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Aquaculture Wastewater Quality Improvement by Floating Raft of Native Aquatic Plants in An Giang Province, Vietnam

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ABSTRACT

The development of aquaculture in An Giang province posed a risk of lowering the surface water quality of the Mekong River. This study assessed the pollution level of surface water affected by aquaculture areas in the province and the efficiency of the floating raft of native aquatic plants on aquaculture wastewater quality improvement. Water samples were analyzed for SS, COD, BOD_5, N-NH_4^+, Total N, and Total P. The Water Quality Index was calculated according to the Vietnamese technical guidelines (VN_WQI). The quadrat method was applied to determine the density of aquatic plants. The result showed that surface water quality affected by aquaculture areas in An Giang province did not meet national standards, and the WQI ranged from heavy to good pollution. Experimental results showed that when using the treatment tank, including floating rafts of Water hyacinth (*Eichhornia crassipes*), Morning glory plants (*Ipomoea aquatica*), and Climbing dayflower (*Commelina diffusa*), the removal percentages of SS, COD, BOD_5, N-NH_4^+, Total N, and Total P were 92.6%, 89.6%, 93.9%, 93.4%, 64.3%, and 94.6%, respectively, in the first three months of the farming season. The removal percentages of SS, COD, BOD_5, N-NH_4^+, Total N, and Total P were 92.7%, 89.9%, 91.5%, 93.6%, 67.8%, and 94%, respectively, in the fourth month until fish harvest in the treatment tank. Therefore, floating rafts of native aquatic plants could absorb nutrients and

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quickly remove pollutants. The quality of aquaculture wastewater after treatment was significantly improved.

Keywords: Aquaculture wastewater, *Commelina diffusa*, *Eichhornia crassipes*, floating raft, *Ipomoea aquatica*, wastewater treatment, water quality

INTRODUCTION

An Giang is a province in the Mekong Delta located in southwest Vietnam. The dense system of rivers, canals, and channels and abundant surface water all year round brings many advantages in varieties and food for aquaculture (An Giang Center for Environmental Monitoring and Techniques, Resources, 2019). The province's aquaculture has experienced remarkable growth in quantity and quality, making a significant contribution to the socio-economic development of the province. However, the strong development of aquaculture caused many increasing environmental impacts on a large and alarming scale, especially the impacts on water bodies receiving aquaculture wastewater. Currently, most aquaculture wastewater from farming fish farms in An Giang province is discharged directly into the natural environment without treatment. Only a few farming areas of enterprises have the investment in wastewater treatment systems (accounting for approximately 10% of farming areas) (Shipin et al., 2005; Khanh et al., 2013; Khanh et al., 2015; An Giang Department of Natural Resources and Environment, 2020). It is necessary to assess the pollution level of aquaculture wastewater in the province and provide solutions.

The Vietnam Water Quality Index (VN_WQI) is suggested by Vietnam Environment Administration and is commonly used in Vietnam. There is much research using VN_WQI. Giao et al. (2021) conducted a study to evaluate and classify surface water quality in Dong Thap, Vietnam, using set pair analysis (SPA) and the VN_WQI method. The findings present that water quality in Dong Thap was ranked at level III (medium) based on the SPA; this water quality rank was at level IV (poor) using the VN_WQI, which was suitable for irrigation and other equivalent purposes. Ha et al. (2021) studied integrating the remote sensing technology with in-situ ground observation to assess the water quality status in Ca Mau city through VN_WQI. The results also illustrated the low quality of surface water and heavy pollution. Lan and Long (2011) assessed surface water quality by VN_WQI at the Cai Sao canal, An Giang. The water quality index (VN_WQI) was in the range of 39-29, indicating mild pollution at the two sites close to the joining of the canal with the river, increasing severe pollution along the rest of the canal. The equations used to calculate the VN_WQI are easy to use; thus, it is a valuable tool for observing the water environment and monitoring pollution.

