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Correlation Between Surface Water Quality and Plankton Composition in Water Bodies in Hau Giang Province, Vietnam

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ABSTRACT

The study was carried out to assess surface water quality in water bodies in Hau Giang province, Vietnam using individual surface water quality parameters and water quality index. In addition, the correlation of phytoplankton and zooplankton composition with surface water quality was also examined. The results showed that surface water quality in Hau Giang province was contaminated with organic matters, nutrients, iron and microorganisms. The water quality index (WQI= 37-84) showed that surface water ranged from moderate to good. A total of 164 species belonging to five phyla of phytoplankton were recorded with the density from 370–2260 individuals/L and 91 species belonging to five phyla of zooplankton with a density of 11,332–121,600 individuals/L. The predominance of the phytoplankton species Oscillaroria, Euglena, Phacus and the predominance of zooplankton species of the Nauplius, Rotifera and Protozoa signalize an aquatic environment rich in organic matters and nutrients. The correlation results showed that BOD, COD, NH_4^+-N, NO_3^--N and PO_4^{3-}-P were closely related to the density of phytoplankton while pH, DO, BOD, NH_4^+-N and coliform play an important role in determining the density of zooplankton species.

Keywords: surface water quality, pollution, organic matters, nutrients, phytoplankton, zooplankton.

INTRODUCTION

Hau Giang is a province in the inland area of the Mekong Delta with a natural area of 1,621.7 km^2, a population of 729,888 people, a province in the process of industrial development. Currently, in the province, there are a number of industrial parks and large industrial clusters such as Song Hau industrial park, Tan Phu Thanh industrial park, Phu Huu A concentrated industrial cluster, Dong Phu industrial cluster and Nhon Nghia A concentrated industrial clusters. The agricultural sector, with the main crop being rice, still makes a great contribution to the region's economic growth. In 2021, the economic growth rate reached 3.08%, of which the agriculture – forestry – forestry sector accounted for 4.04%, industry – construction accounted for 5.32% and trade – services accounted for 0.89% (Department of Natural Resources and Environment of Hau Giang province, 2021). Notably, by the end of 2022, the province's economic growth reached 14.03%, ranking first in the Mekong River Delta and fourth in the whole country (Economic and Budgetary Department of Hau Giang province, 2022). Faced with the current situation of socio-economic development, the pressure on the environment, especially the pressure on the surface water environment, is very great. With a system of interlaced rivers and canals such as Xang Xa No canal, Cai Con canal, Bung Tau canal, Cai Lon river, Ba Voi river, etc. important traffic to go everywhere in the province and other provinces in the region. With the main task of providing water for daily life, however, surface water in Hau Giang province has shown signs of pollution. According to statistics, surface water pollution in the main canals in the province tends to increase in recent years. Therefore, the monitoring and evaluation of surface water quality in Hau Giang province is urgently needed.

Assessment of surface water quality based on the water quality index (WQI) is widely used in Vietnam. With the nature based on the concentration of water quality indicators, the WQI index reflects the overall status of water quality quality for different uses (Vietnam Environment Administration, 2019). Evaluation of surface water quality at Cau Bay and Thien Duc rivers in Gia Lam district, the average WQI index is 24.77 and 16.06, respectively, both showing the heavily tarnished water quality requiring the immediate handling measures (Son et al., 2019). According to research by Hop et al. (2022), the WQI has comprehensively reflected the water quality of the Perfume River with 97.8% of monitoring locations having WQI values of very good and good, and 2.2% of medium. Similarly, for surface water in the Saigon River, the water quality was assessed as average through the results of the calculation of the WQI index (Luu et al., 2020). In recent years, phytoplankton and zooplankton species have been used as indicator organisms in water quality assessment (Parmar et al., 2016; Dan et al., 2017; Lien et al., 2016; Dan et al., 2017; Lien et al., 2020). The abundance of phytoplankton and zooplankton species correlated well with abiotic factors such as temperature, oxygen concentration, organic matter and nutrient levels in the water (Jakhar, 2013). Typically, algae species of Chlorophyta are observed in water with high BOD concentration, which is an indicator of organic rich environment (Jakhar, 2013). The vigorous growth of Cyanophyta is mainly in nutrient-rich media (Senapati et al., 2011). Similarly, Rotifera predominance often indicates eutrophication (Pandit et al., 2020). In this study, individual surface water quality parameters, water quality index, phytoplankton and zooplankton were used to assess surface water quality in Hau Giang province to provide scientific information for potential use of plankton for monitoring and assessing surface water quality.

MATERIALS AND METHODS

Description of the study area

The study was carried out at eight locations (S1-S8) of the main rivers and canals in Hau Giang province. These are areas that are mainly affected by residential, industrial and traffic activities in the province. Location S1 – Xang Xa No canal, near Vi Thanh water plant, the location is affected by the discharge of residential areas living along the canal and urban development activities in Vi Thanh city. Location S2 – Cai Lon River, near the People's Committee of Hoa Tien Commune, this is the main river branch, where the surface water is transferred to – between the two provinces of Kien Giang – Hau Giang. Location S3 – Ba Lang tributary, Rach Goi market, the location is affected by seafood processing companies, market activities and riverside residential activities. Location S4 – Mang Ca Canal – Phung Hiep, is the confluence point, trade gateway between Nga Bay city and Soc Trang province. Location S5 – Hau Giang Canal 3 in Lung Ngoc Hoang Nature Reserve, the assessment of water is of great significance in monitoring environmental changes in the area with diverse biological resources of Vietnam. Conscious. Location S6 – Hau River, the middle section between Cai Dau and Mai Dam, the area affected by waste sources in Song Hau industrial park (Phase 1). Location S7 – Ba Lang River – Port of Tan Phu Thanh Industrial Park, this is the port area of Tan Phu Thanh Industrial Park, in addition to the influence of waste discharge activities of facilities and enterprises in the industrial park. This location is also influenced by the mooring of large ships and daily activities in the port area. Location S8 – Cai Ngang Dua River – near Luong Nghia market, is a large river tributary, adjacent to Bac Lieu province, also the place where water sources intersect with three provinces of Kien Giang – Bac Lieu – Hau Giang. Locations of surface water and plankton monitoring stations are shown in detail in Figure 1.

