster analysis revealed that phytoplankton at 25 sampling locations were divided into four clusters at 30% similarity (Figure 4). Sites on Can San River were divided into two cluster namely Cluster 1 (S12-S17 and S19) and Cluster 4 (S18 and S20). Cluster 1 was located on the first segment of Cai San River (in the Area 2) where was the freshwater. The water environment in first segment of the Cai San River was polluted with organic matters, nutrients and DO deficiency. The results of SIMPER analysis in Cluster 1 showed that the average similarity was 43.73%, in which 9.38% contributed by *Cyclotella meneghiniana* and *Melosira granualata*. *Cyclotella meneghiniana* and *Melosira granulata* are typical for organically polluted areas and nutrient-enriched water bodies [31]. Cluster 4 consists of S18 and S20 sites located at the second segment of the Cai San River (in the Area 2) where the water was brackish (salinity at 1‰) and saline water (salinity at 15‰). Cluster 4 including S18 and S20 was dominated by Bacillariophyta and Dinophyta. The results of this study was in line with prior study that Bacillariophyta and Dinophyta always dominate in saltwater areas [21, 32]. *Skeletonema costatum* (Bacillariophyta) is a species typical for saltwater bodies [33] and *Glenodinium beronense* (Dinophyta) contributed to the average similarity level of 31.67%. The significance of this finding was to predict the shift in composition of phytoplankton in water bodies in the Mekong Delta, Vietnam. It is proposed that the phytoplankton in the water bodies in the delta would be dominated by Bacillariophyta and Dinophyta and this predominance could lead to change of aquatic food webs, then aquatic resources. The driver for the change is that Mekong Delta of Vietnam is believed to suffer saline water intrusion due to sea level rise as a consequent of global climate change. Cluster 2 includes the sites from S21 to S25 in the Area 3 where the water was being affected by agricultural activities and landfilling. Phytoplankton in Cluster 2 was less in abundance but high in species composition. The cluster's average similarity was 54.12% contributing by the organic polluted tolerant species *Cyclotella comta* (Bacillariophyta) and *Trachelomonas sp.*, (Euglennophyta). Cluster 3 included all sites from S1 to S11 in the Area 1 where both species composition and density were high. *Oscillatoria muticola* (Cyanophyta) and *Melosira granulata* (Bacillariophyta) resulted in average similarity of the cluster of 50.07%.

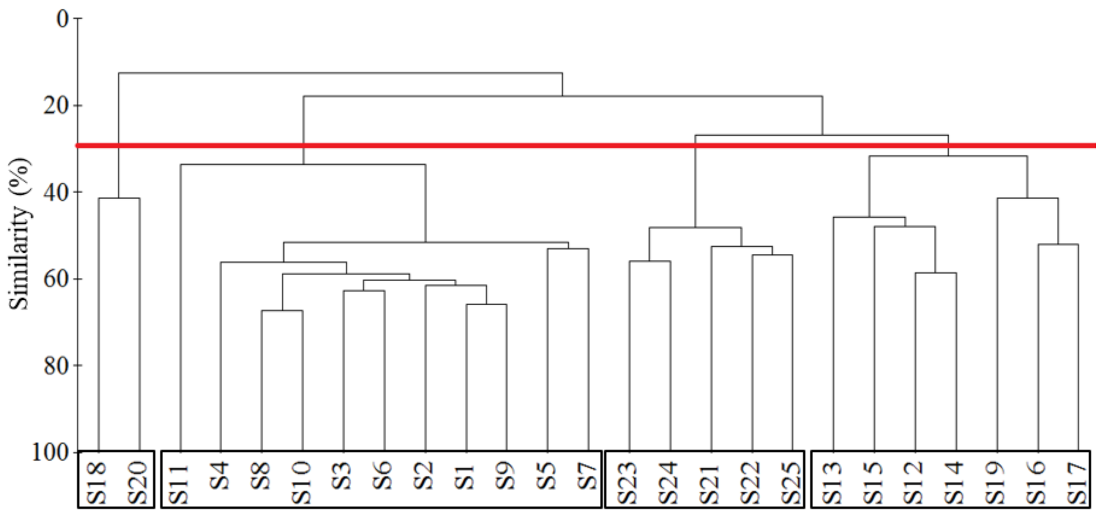

Figure 4 Spatial distribution of phytoplankton.

Cluster analysis clearly pointed out that water environment status including organic matters, nutrients, dissolved oxygen and salinity have a significant influence abundance and composition of phytoplankton making phytoplankton as an indication for water environment. SIMPER results revealed that *Cyclotella meneghiniana*, *Cyclotella comta*, *Melosira granulata*, *Glenodinium beronense* and *Skeletonema costatum* are good indicators for water environment contaminated by organic matters, nutrient-rich, and salinity.