Many studies show that using plants to treat wastewater is an effective method. The study of Minh et al. (2012) evaluated the ability of Water hyacinth and Vetiver to treat dissolved organic nitrogen (N) and phosphorus (P) pollution in ponds used for intensive catfish cultivation in the Mekong River Delta. They found that after one month, Water hyacinth could reduce 88% organic N and 100% organic P compared to their initial concentrations. Similarly, the concentrations of organic N and P reduced by 85% and 99%, respectively, when Vetiver was grown in the culture. Nhien and Trang (2013) researched the role of *Typha orientalis* L. in constructed wetlands to treat close-recirculated intensive catfish culture. The result showed that *T. orientalis* helped remove about 17% N and 34% P from wastewater via vegetative uptake. Kieu et al. (2015) studied the evolution of nitrogen forms in wastewater of intensive catfish pond growing Hymenachne grass (*Hymenachne acutigluma*). The result showed that *Hymenachne* grass reduced NH_4^+-N, NO_2^--N, NO_3^--N, and TKN in wastewater at 69.7–96.9; 96.6–97.3; 99.3–99.9; 48.5–73.5%, respectively. In addition, *Hymenachne* grass reduced TP and PO_4^{3-}-P with respective deduction percentages of 84.8–95.6 and 85.7–92.5% compared to the initial phosphorus level. In the study of Snow and Ghaly (2008), Water hyacinth, Water lettuce, and Parrot's feather plants were examined for their ability to remove nutrients from aquaculture wastewater at two retention times. The TSS, COD, NH_4^+-N, NO_2^--N, NO_3^--N, and PO_4^{3-}-P reductions ranged from 21.4 to 48.0%, from 71.1 to 89.5%, from 55.9 to 76.0%, from 49.6 to 90.6%, from 34.5 to 54.4% and from 64.5 to 76.8%, respectively. Li and Li (2009) investigated nutrient removal and water quality by planting aquatic vegetables on artificial beds in 36 m^2 concrete fishponds. After treatment of 120 days, 30.6% of TN and 18.2% of TP were removed from the total input nutrients by 6 m^2 aquatic vegetable *Ipomoea aquatica*.

The TN, TP, COD, and Chlorophyll concentrations in planted ponds were significantly lower than those in non-planted ponds. No significant differences in the concentration of (TAN), NO_2^--N, and NO_3^--N were found between planted and non-planted ponds. Zhang et al. (2014) used a water spinach floating bed to improve the aquaculture wastewater quality. The results showed significant improvement in the aquaculture water quality at the experimental site, with removal percentages of TN, NH_4^+-N, NO_2^--N, and TP being 11.2%, 60.0%, 60.2%, and 27.3%, respectively. De Vasconcelos et al. (2021) evaluated the efficiency of using the floating aquatic macrophytes *Eichhornia crassipes, Pistia stratiotes*, and *Salvinia molesta* for the treatment of aquaculture effluents. They found that with floating aquatic macrophytes, the concentrations of all evaluated limnology parameters included TN, NO_2^--N, NO_3^--N, NH_4^+-N, TP, turbidity, dissolved oxygen, electrical conductivity, total alkalinity, BOD, and COD, improved significantly. There was also an improvement in the physical aspect of the effluent (transparency and turbidity).

This study assessed the pollution level of aquaculture wastewater in An Giang province and the efficiency of using native aquatic species, including Water hyacinth (*Eichhornia crassipes*), Morning glory plants (*Ipomoea aquatica*), and Climbing dayflower (*Commelina diffusa*) on aquaculture wastewater improvement. The role of the combination of these three native aquatic plants in the treatment of aquaculture wastewater has been investigated for the first time by the model of a floating raft through an experimental method. The study has proposed a biological solution using aquatic plants to remove pollutants in aquaculture wastewater in An Giang province.

MATERIALS AND METHODS

Location of Water Sampling

Surface water samples were collected at 18 sampling locations affected by aquaculture areas. The sample collection schedule was in March and June 2021. Figure 1 shows the location map of surface water sampling. Table 1 shows the code, coordinates, and characteristics of sampling locations.