Sampling and analysis

Surface water sampling and analysis

Samples of surface water were collected at eight monitoring locations on main rivers and canals in Hau Giang province, including Xang Xa No Canal, Cai Lon River, and Ba Lang River, Mang Ca canal, Hau Giang 3 canal, Hau river and Cai Ngang Dua river (Fig. 1). Surface water samples were sampled according to TCVN 6663-1:2011 (ISO 5667-2:2006) regulations on Water quality – Sampling – Part 1: Technical guidance on sampling and TCVN 6663-3:2003

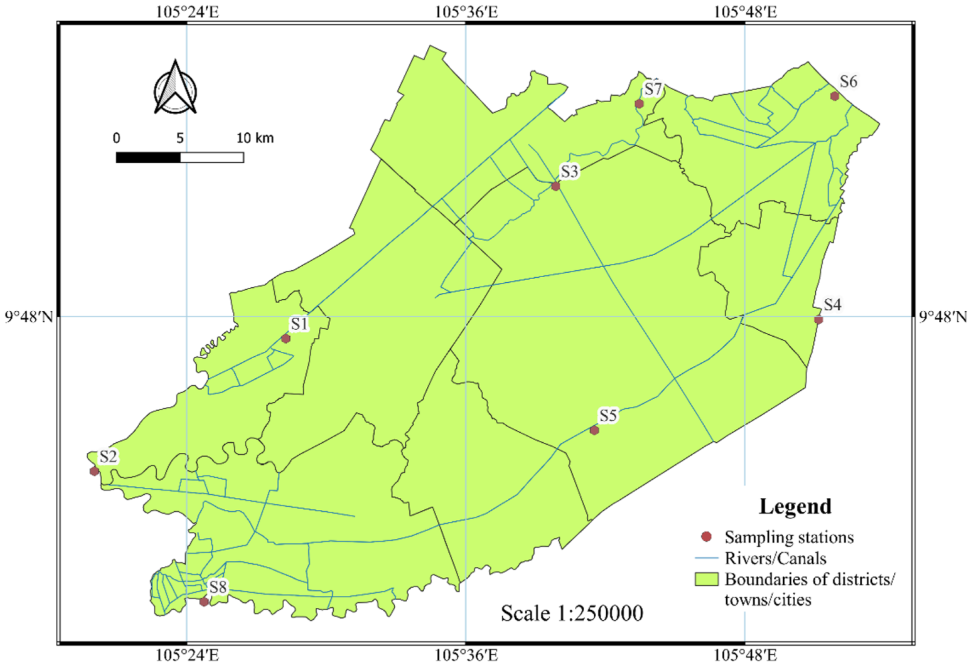

Figure 1. Map of sampling locations for surface water and plankton

(ISO 5667) -3:1985) Regulation on Water Quality – Sampling – Part 3: Guidelines for storage and handling of samples. The collected water samples were analyzed for 11 physicochemical parameters including pH, temperature, total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4^+-N), nitrate (NO_3^--N), orthophosphate (PO_4^{3-}-P), iron (Fe) and coliform. Three indicators including pH, temperature and DO were measured directly in the field, according to TCVN 6492:2011, SMEWW 2550B:2017 and TCVN 7325:2016, respectively. While the remaining parameters are analyzed in the laboratory according to standard methods. Specifically, TSS, BOD, COD were analyzed according to TCVN 6625:2000, TCVN 6001-1:2008 and SMEWW 5220C:2012, respectively. The indicators of nutrient contamination NH_4^+-N, NO_3^--N and PO_4^{3-}-P were analyzed according to TCVN 6179-1:1996, TCVN 6180:1996 and TCVN 6202:2008, respectively. Fe and coliform were analyzed according to TCVN 6177:1996 and TCVN 6187-2:1996, respectively. Physical and chemical parameters of surface water treated and compared with QCVN 08-MT:2015/BTNMT, column A1. Surface water quality index (WQI) is calculated based on eight parametersaccording to regulations of the Vietnam Environment Administration (2019). Water quality index ranges from 0–100, in which 91–100 indicates very good water quality; 76–90 indicates good water quality; 51 – 75 indicates average water quality; 26–50 indicates bad water quality; 10–25 indicates poor water quality and < 10 indicates water quality is very polluted.

Phytoplankton samples

Phytoplankton samples were collected (at the sample places with surface water quality) according to SMEWW 10200.B:2017 method. For qualitative samples (determining species composition), at each monitoring station, use a net to catch phytoplankton with a mesh size of 20–25 m, place the mouth of the net 15–20 cm from the water surface, and then drag the net with zigzag pattern so that the amount of water passing through the grid is as much as possible. For quantitative samples (determining cell density), use a bucket or basin to collect 10L of water at the monitoring point, pour it through a plankton net to filter the sample, then transfer the sample (in the bottom tube) into the container. Quantitative and qualitative samples were fixed with 4% formol, shaken and labeled. Analysis of phytoplankton samples was performed according to SMEWW 10500:2017 method. Phytoplankton species were identified by morphological comparison method, species composition was determined using optical microscope at E10, E40, E100 objective and identified based on documents of Shirota (1966), An (1993), Tien & Hanh (1997), Tuyen (2003) and Bellinger & Sigee (2015). Cell density was determined according to the method of Boyd & Tucker (1992), using a Sedgewick Rafter counting chamber. Collected samples were allowed to settle for 48 h, remove the clear water and transfer to a cylinder for volume determination. Prior to analysis, the sample in the cylinder was thoroughly mixed, aspirated and placed in the Sedgewick Rafter counting chamber. The formula for determining phytoplankton density is as follows:

$$X\,(\text{individual}/L) = (T \times 100 \times V_{conc.} \times 1000) / (A \times N \times V) \quad (1)$$

where: T – the number of algae individuals counted, $V_{conc.}$ – represents the concentrated sample volume (mL), A – the area of 1 counting cell, N – the number of counter cells, V – the sample volume collected (mL).

Zooplankton samples

Zooplankton samples were collected (at the sample places with surface water quality) according to SMEWW 10200.B:2017 method. Qualitative samples of zooplankton were collected zigzag line by plankton net with mesh size of 59 µm. Sampling only at depths between 0–50 cm. For quantitative samples, use a bucket or basin to collect 10L of water at the monitoring point, pour it through a plankton net to filter the sample, then transfer the sample (in the bottom tube) into the sample container. The supernatant samples were kept in plastic vials and fixed in 4% formol solution. The analysis of zooplankton samples was performed according to the method SMEWW 10500:2017. The zooplankton species were observed under the microscope, then identified morphologically through some references to the classification of invertebrates and zooplankton by Voigt (1956), Whipple & Ward (1963), Shirota (1966), Thanh et al. (1980), and Khoi (2001). Samples for quantitative analysis were counted individually under a microscope using a Sedgewick Rafter counting chamber according to the method of Boyd & Tucker (1992). Samples are concentrated to a specified volume, shake the water sample well before analysis, use a dropper to suck the sample and drop it into the plankton counting chamber. Then, put on a microscope to observe and count the number of individuals. The formula for determining the density of zooplankton is as follows:

$$D = 1000x/v \quad (2)$$

where: D – the density or number of zooplankton (individuals/L), x – the number of individuals counted in the water sample, v – the volume of water (L) collected from the sample.

