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Characteristics of Surface Water Quality and Diversity of Zoobenthos in Water Bodies, An Giang Province, Vietnam

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Abstract

The use of zoobenthos to evaluate water quality has gained considerable interest due to its low cost and environmental friendliness. This study analyzed water and zoobenthos samples at 13 sites in the water bodies in An Giang Province in the rainy season (on March) and dry season (on September) in 2018. The results showed that the surface water was contaminated by organic matters, suspended solids and coliforms. There was occurrence of 28 species of zoobenthos divided into five classes including Oligochaeta, Polychaeta, Insecta, Gastropoda, and Bivalvia in which Bivalvia was the most diverse class accounting for 75%. The densities of zoobenthos in the dry and wet season were from 30 divided into three clusters for the dry season and six clusters for the rainy season indicating seasonal variation of zoobenthos composition possibly due to variance of water and sediment characteristics. The results of Pearson correlation indicated that the composition of zoobenthos was strongly correlated with temperature, pH, $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$. Using water quality index (WQI), Shannon-Wiener diversity index (H') and associated average score per taxon (ASPT) for water quality assessment revealed that water quality ranges from medium (from α to β- mesosaprobe) to heavy pollution (Polysaprobe). There was inconsistency between using physicochemicals and diversity index of zoobenthos for water quality identification leading to the use of zoobenthos for water indication could result in misadjustment of water quality. Further study should investigate the relationship between zoobenthos and water quality in different ecological areas to better indicate role of zoobenthos in quick diagnose water quality.

Keywords: An Giang; Organic pollution; Water quality index; Zoobenthos

Introduction

An Giang Province is located in the southern of Vietnam and downstream of the Mekong River. There are several socio-economic activities such as agriculture, forestry, industry, and services in An Giang, especially, planting rice and aquaculture have significantly contributed to the local development. It is necessary to monitor

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the surface water quality in water bodies in An Giang since it is directly influenced on the socio-economic activities. In Vietnam, the assessment of environmental quality is mainly based on physical and chemical indicators [1–2]. However, this method can only assess pollution status at the time of the survey due to the continuous changes of hydrological factors. Meanwhile, the existence or disappearance of a certain organism in the environment is the result of long-term interaction between organisms and their habitats [3–4]. Zoobenthos is a group of organisms that plays a vital role in water bodies. For instance, it is responsible for maintaining stable food webs, able to purify water, and used as indicators for the environmental quality [5]. The distribution of zoobenthos depends on many factors including water quality and physical-chemical characteristics of the bottom sediments [6], organic matter content and residues of pesticides from agricultural activities [7–9]. Due to the rapid and strong development of the socio-economic, anthropogenic activities have extremely impacted on the natural conditions of water bodies. When water conditions are changed, the aquatic life is thus affected, especially zoobenthos [10]. Norris and Thoms (1999) [11] suggested that the effects on biota are usually the final point of environmental degradation and pollution of rivers. Therefore, zoobenthos are usually used as indicator organisms for water quality; especially, in flowing water bodies [12–13]. Evaluation of biodiversity of rivers has proven to be a low cost method and is easy to implement [15]. This study was conducted to assess the water quality and the diversity of zoobenthos and the relationship between the two in some water bodies in An Giang Province. The findings of the current study could provide helpful information whether or not the zoobenthos could be used as indicators for water quality assessment in the water monitoring task.

Methodology

1) Sampling sites

The water and zoobenthos samples were collected in two campaigns, one in March (the dry season) and one in September (the rainy season) in 2018 at 13 points in the canals of An Giang Province. The sampling sites were located on river branches along the banks of Tien and Hau Rivers; large tributaries contiguous between An Giang Province and the other provinces. Previous research has shown that flow regime and water column level are important determinants of benthic community composition [16]. Therefore, both sampling periods were conducted at low tide to minimize the influence of tidal currents resulting in differences in species composition of zoobenthos, in which the water samples were collected at the surface water layer (about 30–50 cm from the water surface), and the zoobenthos samples were collected at bottom sediment. Description of sampling locations were shown in Table 1.

2) Water sampling and analysis

Water samples for physical and chemical indicators were collected at 13 sites as presented in Figure 1. Water samples were collected in accordance with the guidance of TCVN 6663-6:2018 (ISO 5667-6:2014) – Guidance on sampling of rivers and streams [17] and stored according to TCVN 6663-3: 2016 [18]. The pooled samples were applied at the corresponding sampling sites. The water samples were rinsed three times with the field water prior to the two liters of water were collected and covered with caps, stored at 4°C and then transported to the laboratory for analysis. Particularly, microbiological analysis samples were taken in dedicated bottles (glass jar) which have been pasteurized at 175°C for 2 h prior to use. Surface water quality variables including temperature (T, °C), pH, dissolved oxygen (DO, mg L^{-1}), total suspended solids (TSS, mg L^{-1}), biochemical oxygen demand (BOD_5, mg L^{-1}), chemical oxygen demand (COD, mg L^{-1}), nutrients ($N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, mg L^{-1}), and coliforms (MPN 100 mL^{-1}) were examined. The temperature, pH, and DO were measured directly in the field with handheld devices (AD11/ AD12 ADWA - Hungary, DO 7031 GONDO – Taiwan) while the remaining parameters were transported to the environmental analysis lab and analyzed followed the Standard methods for the examination of water and wastewater [19].

The analyzed surface water quality data were synthesized and processed by Microsoft Excel software (Microsoft Excel, 2016). National technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT, column A1-water quality is good for domestic use) [20] and Water Quality Index (WQI) were applied to assess surface water quality.