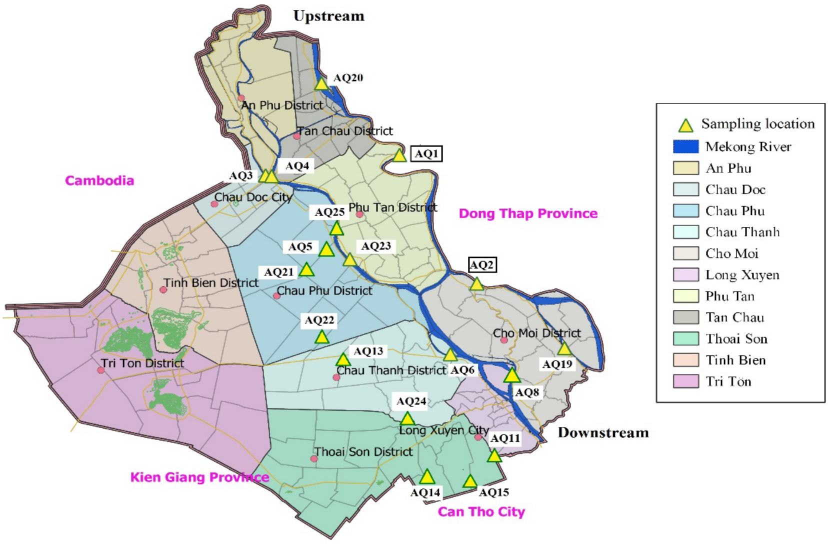

Figure 1. The location map of surface water sampling

Table 1

Location of surface water sampling

No.	Code	Coordinate	Location	Feature
1	AQ1	559.880 1.188.560	Long Hoa commune, Phu Tan district	The end of wastewater source of the Long Hoa raft floating fish farming
2	AQ2	570.753 1.168.426	Kien An commune, Cho Moi district	The end of wastewater source of pen culture and pond fish farming area in Kien An

Table 1 *(Continue)*

No.	Code	Coordinate	Location	Feature
3	AQ3	540.104 1.184.937	Chau Phu A ward, Chau Doc city	The end of wastewater source of the Vinh Nguon raft floating fish farming
4	AQ4	540.708 1.184.988	Da Phuoc commune, An Phu district	The end of wastewater source of the Da Phuoc raft floating fish farming
5	AQ5	548.722 1.172.710	Vinh Thanh Trung commune, Chau Phu district	Impact of wastewater from fish farming ponds on Xang Vinh Tre canal
6	AQ6	567.496 1.156.042	Binh Thanh commune, Chau Thanh district	The end of wastewater source of pond fish farming area in Binh Thanh
7	AQ8	576.289 1.151.944	My Hoa Hung commune, Long Xuyen city	The end of wastewater source of pen culture and pond fish farming area in My Hoa Hung
8	AQ11	574.103 1.139.929	My Thoi ward, Long Xuyen city	Impact of wastewater from fish farming ponds
9	AQ13	552.267 1.153.651	Vinh Thanh commune, Chau Thanh district	Impact of wastewater from a rice-shrimp farming area
10	AQ14	572.673 1.139.250	Phu Thuan commune, Thoai Son district	The beginning of the Don Dong canal, adjacent to the Moi canal
11	AQ15	565.734 1.136.318	Vinh Khanh commune, Thoai Son district	The beginning of the Don Dong channel, adjacent to the Ong Co canal
12	AQ19	584.521 1.157.065	My An commune, Cho Moi district	Impact of wastewater from a raft floating fish farming
13	AQ20	548.134 1.201.285	Vinh Hoa commune, Tan Chau town	Impact of wastewater from pond fish farming area
14	AQ21	546.162 1.169.627	Phu My commune, Chau Phu district	Impact of wastewater from Loc Kim Chi fish farming area, the confluence between Hao De Lon canal and Xang Vinh Tre canal
15	AQ22	548.706 1.158.636	Binh Phu commune, Chau Phu district	Impact from wastewater from Nam Viet Binh Phu fish farming area, the confluence between 13 canals and Xang Cay Duong canal

Table 1 *(Continue)*

No.	Code	Coordinate	Location	Feature
16	AQ23	552.578 1.171.504	Phu Binh commune, Phu Tan district	Impact of wastewater from Pangasius farming area in Phu Binh commune
17	AQ24	561.948 1.145.178	Vinh Trach commune, Thoai Son district	Impacts from aquatic discharge source
18	AQ25	550.885 1.177.362	Hoa Lac commune, Phu Tan district	Impact of wastewater from pond fish farming area of Hoa Lac

Methods of Sampling, Preserving, and Analyzing Water Samples

The parameters for the assessment of 18 water samples included: Temperature, pH, Dissolved Oxygen (DO), Chemical oxygen demand (COD), Biological oxygen demand (BOD_5), Total Suspended Solids (TSS), Ammonium ($N\text{-}NH_4^+$), Nitrate ($N\text{-}NO_3^-$), Phosphate ($P\text{-}PO_4^{3-}$), Total Nitrogen (TN), Total Phosphorus (TP) and Coliform.