RESULTS AND DISCUSSION

Charateristics of surface water quality in the study area

Table 1 shows the values of 11 physical and chemical indicators of surface water quality at eight monitoring locations on canals, rivers and canals in Hau Giang province. Through two monitoring periods, the average pH value in the monitored water bodies fluctuated relatively stable from 6.64±0.37–7.34±0.23. In addition, according to the results of the report of the Department of Natural Resources and Environment of Hau Giang province (2021), in the period of 2019–2021, the pH value at the monitoring locations has little change over the years. In water bodies of neighboring provinces such as Can Tho city, An Giang province, the recorded pH values ranged from 6.9 to 7.3, respectively; 6.2–7.7; 7.15±0.01–7.22±0.11 (Giau et al., 2019; Tuan et al., 2019; Hong & Giao, 2022), which are similar to the current research results. The pH value in water in the study area is still within the allowable limit of QCVN 08-MT:2015/BTNMT, column A1. The temperature at the recorded monitoring points fluctuated in the range of 28.20±0.14–29.95±0.49°C. The above temperature range is within the range of temperature fluctuations of water bodies in the Mekong Delta. For example, in Bung Binh Thien, An Giang province, the water temperature ranges from 28.07±0.06–30.33±1.36°C (Giao, 2020). The water temperature at monitoring stations on the Saigon River ranges from 27.6–31.0°C (Luu et al., 2020). In the monitoring water bodies of Tien Giang province, the minimum value of water is 28.48±0.77oC and the maximum value is 32.53±4.10°C (Hong et al., 2022). TSS concentration in the monitoring water bodies of Hau Giang province varied from 23.50±6.35 mg/L (S5 – Kenh Hau Giang 3) to 75.50±12.02 mg/L (S1 – Kenh Xang Xa No) At site S1 near Vi Thanh water plant, water supply with high TSS concentration will affect the cost and efficiency of water treatment (Tam et al.,

Table 1. Characteristics of surface water quality

Parameter	Unit	S1	S2	S3	S4	QCVN, A1
pH	-	6.70±0.06	6.73±0.13	7.01±0.15	6.64±0.37	6-8.5
Temp.	°C	29.25±0.35	29.30±0.57	29.25±0.78	28.65±1.48	-
TSS	mg/L	75.50±12.02	34.50±24.75	61.50±7.78	68.50±36.06	20
DO	mg/L	3.00±0.28	2.93±0.32	3.48±0.81	3.23±1.03	≥ 6
BOD	mg/L	11.50±0.71	12.00±1.41	12.00±0	10.00±2.83	4
COD	mg/L	19.00±1.41	20.00±2.83	20.50±2.12	16.00±7.07	10
NH_4^+-N	mg/L	0.095±0.04	0.235±0.13	0.28±0.33	0.16±0.17	0.3
NO_3^--N	mg/L	0.54±0.11	0.465±0.01	0.54±0.17	0.41±0.01	2
PO_4^{3-}-P	mg/L	0.13±0.01	0.14±0.04	0.15±0.06	0.17±0.08	0.1
Fe	mg/L	1.00±0.2	1.04±0.44	0.58±0.27	0.98±0.69	0.5
Coliform	MPN/100 mL	34325±24996.22	7600±1131.37	8850±636.4	14400±7212.49	2500
Parameter	Unit	S5	S6	S7	S8	QCVN, A1
pH	-	6.87±0.05	6.8±0.01	7.02±0.14	7.34±0.23	6-8.5
Temp.	°C	28.20±0.14	28.95±0.21	29.23±0.74	29.95±0.49	-
TSS	mg/L	23.50±6.36	39.00±32.53	70.00±2.83	54.00±24.04	20
DO	mg/L	2.48±0.74	4.68±0.46	3.65±0.92	2.50±0.57	≥ 6
BOD	mg/L	9.00±1.41	8.00±1.41	10.50±4.95	12.50±0.71	4
COD	mg/L	15.50±3.54	13.50±0.71	20.00±8.49	21.50±0.71	10
NH_4^+-N	mg/L	0.185±0.16	0.02±0.03	0.04±0.06	0.38±0.41	0.3
NO_3^--N	mg/L	0.395±0.02	0.435±0.08	0.55±0.24	0.63±0.13	2
PO_4^{3-}-P	mg/L	0.085±0.01	0.06±0.03	0.225±0.05	0.21±0.07	0.1
Fe	mg/L	0.615±0.11	0.39±0.16	1.555±0.69	0.975±0.13	0.5
Coliform	MPN/100 mL	5350±4313.35	1360±1470.78	5540±6519.52	9725±601.04	2500

2022; Hong & Giao, 2022). TSS concentration in water in the study area has exceeded the allowable limit of QCVN 08-MT:2015/BTNMT, column A1. The TSS concentration is high and exceeds the standard because the study area has received wastewater from domestic activities, urban development, industrial production and navigation activities in the area. The situation of surface water in water bodies with high concentrations of total suspended solids and exceeding the prescribed threshold has been reported in several other studies, such as the Can Tho River (TSS 14.7–79.6 mg/L), canals in Soc Trang province (TSS 16-176 mg/L), water bodies in Tien Giang province (TSS 39.25±5.56-187.25±71.96 mg/L) (Giau et al., 2019; Tuan et al., 2019; Hong et al., 2022). Research results show that the DO concentration in water in the study area is very low, not reaching the allowable threshold of QCVN 08-MT:2015/BTNMT, column A1, only fluctuates in the range of 2.48±0, 74-4.68±0.46 mg/L. The low DO concentration in water is consistent with the recorded results of high TSS, BOD and COD concentration in water and exceeds the allowable limit of QCVN 08-MT:2015/BTNMT, column A1, respectively from 1.18–3.78 times, 2–3.13 times and 1.35–2.15 times. The process of composting organic compounds has contributed to the depletion of oxygen concentration in water. The recorded BOD and COD concentrations ranged from 8.00±1.41–12.50±0.71 mg/L and 13.50 ± 0.71 ± 21.50 ± 0.71 mg/L, corresponding. Both BOD and COD concentrations are highly concentrated at location S8 – Cai Ngang Dua River, where the combined wastewater sources of three provinces Kien Giang – Bac Lieu – Hau Giang meet. Surface water sources receive a large amount of wastewater and waste from domestic, industrial and urban activities that have not been treated or are only partially used, leading to organic pollution through BOD and COD concentrations. high in water, as in the monitoring water bodies of Ca Mau peninsula, the BOD and COD concentrations ranged from 14.6±16.9 mg/L and 26.5±3.4–29.9±11.5 mg/L, respectively (Giao, 2022), at Hau river, Mac Can Dung canal, Vam Nao river in An Giang province, BOD and COD concentrations were recorded from 12–39 mg/