The water quality was assessed by WQI following Eq. 1 [21].

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

Where WQI_a is the WQI value of five parameters (i.e., DO, BOD5, 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).

Table 1 Brief Information on sampling sites

Code	Coordinates	Location
S1	10° 48′ 17.438″ N 105° 13′ 45.345″E	In the begin of Cai Vung and Tien Rivers – Tan Chau District
S2	10° 43′ 8.612″ N 105° 20′ 45.370″E	In the end of Cai Vung and Tien Rivers – Tan Chau District
S3	10° 25′ 57.772″ N 105° 34′ 18.682″E	In the end of Gieng Island – Cho Moi District
S4	10° 57′ 19.798″ N 105° 5′ 1.472″E	The upstream of Hau River – An Phu District
S5	10° 19′ 31.887″ N 105° 29′ 40.922″E	The downstream of Hau River borders Can Tho – Long Xuyen City
S6	10° 53′ 47.262″ N 105° 2′ 13.840″E	The upstream of Chau Doc River – An Phu District
S7	10° 42′ 39.555″ N 105° 7′ 24.980″E	Chau Doc River junction – Chau Doc Town
S8	10° 30′ 21.286″ N 104° 46′ 56.524″E	The end of Vinh Te Canal adjacent to Tri Ton District, Kien Giang Province
S9	10° 21′ 20.336″ N 105° 51′ 54.312″E	The end of Tam Ngan Canal adjacent to Tri Ton District, Kien Giang Province
S10	10° 11′ 1.235″ N 105° 12′ 21.507″E	The end of Rach Gia Canal adjacent to Thoai Son District
S11	10° 46′ 10.820″ N 105° 12′ 22.685″E	Flood control culvert at the beginning of Than Nong Canal is adjacent to Vinh An Canal – Tan Chau District
S12	10° 38′ 49.934″ N 105° 16′ 23.379″E	In the middle of Than Nong Canal, adjacent to K26 – Phu Tan District
S13	10° 35′ 32.826″ N 105° 18′ 33.748″E	Flood control culvert at the end of Than Nong Canal is adjacent to Cai Tac Canal – Phu Tan District

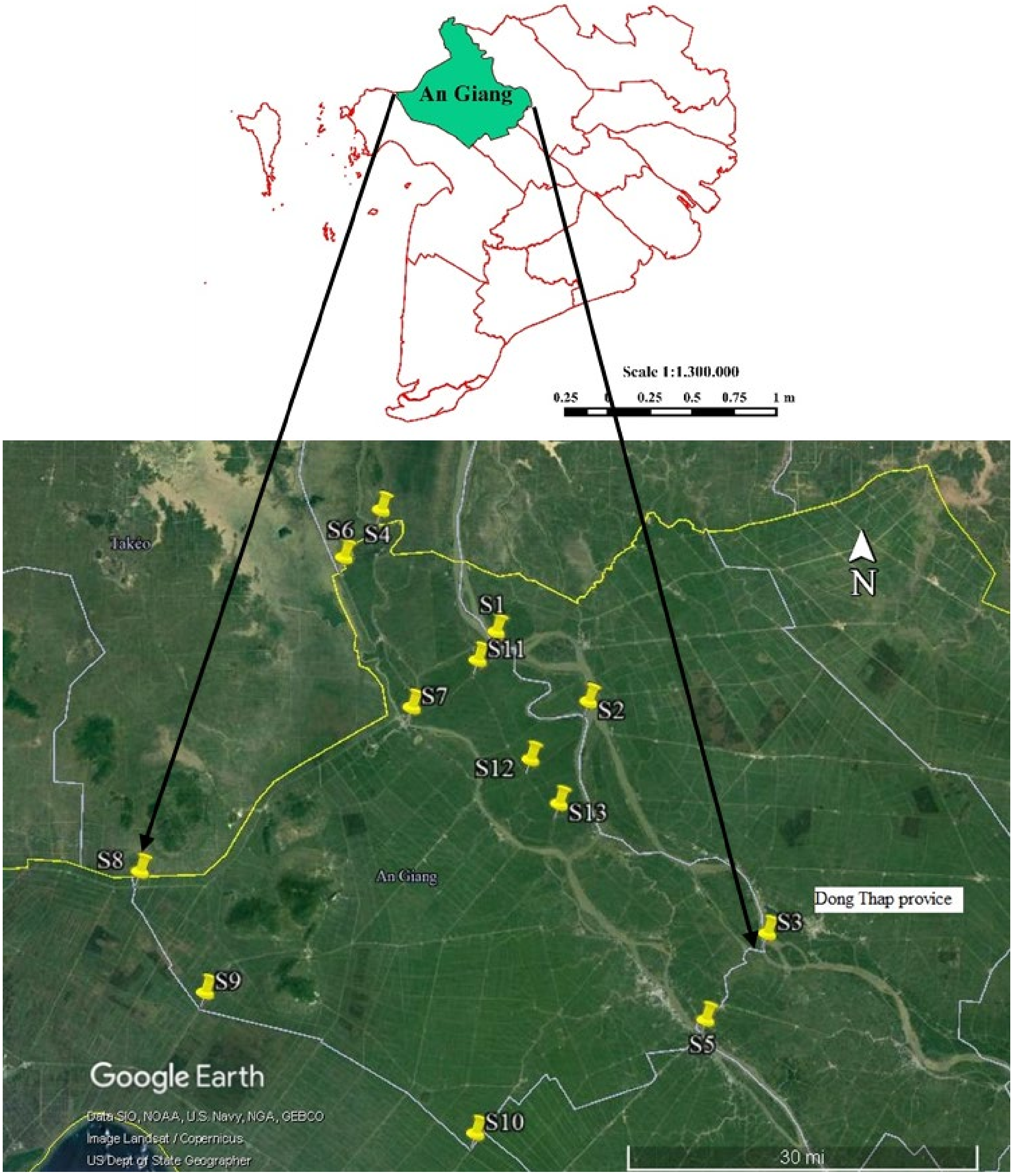

Figure 1 Sampling locations of water and zoobenthos samples (Google Earth, 2019).