The order and methods of environmental monitoring were implemented in accordance with Circular 24/2017/TT-BTNMT on promulgating technical regulations on environmental monitoring and Vietnamese standards and regulations (Vietnam Ministry of Natural Resources and Environment, 2017). Surface water and wastewater were sampled and preserved according to the methods in TCVN 6663-1:2011 and TCVN 6663:3:2016 (Vietnam Ministry of Science and Technology, 2011; Vietnam Ministry of Science and Technology, 2016).

Methods of analyzing samples were in accordance with Standard Methods (Lipps et al., 2018a, 2018b, 2018c, 2018d, 2018e, 2018f) and Vietnam National standard on water quality (Vietnam Ministry of Science and Technology, 1995, 1996, 2000, 2011, 2016) (Tables 2 and 3). Measuring probe used to measure temperature, DO, and pH was PCD 650/pH 600 Eutech.

Table 2
Method of analyzing/measuring water samples

No.	Parameter	Method of analyzing / measuring
1	Chemical oxygen demand (COD)	SMEWW 5220C:2017
2	Biological oxygen demand (BOD_5)	SMEWW 5210B:2017
3	Total Suspended Solids (TSS)	SMEWW 2540D:2017
4	Ammonium ($N\text{-}NH_4^+$)	TCVN 5988:1995
5	Total Nitrogen (TN)	TCVN 6638:2000
6	Total Phosphorus (TP)	SMEWW 4500.P.B&E:2017

Table 2 *(Continue)*

No.	Parameter	Method of analyzing / measuring
7	Nitrate ($N\text{-}NO_3^-$)	SMEWW 4500-NO_3^--E:2017
8	Phosphate ($P\text{-}PO_4^{3-}$),	SMEWW 4500-P.E:2017
9	Coliform	TCVN 6187-2:1996

Water Quality Assessment

The analytical results of water samples were compared with surface water quality parameters according to QCVN:08-MT:2015/BTNMT-National technical regulation on the surface water quality of Vietnam (Vietnam Ministry of Natural Resources and Environment, 2015).

The Water Quality Index (WQI) was calculated based on Decision 1460/QD-TCMT on promulgating technical guidelines for calculation and the Vietnam water quality index (VN_WQI) (Vietnam Environment Administration, 2019). This study's parameters used to calculate WQI include temperature, pH, DO, BOD_5, COD, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, and Coliform.

The calculation equations are as follows:

For parameters of BOD_5, COD, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Coliform, and WQI are calculated according to the following Equation 1:

$$WQI_{SI} = \frac{q_i - q_{i+1}}{BP_{i+1} - BP_i}(BP_{i+1} - C_p) + q_{i+1} \qquad [1]$$

In particular:

WQI_{SI} (SI: sub-index): is the water quality index calculated for each parameter

BP_i: lower limit concentration of monitoring parameters corresponding to level i

BP_{i+1}: upper limit concentration of monitoring parameters corresponding to level i+1

q_i: WQI at level i given corresponds to BP_i

q_{i+1}: WQI at level i+1 corresponds to BP_{i+1}

C_p: Monitoring parameters are taken into account

Calculating WQI_{DO} using Equation 2:

$$WQI_{SI} = \frac{q_{i+1} - q_i}{BP_{i+1} - BP_i}(C_p - BP_i) + q_i \qquad [2]$$

In particular:

WQI_{SI} (SI: sub-index): is the water quality index calculated for each parameter

C_p: Saturated DO%

BP_i. BP_{i+1}. q_i. q_{i+1} are the values corresponding to the level i, i+1

Calculating WQI_{pH}:

If $pH < 5.5$ or $pH > 9$, $WQI_{pH} = 10$.