5) Relationship of phytoplankton species and water quality parameters

SIMPER analysis results indicated that only 19 phytoplankton species appeared regularly and dominated in the study area out of 422 species. The CCA was used to show the relationship between water quality parameters and 19 phytoplankton species in the study area. The results showed that axis 1 and axis 2 accounted for 74.5% and 16.42% of the total variance in the data set, respectively. $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ were the two most pivotal factors affecting species composition in the study area; followed by BOD, TSS and COD. *Skeletonema costatum*, *Nitzschia vermicularis*, *Coscinodiscus excentricus*, *Bidduphia regia*, *Ulothrix variabilis* were highly correlated with axis 1 and positively correlated with $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$. The species such as *Cyclotella comta*, *Navicula gracilis*, *Strombomonas* sp., were also found to be positively correlated with $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$. *Oscillatoria muticola*, *Melosira granulata*, *Nitzschia longissima*, *Chodatella chodatii*, *Cyclotella meneghiniana*, *Cyclotella comta*, *Cyclotella comta*, *Glenodinium berolinense*, *Staurastrum sp.*, *Navicula gracilis*, *Asterococcus sp.*, *Glenodinium quadridens*, *Strombomonas sp.*, *Aphanocapsa pulchra* were correlated with BOD and TSS. The study of Luu et al. [34] and Ian & David [35] indicated that nutrients play an important role in forming the species composition of an area which was in accordance with the findings in the current study.

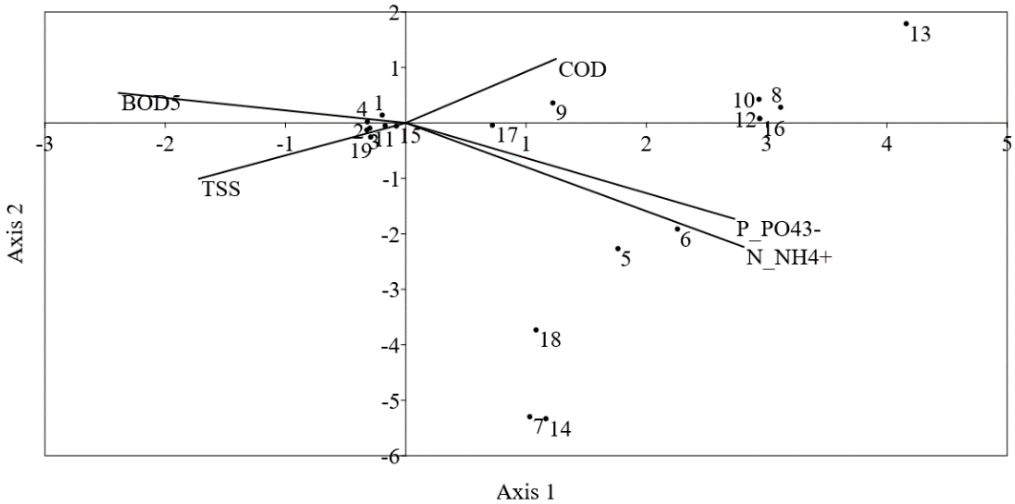

Figure 5 Relationship of phytoplankton species and water quality parameters.
Notes: 1- *Oscillatoria muticola*, 2- *Melosira granulata*, 3- *Nitzschia longissima*, 4- *Chodatella chodatii*, 5- *Cyclotella Meneghiniana*, 6- *Cyclotella comta*, 7- *Cyclotella comta*, 8- *Skeletonema costatum*, 9- *Glenodinium berolinense*, 10- *Nitzschia vermicularis*, 11- *Staurastrum sp.*, 12- *Coscinodiscus Excentricus*, 13- *Bidduphia regia*, 14- *Navicula gracilis*, 15- *Asterococcus sp.*, 16-*Ulothrix variabilis*, 17- *Glenodinium quadridens*, 18- *Strombomonas sp.*, 19- *Aphanocapsa pulchra*.

Conclusion

Surface water in the studied areas was organically polluted. Area 1 was additionally contaminated by coliforms while water quality in the Area 2 and Area 3 was further degraded by high nutrients ($N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$) and low DO. Five phyla of phytoplankton including Bacillariophyta, Cyanophyta, Chlorophyta, Dinophyta and Euglenophyta, with total 422 species were found at all study sites. Phytoplankton density highly varied from 13 to 77,328 individuals L^{-1}. Chlorophyta, Cyanophyta and Bacillariophyta were high in species composition and abundance. In the Area 2, Euglenophyta was the highest density in the freshwater segment, however, Dinophyta and Bacillariophyta were more dominant in brackish and saline water segment. In the Area 3, Euglenophyta and Chlorophyta were highly abundant compared to the other areas. *Cyclotella meneghiniana*, *Cyclotella comta*, *Melosira granulata*, *Glenodinium beronense* and *Skeletonema costatum* were good indicators for water environment with high organic matters, nutrient-rich, and salinity. WQI ranged from 57 to 88 indicated water quality in the study areas classified as medium to good water quality. H' ranged from 0.71 to 3.89 indicated water quality at study sites ranged from no pollution to heavy pollution. Based on the CCA, phytoplankton was positively correlated with $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, BOD and TSS. In clean freshwater environment, H' could be a good water quality indicator, however, in saline water or water with various pollutants, H' could not be used as a good water quality indication. The findings of this current study revealed that H' could partially reflect water quality, therefore, physicochemical characteristics of water should also be examined for water monitoring.

Conflict of interest:

There is no conflict of interest.

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