3) Zoobenthos

Zoobenthos samples were collected by Petersen grab [22], whose open mouth area is 0.02 m^2. At each sampling point, collecting benthic species samples were repeated five times; after that, the separate samples at each point were mixed into the pooled samples representing the sites. The collected samples were sieved to 0.5 mm size to remove mud and debris. After that, the sieved samples were stored in nylon bags and fixed with 8% formaldehyde to maintain the good shapes and prevention of decomposition of the zoobenthic species in the samples. The collected samples were transported to the laboratory, at which the samples were further processed by eliminating all organic matters and just retained zoobenthos [16, 23]; this process was done as the further sample cleaning process for the ease of the zoobenthos analysis. The collected zoobenthos were fixed with 4% formaldehyde solution (to remain good shapes for identifying and preventing decomposition of zoobenthos species) until qualitative and quantitative analyses were performed. For qualitative analysis, zoobenthos were observed by using microscope and magnifying glass to determine the structural morphological characteristics and classification characteristics following the taxonomy textbooks of Zamora and Co, (1986), Hayward and Ryland (1990), Carpenter and Niem (1998), Dang et al. (2002), and Hung (2010) [24–28]. For quantitative analysis, the zoobenthos in each sample were counted separately for each individual and determined density by Eq. 2.

$$D = X/S \quad \text{(Eq. 2)}$$

Where D is the density calculated by individual per m^2, X is the number of counted individuals in the collected sample; S is the sampling area (S = n x d), n is the number of collected Petersen grab, d is the open mouth area of the Petersen grab.

Data on species composition and density of zoobenthos were used to calculate Shannon-Weiner diversity index (H') using Eq. 3 [29].

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

Where $p_i = n_i/N$; n_i is the numbers of ith individual; N is total amount of individuals in the samples. Water quality is divided at three levels of pollution based on H' values. H' varies from 0 to 0.9 indicates heavy pollution (Polysaprobe). H' ranges from 1 to 1.9 showed medium pollution at α level (α-mesosaprobe). Finally, 2<H'<2.9 revealed that water is medium pollution at β (β-mesosaprobe) [30].

The associated average score per taxon (ASPT) was calculated based on the scored table of BMWP^{VIETNAM} (Biological Monitoring Working Party-VIETNAM) [31] using Eq. 4 [32].

$$ASPT = \frac{\sum_{i=1}^{n} \mathrm{BMWP}}{\mathrm{N}} \quad \text{(Eq. 4)}$$

Where N is total families used for calculating tolerance scale; BMWP is BMWP^{VIETNAM}.

4) Data analysis

Cluster Analysis technique (CA) was used to group the sampling position according to the composition of zoobenthos, in which, the similar species composition would be grouped into the same group, and vice versa, then presented in the form of a dendrogram. It was implemented by PRIMER software V.5.2.9 [33].

The Pearson correlation coefficient was performed using SPSS version 20 statistical software to determine the relationship between different physical and chemical parameters and zoobenthos. A positive correlation means that the two variables increase or decrease simultaneously, while a negative correlation means that when one variable increases, the other variable decreases [34–35].

Results and discussion

1) Surface water quality in the study area

The results of surface water parameters at 13 points of water bodies in An Giang Province were presented in Figure 2. These indicators were compared with the national technical regulations on surface water quality (QCVN 08-MT: 2015/BTNMT, column A1). pH values at all surface water monitoring points were within the limits of the regulation and there were no significant differences between two monitoring periods (Figure 2a). pH is a dominant factor for the distribution of aquatic species, pH values ranging from 6 to 8 which did not affect the growth and development of the zoobenthos [36–37]; therefore, the pH value in the study ranged from 6.85 to 7.41, which was a suitable range for the growth of aquatic organisms in the study area. The results of DO concentration analyzed at study sites ranging from 3.04–6.86 mg L^{-1} in the dry season and 4.02–6.23 mg L^{-1}

in the rainy season, which were lower than the national standard (Figure 2b). Normally, DO value is suitable for aquatic life ranging from 5 to 7 mg L^{-1} [38–39]. In the dry season, the concentration of TSS (27–134 mg L^{-1}) (Figure 2c), COD (8–25 mg L^{-1}) (Figure 2e), and BOD (5–17 mg L^{-1}) (Figure 2d) were higher than the standards due to the discharges of domestic wastes and agricultural activities into the rivers and low rainfall can lead to low pollutant dilution capacity. These indicators also exceeded the regulations in the rainy season except for COD at the S6 and S7 positions because rainwater possibly helped in diluting pollutants. Besides that, the runoff caused by rainwater flowing through agriculture, industry, urban areas, markets areas could lead to water pollution when the volume of the water river is not capable of diluting the pollutants. However, TSS in this season was relatively high due to rainfall and erosion, ranged from 28 to 58 mg L^{-1}. The combination of high COD, BOD and low DO value in the water is favorable for the development of some zoobenthos species. For instance, the family *Chironomidae* (*Insecta* and *Oligochaeta*) is used as an indicator for the organic pollution in the environment from medium to severe [27, 40]. In the dry season, unlike $N\text{-}NO_3^-$ values, the concentration of $N\text{-}NH_4^+$ exceeded the regulation that could be due to the discharging wastewater from the paddy field (Figure 2h). $P\text{-}PO_4^{3-}$ in this season ranged from 0.066 to 0.331 mg L^{-1} (Figure 2g) and was 3.31 times higher than the standard (0.1 mg L^{-1}). The high concentration of $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ could potentially cause eutrophication in the surface water. In contrast, in the rainy season, concentrations of $N\text{-}NO_3^-$, $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ were in line with the permitted limits. This could be explained by higher dilution capacity in rainy season. Coliforms in the rainy season ranges from 21,000 to 93,000 MPN 100 mL^{-1} exceeded the standard (2,500 MPN 100 mL^{-1}) (Figure 2i). In the dry season, density of coliforms at S6, S7, S8, and S9 met the permitted standards. These results were consistent with an environmental status report in An Giang Province [40] and Vietnam [1] that the coliforms is one of the main concern for surface water quality.