If $5.5 < pH < 6$, using Equation 2 to calculate WQI_{pH}

If $6 \leq pH \leq 8.5$, $WQI_{pH} = 100$

If $8.5 < pH < 9$, using Equation 1 to calculate WQI_{pH}

After calculating WQI for each of the above parameters, the WQI calculation is applied according to the following Equation 3:

$$WQI = \frac{WQI_{pH}}{100}\left[\frac{1}{6}\left(\sum_{i=1}^{6} WQI_a\right)^2 x\ WQI_b\right]^{\frac{1}{3}} \quad [3]$$

where WQI_a: The value of WQI has been calculated for six parameters: DO, BOD_5, COD, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$; WQI_b: WQI value calculated for Total Coliform; WQI_{pH}: WQI has calculated for pH coefficient.

Table 3 displays the water quality rating based on Water Quality Index ranges and recommendations for surface water usage.

Table 3

Water quality rating and recommendation of usage

Water quality Index Range	Water Quality Rating	Color	Intended use
91-100	Excellent		Good for water supply
76-90	Good		For water supply but requires appropriate treatment measures
51-75	Medium		For irrigation and other similar purposes
26-50	Poor		For water transport and other similar purposes
10-25	Polluted		Water is heavily polluted and requires future treatment
<10	Serious polluted		Water is poisoned and requires treatment

Note. From "Decision 1460/QD-TCMT on promulgating technical guidelines for calculation and Vietnam water quality index (VN_WQI)" by Vietnam Environment Administration, 2019

Assessment of Wastewater Quality of Pangasius Catfish Ponds

Two fish farms raising pangasius catfish were selected in Chau Phu district, An Giang province. Aquaculture wastewater was sampled in the pangasius catfish ponds of these two fish farms and analyzed parameters of SS, COD, BOD_5, $N\text{-}NH_4^+$, Total N, and Total P.

There are two growth stages of the pangasius catfish. In the first three months of the farming season, food must be ensured to have a protein content of 25–28%. In the fourth month until harvest, the protein content of the feed is reduced to 18–22%. Therefore, the study collected wastewater samples in two stages in two fish farms:

Stage 1: Wastewater was sampled in pangasius catfish ponds of Fish Farm 1 in the first three months of the farming season. Fish Farm 1 has a pond water surface area of 12,500 m^2 2 m deep water level. Farmers used homemade food combined with industrial feed with a 25–28% protein content. Wastewater was changed periodically every three days and discharged 10% of the water in the pond with a flow of 2,500 m^3/day and night.

Stage 2: Wastewater was sampled in pangasius catfish ponds of Fish Farm 2 in the fourth month until the harvest: Fish Farm 2 has a pond water surface area of 8,000 m^2, 2 m deep of water level. Farmers fully used industrial pellets with a protein content of 18–22%. Wastewater was changed every three days and discharged 30% of the water in the pond with a flow of 4,800 m^3/day and night.

Selection of Native Aquatic Plants

In the areas affected by wastewater from two selected fish farms in Chau Phu district, a survey was conducted to identify native aquatic plant species and determine the density of aquatic plants. Identification of plant species was based on An Illustrated Flora of Vietnam parts I, II, II (Ho, 1999a, 1999b, 1999c) and Common weeds in Vietnam (Koo et al., 2000). Floating aquatic plants were collected from the wastewater discharge area of the fishponds. The Quadrat method (Dan et al., 2012; Rastogi, 1999) was applied to determine the density of aquatic plants in the study site. The area of each quadrat was 1 m^2 (1 m x 1m). Five transects were laid in the study site. In each transect, four quadrats were laid from the riverbank to determine the frequency of species occurrence (%). All aquatic plants presented in the quadrant were recorded. The frequency of occurrence and density was defined by Equations 4 and 5.

Frequency of occurrence (%):

$$\mathrm{F}_i = \frac{\mathrm{a}}{\mathrm{b}} \times 100 \quad [4]$$

Where: F_i: Frequency of occurrence of species i (%); a: Number quadrats with the species i; b: Total number of quadrats studied

Density (plants/m^2):

$$D_i = \frac{n_i}{N} \quad [5]$$

Where: D_i: Density of species i; n_i: Total number of plants of species i; N: Total number of quadrats studied

Design of Experiment

The study was carried out at two selected fish farms in Chau Phu district, An Giang province. The experiment had three main parts: wastewater tank, wastewater, and floating aquatic plants. The wastewater tank was surrounded by bamboo poles and had a waterproof rubber lining with dimensions of 1.5 m x 1.5 m x 1 m. The depth of water level for planting plants was 0.8 m. So, the total water storage volume is 1.8 m^3 (1.5 m x 1.5 m x 0.8 m). Floating aquatic plants were collected at the wastewater discharge area according to the survey density. Water hyacinth plants in the experiment had a length of 20 cm and 4–5 leaves. Their roots were cut, and their damaged stems and leaves were removed. Water hyacinth plants were put in clean water for seven days before the experiment (Loc, 2015).