Land 14–60 mg/L, respectively (Hong & Giao, 2022). NH_4^+-N concentration at monitoring points on canals, rivers and canals in Hau Giang province fluctuates in the range of 0.02±0.03-0.38±0.41 mg/L, respectively the lowest in position S6 – Song Hau and the highest at position S8 – Song Cai Ngang Dua. In general, the concentration of NH_4^+-N in water in the study area is within the allowable limits of QCVN 08-MT:2015/BTNMT, column A1. Notably, at position S8, the concentration of ammonium continued to exceed the allowable limit of the standard, exceeding 1.27 times. In many previous studies, it has been shown that nutrient pollution, typically high NH_4^+-N concentration in water, originates from various metabolic processes such as agriculture, domestic and industrial activities (Tam et al., 2022; Hong & Giao, 2022). The concentration of NO_3^--N in water in the study area is very low, only fluctuates in the range of 0.395±0.02–0.63±0.13 mg/L, still within the allowable limit of QCVN 08-MT:2015/BTNMT. Because in the aquatic environment, the oxygen concentration is very low (low DO), so the nitrification process occurs quite well, leading to low NO_3^--N concentration. In many water bodies lacking oxygen in the water, the concentration of NO_3^--N is also very low, typically in Soc Trang province (0.05–1.14 mg/L) (Tuan et al., 2019), the province Tien Giang (0.09±0.04–0.67±0.09 mg/L) (Hong et al., 2022), Can Tho city (0.34–0.61 mg/L) (Tam et al., 2022). The concentration of NO_3^--N formed in water can come from many different sources, such as fertilizer use in agricultural production, septic tank systems, wastewater, domestic and industrial waste (Sallenave, 2011; Savci, 2012). The concentration of PO_4^{3-}-P in water at monitoring stations mostly exceeds the allowable limit of QCVN 08-MT:2015/BTNMT, column A1. Except for two locations S5 – Hau Giang Canal 3 and S6 – Song Hau, the PO_4^{3-}-P concentration is still within the regulated threshold. Orthophosphate concentration fluctuates in the range of 0.06±0.03–0.225±0.05 mg/L, highly concentrated at location S7 – Ba Lang River, an area affected by production activities in the Tan Phu Thanh industrial park and daily activities in this port area. Compared with some other studies, in water bodies of Bac Lieu province (0.05–0.9 mg/L), Can Tho city (1.17–2.85 mg/L), Tien Giang province (0.116). ±0.09 mg/L), the PO_4^{3-}-P concentration was relatively higher than in the present study area (Giao et al., 2021; Tam et al., 2022; Hong et al., 2022). The use of detergents in daily life, industrial wastewater, and washing powder production is considered to be the cause of high PO_4^{3-}-P concentration in the water in the study area. Fe concentration in water in the study area ranges from 0.39±0.16 mg/L (S6 – Song Hau) to 1,555±0.69 mg/L (S7 – Ba Lang River). With this result, surface water in rivers, canals and canals in Hau Giang province was contaminated with iron, Fe concentration exceeded the allowable limit of QCVN 08-MT: 2015/BTNMT, column A1, only one position (S6) Fe concentration is still up to standard. The problem of iron pollution in the study area mainly comes from natural characteristics (acid sulfate soil) that have contributed to the formation of an abundant amount of Fe in the water. In some neighboring areas such as Soc Trang and Can Tho provinces, Fe was also detected at high concentrations (Tuan et al., 2019; Tam et al., 2022). According to Giao et al. (2021), the presence of Fe in water leads to deterioration of water quality, treatment costs, loss of beauty, and many human health risks. The concentration of coliform microorganisms in water was recorded from 1360±1470.78 MPN/100 mL (S6 – Song Hau) to 34,325±24,996.22 MPN/100 mL (S1 – Channel Xang Xa No). The lowest coliform concentration at location S6 – the area affected by Song Hau industrial park can be seen, the wastewater and waste treatment process in this area is quite good, not negatively affecting the environment. Meanwhile, at location S1, receiving wastewater from residential areas and urban development activities in Vi Thanh city. In general, most of the monitoring sites (especially location S6), the coliform concentration in the water exceeded the standard QCVN 08-MT:2015/BTNMT, column A1, exceeding 13.73 times at most. Surface water sources contaminated with microorganisms, typically coliform due to receiving wastes of warm-blooded animals, have been reported in many water bodies (Giau et al., 2019; Giao, 2022; Hong & Giao, 2022).

Water quality index

The results of surface water quality index (WQI) at each monitoring location on canals, rivers and canals in Hau Giang province are detailed in Figure 2. WQI values at eight monitoring points fluctuated between 37.16-84 and averaged 58.42. According to the WQI index rating scale, surface water quality in the study area ranges from bad to good (Vietnam Environment Administration, 2019). Bad water quality accounted for 37.5% of the total number of monitoring locations, concentrated at locations S1 – Canal Xang Xa No, S4 – Kenh Mang Ca – Phung Hiep and S8 – River Cai Ngang Dua. Locations with poor water quality mainly have high concentrations of organic, nutrient and microbial pollutants in the water. With the above WQI value, surface water at positions S1, S4 and S8 is only suitable for use for navigation and equivalent purposes. Average water quality, suitable for irrigation purposes and equivalent purposes was determined at four locations (S2 – Cai Lon River, S3 – Ba Lang River Branch – Rach Roi market, S5 – Kenh Hau) Giang 3 and S7 – Ba Lang River – Port of Tan Phu Thanh Industrial Park) account for 50% of the total number of monitoring locations. In particular, only one location (S6 - Song Hau) has good water quality, meeting the purpose of domestic water supply but needs appropriate treatment measures. It can be seen that surface water in the study area of Hau Giang province is no longer capable of being used for domestic water supply purposes. Currently, the water source has been seriously contaminated with organic matter, nutrients and microorganisms. However, compared with neighboring provinces such as Binh Duong province, Ca Mau peninsula, An Giang province, the WQI index shows that surface water quality in the study area tends to be better (Tuan et al., 2018; Giao, 2022; Khanh et al., 2022). From the current state of water quality, the local government of Hau Giang province needs to have an optimal plan to ensure that it meets the people's water use needs.