2) Diversity of zoobenthos in water bodies

This study found 28 zoobenthos species divided into five classes including Oligochaeta, Polychaeta, Insecta, Gastropoda, and Bivalvia. In particular, the most diverse species was found in the class of Bivalvia (13 species accounting for 46.4%). In contrast, just one species of Polychaeta and Insecta was discovered accounting for 3.6% for each. The composition of zoobenthos at all sampling sites ranged from 1 to 11 species (Figure 3) over the sampling periods. Oligochaeta and Gastropoda groups were found in all study sites during 2 monitoring times. In the dry season, Tubificidae family (Oligochaeta) is the dominant zoobenthos, especially, at site S1 and S4 due to high occurrence of organic matters as discussed in the previous section. High level of organic matters in surface water generates favorable conditions for the growth of Tubificidae family (Oligochaeta) [27, 41–42]. In rainy season, the composition of zoobenthos decreased because of the change of water quality and characteristics of the bottom sediment; especially the bottom properties of the water body [43]. Prior study revealed that the species composition of zoobenthos decreased in rainy season due to the change of bottom sediment characteristics [43].

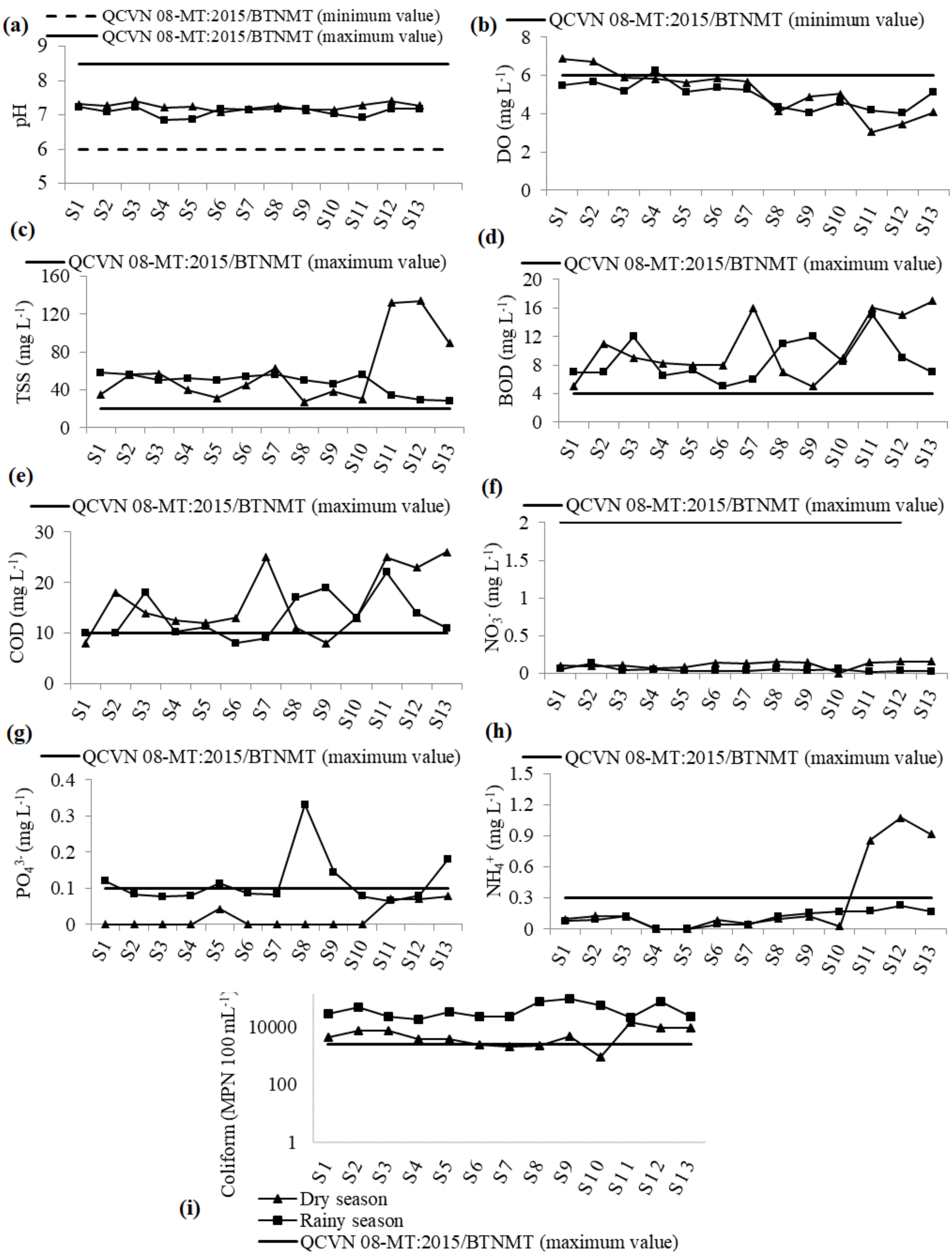

Figure 2 Water quality in the water bodies in 2018.