Morning glory plants and climbing dayflowers in the experiment were young, immature, healthy, and uniform in color with a height of 20 cm and were washed with distilled water before the experiment (Khoi et al., 2012). The frame of the aquatic floating raft was made of D90mm PVC pipe, the length and width of the raft were 1 m x 1 m, and the net supporting the aquatic plants in groups was a polyethylene net with meshes of 2 cm. Wastewater was collected at the wastewater discharge pipe of two fishponds in the selected fish farms above for each stage. Aquatic plants were arranged in floating rafts with a distance between plants of 30 cm and a distance between rows of 30 cm across the wastewater tank. According to the test in practice, this distance was the appropriate distance for arrangement and suitable for the size of the plants. In each floating raft, there were three types of plants, including nine groups of plants with 2–3 types of plants per group. The density of plants was arranged in the rafts according to the actual density investigated in the survey area. Then the rafts were fixed with ropes in the wastewater tank.

Figure 2 displays the wastewater tank and floating raft, and Figure 3 displays the design of the experiment.

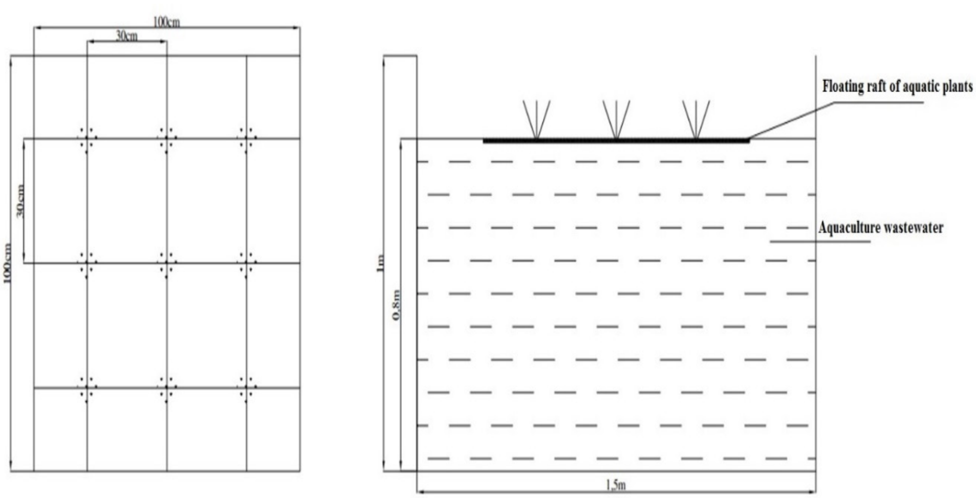

Figure 2. The wastewater tank and the floating raft of aquatic plants

The experiment was arranged in batch form, loaded with water once, with the following treatments:

Treatment 1 (T1): Wastewater in the first three months of the farming season + aquatic flora with actual density investigated in the natural area

Treatment 2 (T2): Wastewater in the first three months of the farming season (control)

Treatment 3 (T3): Wastewater in the fourth month until harvest + aquatic flora with actual density investigated in the natural area

Treatment 4 (T4): Wastewater in the fourth month until harvest (control)

Each treatment was repeated thrice with a maximum retention time of 28 days. Wastewater was sampled after seven days, 14 days, 21 days, and 28 days with one sample per treatment in the morning. Water quality was evaluated through parameters such as SS, COD, BOD_5, N-NH_4^+, Total N, and Total P. The analytical results of water samples were compared with surface water quality parameters according to QCVN 40:2011/BTNMT–National Technical Regulations on industrial wastewater, column A (Vietnam Ministry of Natural Resources and Environment, 2011). The plant growth ability in the wastewater treatment tank was evaluated by counting the number of branches of each plant at each experimental stage and measuring the length of the plant's stem before and after the experiment of 28 days.