Implication of surface water quality from phytoplankton diversity

Through two observations, the study recorded a total of 164 species of phytoplankton belonging to 5 algae phylums including Bacillariophyta, Chlorophyta, Cyanophyta, Euglenophyta and Pyrrophyta (Figure 3). In which, phylum Bacillariophyta has identified 53 species, accounting for 32.32%, phylum Chlorophyta has 47 species, accounting for 28.66%, phylum Cyanophyta has 39 species, accounting for 23.78%, phylum Euglenophyta has 24 species, accounting for 14.63% and phylum Euglenophyta has 24 species, accounting for 14.63%. Pyrrophyta only recorded 1 species, accounting for 0.61%. The composition of phytoplankton species in water bodies in Hau Giang province tends to be lower than some other water bodies in neighboring provinces. Typically, in Soc Trang province, the composition of phytoplankton has 221 species belonging to 5 phyla including Bacillariophyta, Chlorophyta, Euglenophyta, Cyanophyta, Dinophyta; in which Bacillariophyta has the largest number of species (Lien et al., 2020), similar to the current research results. In the main canals in Vinh Long province, phytoplankton composition recorded a

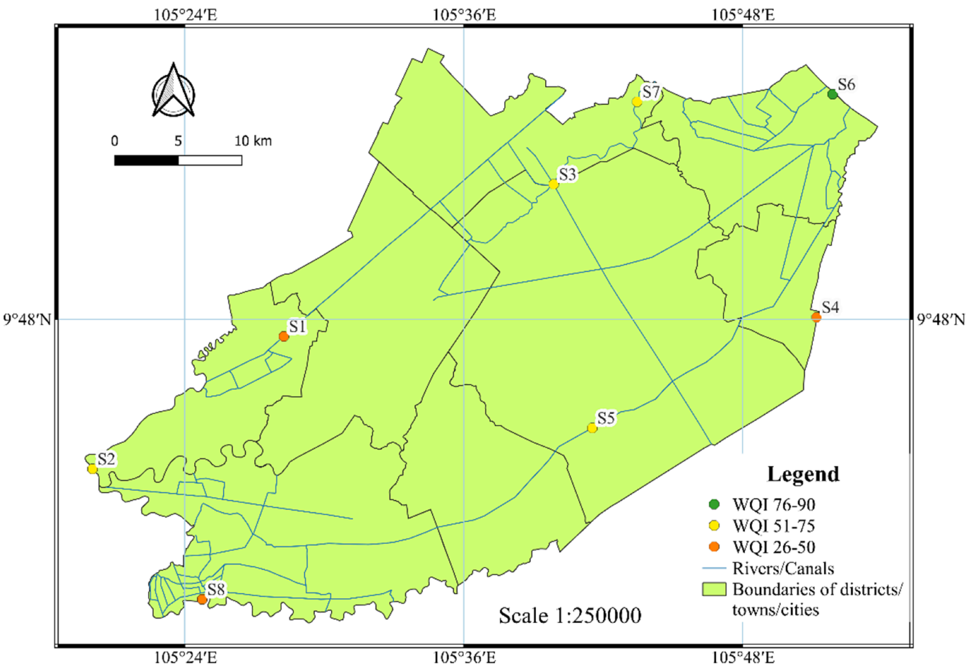

Figure 2. Spatial distribution of water quality index in te study area

total of 209 species with 82 species of Bacillariophyta, 61 species of Chlorophyta, 39 species of Cyanophyta, 21 species of Euglenophyta, 3 species of Chrysophyta and 3 species of Pyrrophyta (Trang et al., 2019).

As shown in Figure 3, the Bacillariophyta phylum has the largest number of species, and the presence of indicator species for the saltwater – brackish water environment in the study area (Yen et al., 2018; Lien et al., 2022). However, the phylum Chlorophyta and Cyanophyta also have a fairly high number of species, and the diversity of green and blue algae represents freshwater, nutrient-rich and organic environments in the water. From that, it can be seen that the situation of salinity – brackish in the study area is not significant. Notably, the appearance of Euglenophyta in most of the monitoring locations, typically Euglena and Phacus varieties, shows the state of organic pollution in the water, which is consistent with the results of BOD concentration. COD all exceeded the allowable limit of QCVN 08-MT:2015/BTNMT. The study also identified a number of algae species that frequently occur in water bodies such as *Oscillatoria chalybea*, *Oscillatoria linmosa* of Cyanophyta, *Coscinodiscus radiatus*, *Coscinodiscus lineatus*, *Melosira malayensis* of Bacillariophyta and *Euglena acus*, *Phacus longicauda*, *Phacus pleuronectes* belongs to Euglenophyta. According to Dan et al. (2017), species of genera *Euglena*, *Phacus* often occur in water bodies with high organic pollution. While, the cyanobacterial species *Oscillaroria linmosa* was used to assess the average level of soil pollution (Yen et al., 2019). The diatom species of the genus *Coscinodiscus* are usually brackish tolerant marine species that can live in inland areas (Yen et al., 2019). The variation of phytoplankton density at each monitoring location along the canals, rivers and canals in Hau Giang province is detailed in Figure 4. The results of the study recorded, at each monitoring station, the total phytoplankton density varied from 370 individuals/L (S6 – Song Hau) to 2,260 individuals/L (S8 – Cai Ngang Dua River) (Figure 4a). The individual density of each phylum of phytoplankton including Bacillariophyta, Chlorophyta, Cyanophyta and Euglenophyta ranges from 192–610 individuals/L, 25–150 individuals/L, 60–1270 individuals/L and 5–580 individuals/L (Figure 4b). The phylum Pyrrophyta is only present at position S6 – Song Hau with a density of 5 individuals/L. The density of Bacillariophyta is dominant at most of the monitoring locations, possibly because these locations have high water flow, water exchange brings algae from the main river. The Cyanophyta has the dominant density at position S8 with 1,270 individuals/L, accounting for 32.20%. The predominance of Cyanophyta represents a nutrient-rich environment, the concentrations of NH_4^+-N, NO_3^--N and PO_4^{3-}-P determined at this location are very high, the highest of all monitoring points. At the same time, the high density of Cyanophyta at location S8 may also be due to the water circulation that has brought Cyanophyta from the water bodies of neighboring provinces of Kien Giang and Bac Lieu to this place. Euglenophyta had the lowest individual density at site S6 – Song Hau, where it was assessed to have low levels of organic pollutants COD, BOD, nutrient pollutants NH_4^+-N, PO_4^{3-}-P, and coliform of all monitoring locations. Based on the distribution and structure of phytoplankton, it can be concluded that the surface water environment in Hau Giang province