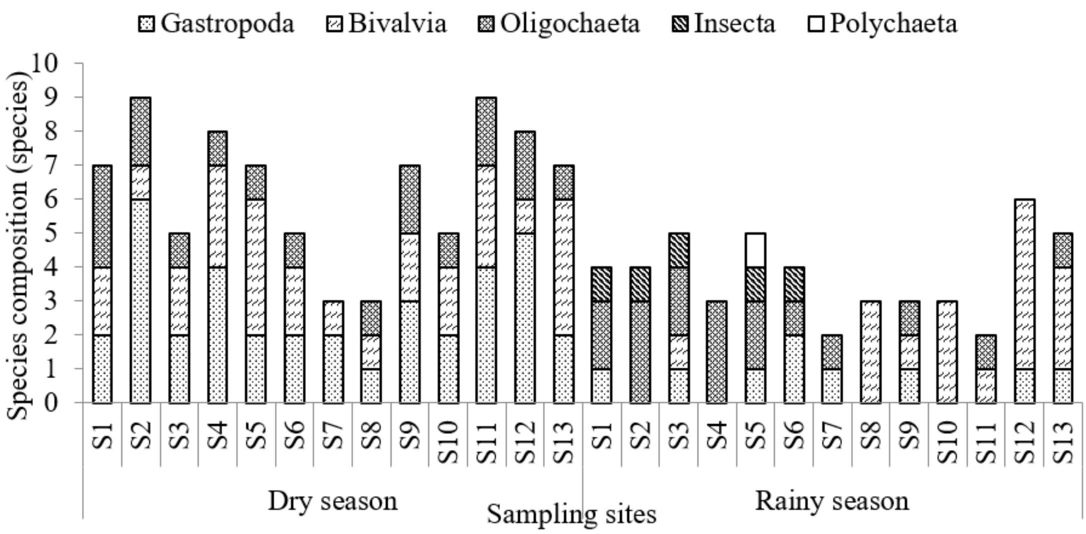

Figure 3 The composition of zoobenthos by seasonal variation in An Giang.

The density of zoobenthos greatly fluctuated among surveyed sites from 10 to 240 individuals m^{-2} (Figure 4). Especially, the number of Bivalvia, Gastropoda, and Oligochaeta classes were dominant species in the surveyed area. The highest density of zoobenthos was 240 individuals m^{-2} at S1 and S5 sites in the dry season. The difference of the density between the survey points was due to the change in the number of organisms in the Tubificidae family, which is mainly the *Branchiura sowerbyi* species (410 individuals m^{-2} in the dry season). This species could adapt to all types of bottom sediments [44]. The *Branchiura sowerbyi* species was abundant and frequently found at all survey locations, especially at site S1 and S5. The study found that the number of zoobenthos in the dry season was higher than that in the rainy season. This could be due to the change in water and sediment characteristics. In addition, the more occurrence of fish in the rainy season could result in decline of zoobenthos since zoobenthos play important role in aquatic food webs [43]. Water flows from upstream of Cambodia to An Giang Province during the rainy season and fish populations also follow water flows to more present in the downstream water bodies. Meanwhile, benthic animals are the food source of many types of fish, especially benthic fish. Therefore, this can be considered to be one of the causes of the decrease in the density of benthic animals in the water.

3) Water quality assessment

3.1) Water quality assessment using WQI

The water quality based on WQI (in the range of 0–100) is classified in five categories. First, the excellent water quality (100> WQI> 91) which is used for water supply. Second, the good water quality (90>WQI>76) which is used for domestic activities but appropriate treatment is needed. Third, the medium water quality for irrigation (75>WQI>51). Next, the bad water quality (50>WQI>26) for transport. Last, the very bad water quality (25>WQI>0) which is heavily polluted water.

In this study, WQI ranged from 3.8 to 85.6 in the dry season and from 15.5 to 70.1 in the rainy one. In the dry season, the water quality in the area was divided into four types including good (S5, S6, S8, S9, S10), medium (S7), bad (S13) and very bad (S1–S4, S11–S12). Meanwhile, in the wet season, the water quality was separated into two groups comprising medium water quality (S1–S3) and very bad (from S4 to S13). This indicated that water quality was seasonally fluctuated. In addition, surface water quality also greatly fluctuated by sampling locations due to the impact of differently locally socio-economic activities in the studied areas. Typically, the socio-economic region was divided into three main regions, such as the agricultural - forestry - aquacultural development region, the central economic development region (industry, service, and urban area) [45]. Further investigations should be conducted to identify pollution sources to propose appropriate measures for controlling discharges. Previous studies revealed that organic matters, suspended solids and fecal microbes are the main constraints for water quality in An Giang Province over long period of time [2, 46]. The occurrence of suspended solids and coliforms mainly resulted in low WQI in the study areas.

3.2) Water quality assessment using Shannon-Weiner diversity index (H')

The value of H' from 0 to 0.9 is heavy pollution or very bad water quality (Polysaprobe), from 1 to 1.9 is medium pollution at α level (α-mesosaprobe) and from 2 to 2.9 is medium pollution at β (β-mesosaprobe).