Wastewater samples were collected with a volume of 2 L in the middle of the tank with a depth of about 20 cm according to Vietnamese standards—TCVN 6663-1:2011. Wastewater samples after collection were analyzed immediately for physico-chemical criteria or acidified and refrigerated at 4°C if not analyzed immediately, according to Vietnamese standards—TCVN 6663:3:2016.

Wastewater tank | Floating raft with aquatic plants

Figure 3. Design of experiment

Microsoft Excel 2010 was used to synthesize data, and Statgraphics software to analyze and process data on treatment efficiency as well as statistics on the difference in treatment efficiency at different pollutant loads and hydraulic retention time. In this study, the removal percentages (%) of SS, COD, BOD_5, $N\text{-}NH_4^+$, Total N, and Total P were calculated by the following Equation 6 (de Vasconcelos et al., 2021):

$$\%R = 100 - \left(100\ x\ \frac{CE_t}{CE_b}\right) \qquad [6]$$

Where: %R is the removal percentage, CE_t is the nutrient concentration in the treated effluent, and CE_b is the nutrient concentration in the raw effluent.

RESULTS AND DISCUSSION

Surface Water Quality Assessment of Areas Affected by Aquaculture Wastewater in An Giang Province

The results of surface water monitoring affected by aquaculture areas in An Giang province in the first six months of 2021 (Tables 4 and 5) showed that 7/10 parameters at sampling locations, including DO, TSS, COD, BOD_5, $P\text{-}PO_4^{3-}$, $N\text{-}NH_4^+$ and Coliform that exceeded allowable limits in the National technical regulation on surface water quality of Vietnam—QCVN 08-MT:2015/BTNMT (column A1); pH and $N\text{-}NO_3^-$ were within the allowable limits. DO of surface water at the aquaculture areas ranged from 2.12–5.26 mg/L, which was 1.14–2.83 times lower than the allowable limits in National technical regulations at 18/18 sampling locations. TSS of surface water at the aquaculture areas ranged from 45–112 mg/L, which was 2.25–5.60 times higher than the allowable limits in National technical regulations at 18/18 sampling locations.

COD of surface water at the aquaculture areas ranged from 14–79 mg/L, 1.40–7.90 times higher than the allowable limits in National technical regulations at 18/18 sampling locations. BOD_5 of surface water at the aquaculture areas ranged from 8–50 mg/L, 2–12.5 times higher than the allowable limits in National technical regulation at 18/18 sampling locations. $P\text{-}PO_4^{3-}$ of surface water at the aquaculture areas ranged from 0–0.996 mg/L that were 1.21–9.96 times higher than the allowable limits in National technical regulation at 11/18 sampling locations. $N\text{-}NH_4^+$ of surface water at the aquaculture areas ranged from 0.126–6.98 mg/L, which was 1.04–23.27 times higher than the allowable limits in National technical regulation at 18/18 sampling locations. Coliform of surface water at the aquaculture areas ranged from 1.5–110 MPN/100 mL, which was 1.72–44 times higher than the allowable limits in National technical regulations at 17/18 sampling locations. The pH of surface water in the aquaculture areas ranged from 6.63–7.51, all within the allowable limits according to the National Technical Regulation. $N\text{-}NO_3^-$ of surface water at the aquaculture areas ranged from 0.032–0.327, all within the allowable limits according to the National Technical Regulation. The results of monitoring surface water affected by aquaculture areas in the first six months of 2021 (Tables 4 and 5) show that pond fish farming had higher pollution than cage and raft floating fish farming. The main reason is that the ponds are often more stagnant than cage and raft floating fish, and their exchange and water self-cleaning capacities are also more limited. Therefore, the wastewater needs to be treated before being discharged into the receiving source.

In An Giang, pond fish farming is the main form with high economic efficiency. It refers to the commercial cultivation and the rearing of fish in the enclosures as ponds for food production. The main cultured species of pond fish farming are pangasius conchophilus, tinfoil barb, mozambique tilapia, snakehead fish, and red tilapia. Most aquaculture wastewater from fishponds is discharged directly into rivers and canals (accounting for approximately 90% of farming areas) (An Giang Department of Natural Resources and Environment, 2020). Cage culture is an aquaculture production system with fish in floating net pens. The cage culture of fish utilizes existing water resources but encloses the fish in a cage or basket, which allows water to pass freely between the fish and the pond, permitting water exchange and waste removal into the surrounding water (Soltan, 2016). The main cultured species of cage culture are pangasius, snakehead fish, giant freshwater prawns, mozambique tilapia, catfish, and flounder.