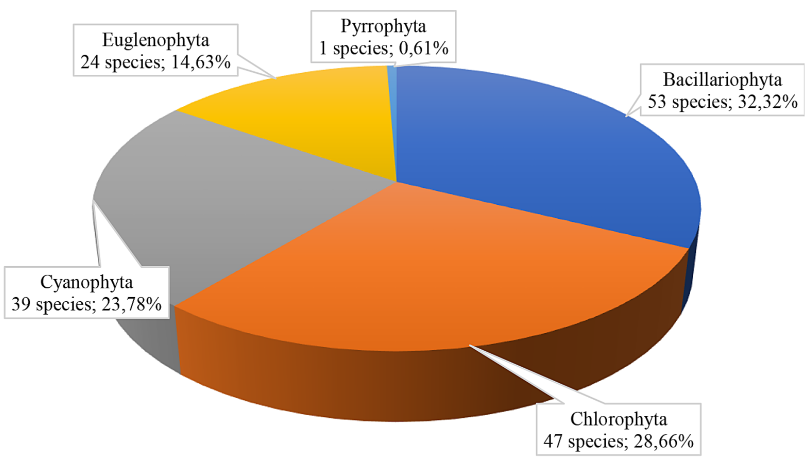

Figure 3. Composition of phytoplankton in the study area

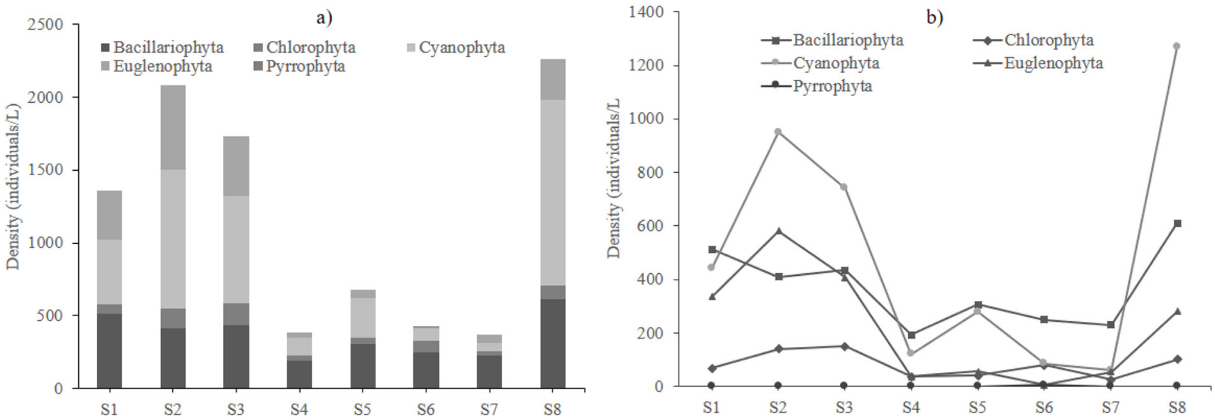

Figure 4. Density of phytoplankton in the study area

has been contaminated with organic matter and nutrients with the presence of some algae species of the genus *Oscillaroria*, *Euglena* and *Phacus*.

Implication of surface water quality from zooplankton diversity

The composition of zooplankton species at monitoring points on canals, rivers and canals in Hau Giang province recorded a total of 91 species, including 43 species belonging to the Rotifera phylum and 19 species of the phylum Copepoda, 14 species of protozoa, 14 species of phylum Cladocera and 1 species of Ostracoda. The percentage of species of each phylum is detailed in Figure 5. The composition of zooplankton in the study area is relatively higher than in some other study areas in the Mekong Delta. For example, the composition of zooplankton in water bodies in Ben Tre province only recorded 63 species belonging to 5 groups with 1 species of protozoa, 35 species of Rotatoria, 6 species of Cladocera, 16 species of Copepod and 2 species of Ostracoda (Van & My, 2020). In water bodies in Can Tho city, 79 species of zooplankton were identified, of which 21 species of Protozoa, 42 species of Rotatoria, 10 species of Cladocera and 7 species of Copepoda (Dung & Oanh, 2011). Similarly, in the canal system in Ho Chi Minh City, only 69 species of zooplankton were recorded, however, the Rotifera phylum has the most diverse species, which is similar to the current research results (Hoang et al., 2017).

The research results determined that the phylum Rotifera had the largest number of species, representing a nutrient-rich, organic water environment and insignificant saltwater status in the study area. The species commonly occurring in the observed water bodies are *Brachionus falcatus*, *Filinia terminalis*, *Polyathra vulgaris* and *Rotaria neptunia*. These are zooplankton species commonly distributed in water bodies rich in organic matter, sewage, ponds with dirty water and water bodies contaminated with domestic wastewater (Lien et al., 2014; Nhi & My, 2017). Next,

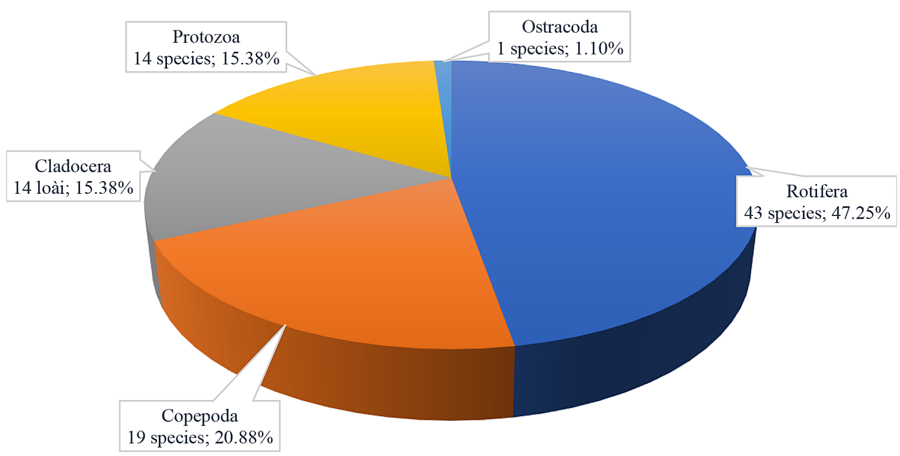

Figure 5. Composition of zooplankton in the study area

the Copepoda group has the second most abundant species in the study area. These are widely distributed species, with strong tolerance to environmental changes, so they appear at most monitoring locations, typically *Micricyclops varicans*. Notably, saltwater species such as *Oithona spp*, *Oncaea spp*, *Calanus gracilis* and *Paracalanus nanus* were not detected in the 11 monitoring period. The reason is that under the influence of rain and flood water, the salinity in the water decreased significantly. and salt intrusion is less, so these species do not appear, instead there are freshwater species such as *Eucyclopss serularus*, *Schmarkeria speciosa* and *Mescocyclops leukarti*. In particular, the appearance of Cladocera species, shows that the surface water environment in Hau Giang province does not have agricultural pollution (Department of Natural Resources and Environment of Hau Giang province, 2021). Salinity is negligible, has not affected the growth and development of Cladocera species (Lien et al., 2014). At the same time, Cladocera species are indicators of water environment with medium nutrient level, common species are *Bosmina longirostris*, *Bosminopsis deitersi*, *Moina macrocopa* (Lien et al., 2020).