Shannon-Weiner diversity index (H') in the dry season and the rainy season varied from 1.22 to 3.0 and from 0.54 to 2.25, respectively (Figure 6). The diversity of zoobenthos in this area was relatively high and approximately 89.3 % of surveyed sites had the H' value larger than 1. H' values showed that the diversity of zoobenthos in the dry season had a tendency of being higher than that of the rainy season. This could mean that water quality at all sites was at medium pollution (from α to β- mesosaprobe) in 2018, excepted for the site S7 with the heavy pollution (Polysaprobe) in the rainy season. There is inconsistence in evaluating water quality based on WQI and H'. Using H' for water quality assessment resulted in better quality comparing to the use of WQI.

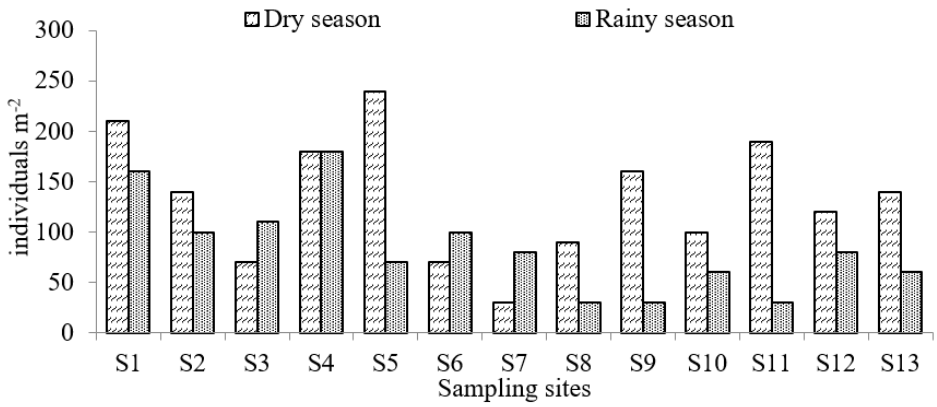

Figure 4 The density variation of zoobenthos in An Giang.

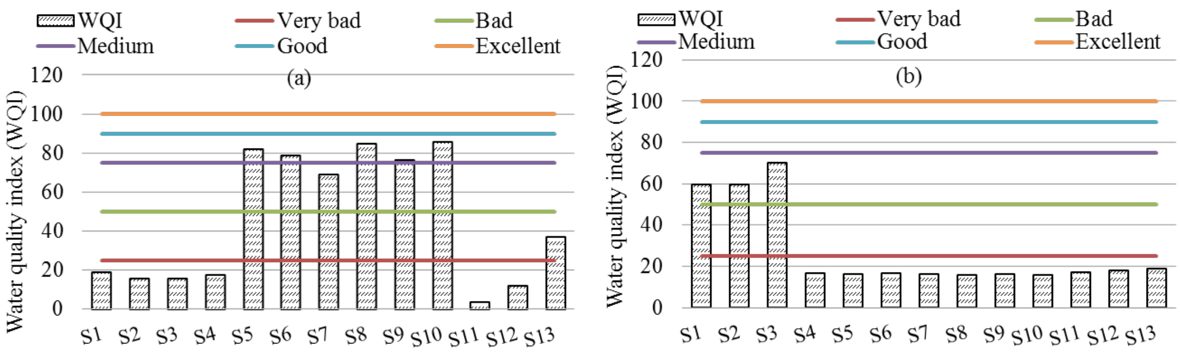

Figure 5 WQI in the dry (a) and wet (b) season.

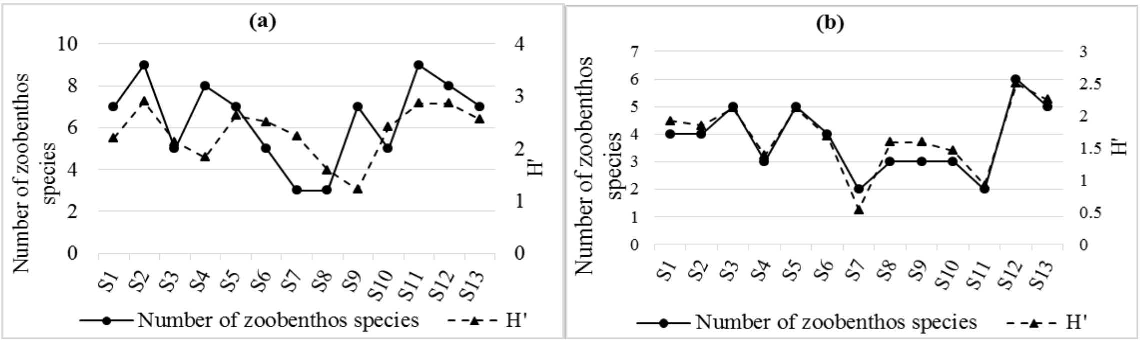

Figure 6 H' in the dry (a) and wet (b) season.

3.3) Water quality assessment using ASPT

The calculated values of ASPT based on the BMWP^{VIET} for the two seasons at 13 surveyed sites were presented in Table 2. The values of ASPT in the dry season ranged from 2.5 to 9.0 (mean 4.8±1.1, CV 23.4%) and in the rainy season from 3.0 to 6.6 (mean 3.9±2.1, CV 53.3%). All the ASPT scores in the dry season were lower that those in the rainy season (except S8 and S12, good to excellent water quality, oligosaprobe) indicating water quality in the dry season was better than in the rainy season. Water quality in the two season is classified from very bad (polysaprobe) to medium pollution at α level (α-mesosaprobe) according to Richard et al. (1997) [32].

Certain inconsistency on the level of water pollution of using WQI, H' and ASPT in water quality assessment was identified in this study. Specifically, in the dry season, the water quality index at locations S1 – S4 and S10 – S13 was assessed to be very polluted; however, according to the H' and ASPT values, the water quality at these locations was evaluated at the average pollution level (from α to β- mesosaprobe). This was similarly recorded during the rainy season at S5, S12, and S13. The difference among the three indexes could be from the methods being used. For WQI the parameters TSS, BOD, COD, and coliforms would probably decide the results of WQI index. The H' is calculated mainly based on the diversity of species, but not species abundance [47–48]. The obtained ASPT values mainly based on scoring the family of zoobenthos. Using the families of zoobenthos for grading the water quality may not be accurate since various species in the same family may have different capability of pollution tolerance. This may lead to misjudgment of water quality [49]. This is the very important point to consider when using only zoobenthos for assessing water quality.

4) Spatial variation of zoobenthos

Cluster analysis indicated that zoobenthos could be divided into three clusters for the dry season (Figure 7a) and six clusters for the rainy season (Figure 7b) at a similarity of 40% level. In the dry season, the three clusters namely Cluster 1 (S7), Cluster 2 (S8) and Cluster 3 (S1–S6 and S8–S13). Site S7 in Cluster 1 had the lowest density of zoobenthos. The higher density of zoobenthos was classified in Cluster 2 and Cluster 3. The abundant presence of the Bivalvia family would probably determine the formation of the clusters in the dry season since these survey sites were similar in species composition and density. Meanwhile, six clusters of zoobenthos were formed in the rainy season. Cluster 1 (S11, S13), Cluster 2 (S8, S10, S12), Cluster 3 (S9), Cluster 4 (S9), Cluster 5 (S1, S2, S3, S5) and Cluster 6 (S4, S6, S7) were arranged according to increase the density of some specific zoobenthos, for example. Cluster 6 was abundant by Oligochaeta class. The cluster analysis clearly confirmed the seasonal change of zoobenthos composition resulting from the changes of water quality and bottom sediment characteristics.

Table 2 ASPT based on the BMWP^{VIET} for the two seasons

Sites	Rainy season			Dry season		
	Total family	BMWP	ASPT	Total family	BMWP	ASPT
S1	6	23	3.8	3	8	2.7
S2	6	36	6.0	3	8	2.7
S3	5	16	3.2	5	16	3.2
S4	6	30	5.0	1	3	3.0
S5	5	27	5.4	4	12	3.0
S6	5	18	3.6	4	11	2.8
S7	3	14	4.7	2	5	2.5
S8	3	9	3.0	1	9	9.0
S9	5	27	5.4	3	10	3.3
S10	3	17	5.7	2	10	5.0
S11	7	32	4.6	2	5	2.5
S12	5	33	6.6	3	21	7.0
S13	5	28	5.6	4	15	3.8

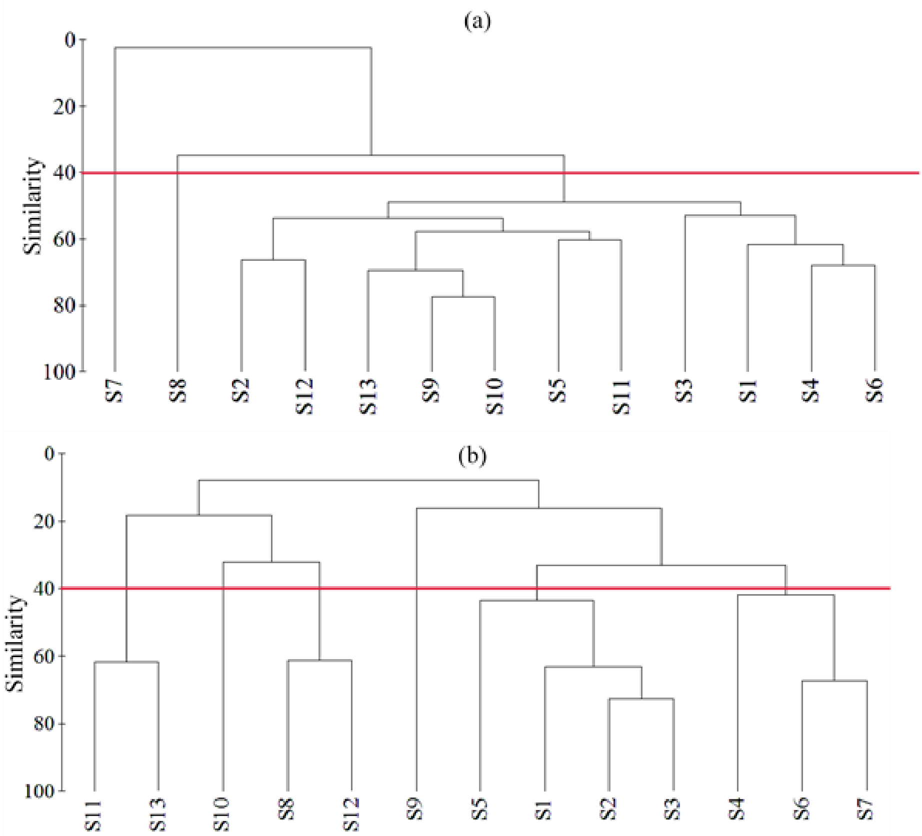

Figure 7 The similarity of zoobenthos in the dry (a) and wet (b) season.