Figure 6 shows the evolution of plankton density at each monitoring location in Hau Giang province. The analysis results showed that the total density of floating fauna between the monitoring points is quite large, ranging from 13,332 individuals/L (S6 – Song Hau) to 121,600 individuals/L (S5 – Hau Giang canal 3) (Figure 6a). Density of phylum Nauplius, Copepoda, Cladocera, Rotifera, Protozoa and others fluctuated among eight monitoring locations from 3,753–36,460 individuals/L, 463–18,384 individuals/L, 232–4,547 individuals/L, 1,895–32,480 individuals/L, 1,232–33,032 individuals/L and 132–1,053 individuals/L, respectively (Figure 6b). From that, it can be seen that the density of Nauplius species is very high, distributed in all water bodies, showing that the surface water environment in the study area is rich in organic matter (Lien et al., 2014). Especially at positions S5 and S8, the density of Nauplius larvae was highest, accounting for 25.62% and 24.11% of the total, respectively. At site S1, the number of protozoa is the highest with a density of 33,032 individuals/L, accounting for 39.84%, showing that this place is in a state of organic pollution with concentrations of BOD pollutants (11.50±0.71 mg/L), COD (19 mg/L) all exceeded the allowable limit of column A1, QCVN 08-MT:2015/BTNMT. At the same time, the WQI index also shows the bad water condition at position S1. For the phylum Rotifera, the highest density at position S5 (32,480 individuals/L, accounting for 32.55% of the total) shows that this location is always rich in organic matters (BOD 9±1.41 mg/L and COD 15.50±3.54 mg/L). The zooplankton groups used as indicators for polluted environments such as Nauplius, Rotifera and Protozoa all had low densities at site S6, indicating that the water source at this site was not polluted or the pollution was not significant. From the results of the study, it was found that the surface water environment in Hau Giang province was contaminated with organic matters and nutrients with the predominant presence and development of Nauplius, Rotifera and Protozoa species.

Correlation between water quality parameters and plankton

The correlation between the density of phytoplankton, zooplankton and surface water quality parameters is detailed in Table 2. The results

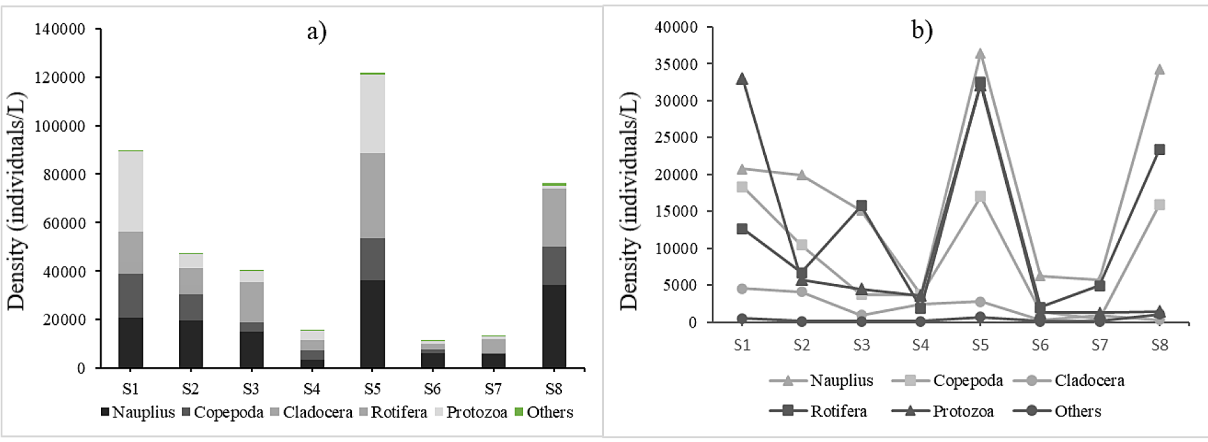

Figure 6. Density of zooplankton in the study area

Table 2. Correlation matrix between water quality and plankton

Par.	Bacillariophyta	Chlorophyta	Cyanophyta	Euglenophyta	Pyrrophyta	Nauplius	Copepoda	Cladocera	Rotifera	Protozoa
pH	**0.508**	0.197	**0.547**	0.050	-0.157	**0.435**	0.100	**-0.664**	**0.478**	**-0.335**
Temp.	**0.714**	**0.506**	**0.707**	**0.534**	-0.116	0.092	0.073	-0.248	-0.102	**-0.450**
TSS	0.088	-0.195	-0.131	-0.007	**-0.305**	**-0.472**	-0.214	-0.012	**-0.402**	-0.130
DO	**-0.523**	-0.022	**-0.552**	**-0.366**	**0.812**	**-0.788**	**-0.792**	**-0.458**	**-0.707**	**-0.465**
BOD	**0.764**	**0.574**	**0.810**	**0.811**	**-0.678**	**0.304**	**0.325**	0.204	0.160	-0.113
COD	**0.675**	**0.454**	**0.715**	**0.688**	**-0.670**	0.266	0.207	0.039	0.174	-0.184
NH_4^+-N	**0.679**	**0.585**	**0.884**	**0.553**	**-0.508**	**0.627**	**0.420**	-0.072	**0.553**	-0.133
NO_3^--N	**0.726**	**0.302**	**0.596**	**0.384**	-0.299	0..212	0.165	-0.294	0.145	-0.237
PO_4^{3-}-P	0.206	-0.083	**0.303**	0.138	**-0.617**	-0.090	-0.129	-0.205	-0.098	**-0.432**
Fe	-0.025	**-0.351**	-0.005	0.074	**-0.561**	-0.181	-0.060	0.176	-0.258	-0.150
Coliform	**0.419**	-0.091	0.061	0.282	**-0.378**	0.078	**0.513**	**0.639**	-0.005	**0.568**