5) Relationship of zoobenthos species and water quality parameters

The correlation matrix of water quality parameters collected from 13 locations and density of zoobenthos was shown in Table 3. If the correlation value is greater than 0.05, correlation between the two variables is significant at 5% ($p<0.05$). A positive correlation means that the two variables increase or decrease simultaneously, while a negative correlation means that when one variable increases, the other variable decreases [34].

Table 3 Correlation matrix between water quality and zoobenthos

	Temp	**pH**	**DO**	**TSS**	**COD**	**BOD**	**$N\text{-}NO_3^-$**	**$P\text{-}PO_4^{3-}$**	**$N\text{-}NH_4^+$**	**Coliform**	**Zoobenthos**
Temp	1										
pH	-0.272	1.00									
DO	0.341	-0.081	1.00								
TSS	-0.497	0.343	-0.449	1.00							
COD	-0.494	0.226	-0.518	0.609	1.00						
BOD	-0.494	0.211	-0.533	0.599	0.996	1.00					
$N\text{-}NO_3^-$	-0.430	0.443	-0.103	0.499	0.304	0.275	1.00				
$P\text{-}PO_4^{3-}$	-0.376	0.326	-0.140	-0.116	0.077	0.061	0.548	1.00			
$N\text{-}NH_4^+$	-0.635	0.427	-0.650	0.846	0.673	0.669	0.512	0.195	1.00		
Coliform	0.375	-0.245	-0.353	-0.101	0.010	0.011	-0.399	-0.516	-0.075	1.00	
Density of zoobenthos	-0.394	0.273	0.279	0.160	-0.209	-0.209	0.27	0.197	0.140	-0.479	1.00
Composition of zoobenthos	-0.544	0.528	0.020	0.387	0.200	0.173	0.417	0.279	0.476	-0.388	0.655

The analysis results showed that temperature was negative correlation with the most physico-chemical parameters, such as TSS (r=0.497, p=0.01), BOD (r=0.494, p=0.01), COD (r=0.494, p=0.01), $N\text{-}NH_4^+$ (r=0.635, p=0.00). This suggested that water temperature was an important factor influencing the change of both physico-chemical parameters. The pH value in the study was positive correlation with $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$. The negative correlation of DO content with TSS, BOD, COD, $N\text{-}NH_4^+$ indicated that the pollution tended to decrease in the study area. The high levels of TSS can reduce dissolved oxygen levels in the surface water that have been reported in many previous studies [49–50]. Moreover, the oxidation of organic substances by microorganisms, the oxidation of chemical compounds (both inorganic and organic) and nitrification required a certain amount of dissolved oxygen; therefore, when these processes take place in the water body, the DO will decrease while the remaining factors increase. In addition, the negative correlation of DO with nutrients showed that nutrients play a major role in influencing concentration of dissolved oxygen in the study area. In contrast to DO, the concentration of TSS was negatively correlated with BOD, COD, $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$. BOD and COD were strongly correlated [46], which was positively correlated with the content of $N\text{-}NH_4^+$. $N\text{-}NO_3^-$ values in the study were positively correlated with $P\text{-}PO4_3^-$ and $N\text{-}NH_4^+$, while $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$ were negatively correlated with coliforms in the study area. The density of coliform was negative correlation with the density of zoobenthos. In general, the most water quality parameters were strongly correlated. The density of zoobenthos was partially affected by water quality parameters, which only had a weak correlation with the temperature (r=0.394, p=0.046) and coliform (r=0.479, p=0.013). Correlation of coliform and zoobenthos was also noted in previous study by Kokmen et al. (2007) [51]. However, temperature, pH, $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ were closely related and significantly correlated with the composition of zoobenthos [52]. Different organisms have their own optimal the temperature, so temperature was also a factor affecting the number of species present in the water body [53]. Besides, according to the study by Lien et al. (2016) [43], Luu et al. (2017) [54], Ian & David (2009) [55] also reported when the concentrations of organic substances and other nutrients were high, it is favorable for the development of zoobenthos in both species composition and density, this has also been reported in the present study. Nevertheless, the concentration of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$ increased generally causes dissolved oxygen depletion due to aquatic organisms competes for oxygen consumption in their ecological niche, and dissolved oxygen concentrations also limit the available species of zoobenthos [51].

Conclusion

The surface water quality on water bodies in An Giang in 2018 was polluted by suspended solids (27–134 mg L^{-1}), organic matters (the content of BOD and COD varied from 5–17 mg L^{-1} and 8–26 mg L^{-1}, respectively) and coliform (21,000-93,000 MPN 100 mL^{-1}). The WQI values indicated surface water quality from very bad to good and from very bad to medium in the dry and wet season, respectively. Shannon-Weiner diversity index (H') ranged from 1.22 to 3.0 in the dry season and from 0.54 to 2.25 in the rainy season, which showed water quality from bad to medium and very bad to medium in the dry and wet season, respectively. ASPT revealed that water quality from bad to excellent and bad to good, respectively. The results showed that water quality in water bodies in An Giang was polluted and seasonally fluctuated. There was inconsistency in using WQI, H' and ASPT for water quality assessment. Cluster analysis indicated that zoobenthos could be divided into three clusters for the dry season and six clusters for the rainy season indicating seasonal variation of zoobenthos composition resulting from changes of water quality and bottom sediment characteristics. Pearson's analysis showed that the composition of zoobenthos was correlated with the temperature, pH, $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$, while the density of zoobenthos was inversely correlated with temperature and coliform. Further study should investigate main factors resulting in zoobenthos changes to better explain its relationship with sediment and water quality.

Conflict of Interest: The authors declare that they have no conflict of interest

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