show that the density of Bacillariophyta is strongly influenced, similar positively correlated with pH, temperature, BOD, COD, NH_4^+-N, NO_3^--N and coliform with correlation coefficient *r* of 0.598, respectively; 0.714; 0.764; 0.675; 0.679; 0.726 and 0.419. This shows that, when the level of nutrients and organic matter is high in the water, it would create favorable conditions for Bacillariophyta to grow and distribute throughout the monitoring water bodies. Some typical Bacillariophyta such as Coscinadiscus, Cyclotella, Melosira, Navicula, Nitzchia and Suritella (Lien et al., 2020). In addition, the density of Bacillariophyta was also determined to have a statistically significant positive correlation ($p < 0.05$) with salinity (Yen et al., 2018). Some varieties of Bacillariophyta have a positive correlation with salinity such as Asterionella, Biddulphia, Coscinodiscus, Diatoma, Navicula, Nitzchia, Pleurosigma, Phizosolenia, Thalassionema (Lien et al., 2020). The density of Chlorophyta was linearly correlated with temperature ($r = 0.506$), BOD ($r = 0.574$), COD ($r = 0.454$), NH_4^+-N ($r = 0.585$) and NO_3^-- N ($r = 0.302$).

Similar results were observed for the phylum Euglenophyta, where the density of Euglenophyta showed a linear correlation with temperature, BOD, COD, NH_4^+-N, and NO_3^--N with coefficients *r* of 0.534; 0.811; 0.688; 0.553 and 0.384, respectively. For the density of Cyanophyta there was a positive correlation with most water quality parameters, including pH ($r = 0.547$), temperature ($r = 0.707$), BOD ($r = 0.810$), COD ($r = 0.715$), NH_4^+-N ($r = 0.884$), NO_3^--N ($r = 0.596$), PO_4^{3-}-P ($r = 0.303$). It can be seen that Bacillariophyta, Chlorophyta, Cyanophyta, and Euglenophyta species appearing in water bodies of Hau Giang province all prefer water rich in organic matters and nutrients. Some typical varieties commonly encountered in this environment are Closterium, Pediastrum, Scenedesmus, Staurastrum (Chlorophyta), Anabaena, Oscillatoria, Spirulina (Cyanophyta), Euglena and Phacus (Euglenophyta) (Lien et al., 2020). Particularly for Pyrrophyta, it is negatively correlated with most of the water quality indicators, except DO (strong positive correlation, $r = 0.812$). Pyrrophyta was only recorded at one location (S6), which was evaluated as the best surface water quality in all monitoring locations. In summary, environmental parameters representing organic pollutants (BOD, COD) and nutrients (NH_4^+-N, NO_3^--N and PO_4^{3-}-P) play the most important role in constituting community structure of phytoplankton.

The density of Nauplius larvae of the Copepoda was found to be strongly correlated with BOD ($r = 0.304$), NH_4^+-N ($r = 0.627$) and pH ($r = 0.435$), while the negative correlation occurred between larval density with TSS (r = -0.472) and DO ($r = -0.788$). This can be demonstrated that, when the environment is rich in organic matters and nutrients, Nauplius larvae would grow and develop well, with a high density in the water body (Van & My, 2020). For the Copepoda, the density was negatively correlated with DO ($r = -0.792$), positively correlated with BOD (0.325), NH_4^+-N (0.420) and coliform (0.513). The density of Copepod increases as the nutrient and organic concentration in the water body increases. In the study, PO_4^{3-}-P did not have a significant correlation with the density of Copepoda. However, this relationship is determined by the study of Son et al. (2021). Density of Cladocera was negatively correlated with DO ($r = -0.458$), pH ($r = -0.664$). Cladocera is a clean-loving group that has a close relationship with dissolved oxygen concentration (Ha et al., 2016). Therefore, when DO concentration in water bodies is low, adverse environmental conditions will affect the distribution and development of Cladocera. The Rotatoria has a characteristic distribution for freshwater environments, adapted to nutrient-rich water environments (Ismail & Adnan, 2016). The results of Pearson analysis showed that the density of rotifers was positively correlated with NH_4^+-N (r = 0.553), pH (r = 0.478) and negatively correlated with TSS (r = -0.402) and DO (r = -0.402). In the environment with low DO concentration, Rotifera species can still live and develop, the reason is that Rotifera is an organic-loving group, which is closely correlated with the oxygen demand in water (Ha et al., 2016). Some species of Rotifera are often indicator for organic polluted water environment such as *Brachionus angularis*, *Brachionus calyciflorus*, *Brachionus falcatus*, *Filinia terminalis*, *Polyrhtra vulgaris* and *Philodina roseola* (Lien et al., 2020). The Protozoa often indicates an organically contaminated, nutrient-rich environment. However, the correlation analysis identified a negative correlation between the density of protozoa with PO_4^{3-}-P, pH, temperature, DO and a positive correlation with the coliform concentration in the water. According to research by Lien et al. (2020), Protozoa density has a positive correlation with pH, TP concentration in water and some species of Protozoa are often indicators for organic polluted water environment such as Difflugia, Centropyxis, Tintinnidium, Tintinnopsis. The negative correlation between DO and Cladocera, Copepoda and Rotifera was also shown in the study of Shayestehfar et al. (2010). In general, environmental parameters such as pH, DO, BOD, NH_4^+-N and coliform have the most influence on the density of plankton species.

CONCLUSION

Surface water quality in Hau Giang province has been contaminated with organic matter, nutrients, alum and microorganisms. Concentrations of environmental parameters including DO, BOD, COD, TSS, PO_4^{3-}-P, Fe and coliform all did not reach the allowable threshold of QCVN 08-MT:2015/BTNMT, column A1. The water quality index (WQI) ranges from 37.16 to 84, showing that the water quality fluctuates from bad to good and the surface water here is no longer suitable for water supply purposes. The phytoplankton species composition recorded 164 species belonging to 5 branches with the density of algae species ranging from 370-2260 individuals/L. The presence of the species Oscillaroria, Euglena and Phacus, indicates the status of organic and nutritional pollution in the water body. The composition of zooplankton identified 91 species belonging to 5 phyla with the density of zooplankton fluctuating in the range of 11,332-121,600 individuals/L. Predominant presence and development of Nauplius, Rotifera and Protozoa species represent rich organic matter and nutrients in the observed water bodies. Pearson correlation analysis found that the density of phytoplankton species was strongly influenced by environmental criteria such as BOD, COD, NH_4^+-N, NO_3^--N and PO_4^{3-}-P. While, environmental parameters such as pH, DO, BOD, NH_4^+-N and coliform have the most influence on the density of zooplankton species.

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