Several aquatic species are commercially produced in the Mekong delta, of which striped catfish (Pangasius) is the most important. There are two kinds of feed used in catfish farming in Viet Nam—manufactured pelleted feeds (MPF) and farm-made feeds (FMF). The most used ingredients in MPF are fishmeal, soybean meal, rice bran, blood meal, and meat and bone meal. The FMF is formulated from inexpensive, locally available feed ingredients, including rice bran, broken rice, fresh trash fish and/or dried trash fish, soybean meal, and fishmeal (Nguyen, 2013). Catfish absorb only 27–30% nitrogen, 16–30% phosphorus, and 25% organic matter from the feed; the rest was retained in the aquatic environment. This excess food affected the quality of the pond water environment and the growth and normal development of aquatic species, especially the rate of fish parasite infection (Gross, 1989). Before treatment, pond waters are tainted by fish feces, uneaten feed, dead fish, and related chemicals, including toxic substances and pathogens (Nguyen et al., 2014).

Table 4
Analytical results of surface water affected by raft floating fish farming areas

Code	Month	Temperature	pH	DO	TSS	COD	BOD_5	$N\text{-}NO_3^-$	$P\text{-}PO_4^{3-}$	$N\text{-}NH_4^+$	Coliform
		^0C		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	MPN/100 mL
AQ1	Mar	30.8	7.13	5.08	51	17	11	0.036	ND	0.413	15,000
	Jun	30.9	7.38	3.87	64	29	18	0.180	0.121	0.978	110,000
AQ3	Mar	27.4	7.23	5.05	47	16	10	0.122	0.045	0.314	9,300
	Jun	30.8	7.20	3.33	48	14	9	0.236	0.056	0.438	75,000
AQ4	Mar	27.2	7.21	4.95	45	18	12	0.063	0.063	0.484	7,500
	Jun	32.0	7.04	3.50	49	17	11	0.085	0.064	0.666	24,000
AQ19	Mar	30.8	7.22	5.12	46	15	10	0.061	0.065	0.189	24,000
	Jun	31.8	7.16	4.99	51	19	12	0.047	0.052	0.654	9,300
National technical regulation			6-8.5	≥6	20	10	4	2	0.1	0.3	2,500

Notes: "Underline": The value does not meet the standard according to QCVN 08-MT:2015/BTNMT: National technical regulation on surface water quality, column A1 ; ND = Not detected

Table 5

Analytical results of surface water affected by pond fish farming areas

Code	Month	Temperature	pH	DO	TSS	COD	BOD_5	$N\text{-}NO_3^-$	$P\text{-}PO_4^{3-}$	$N\text{-}NH_4^+$	Coliform
		^0C		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	MPN/100 mL
AQ2	Mar	29.5	7.27	4.75	56	24	16	0.087	0.041	1.21	15,000
	Jun	29.8	7.20	5.13	57	31	20	0.117	0.285	2.94	15,000
AQ5	Mar	28.4	6.72	2.99	68	67	43	0.06	0.904	4.5	24,000
	Jun	32.8	6.63	2.59	73	79	50	0.12	0.996	6.98	15,000
AQ6	Mar	27.9	6.85	5.26	46	19	12	0.131	0.077	0.47	4,300
	Jun	31.5	7.12	2.36	48	16	10	0.18	0.042	0.385	93,000
AQ8	Mar	28.3	7.19	5.11	50	20	13	0.077	ND	0.934	9,300
	Jun	31.6	7.3	4.98	46	24	15	0.106	0.08	0.673	2,300
AQ11	Mar	28.7	6.89	3.91	89	32	21	0.093	0.057	2.46	24,000
	Jun	32.8	7.35	4.31	60	32	21	0.122	0.277	3.01	46,000
AQ13	Mar	31.6	7.51	3.82	112	21	13	0.094	0.187	2.72	4,300
	Jun	33.7	7.45	2.67	58	26	16	0.221	0.049	1.06	9,300
AQ14	Mar	28.9	6.91	4.03	52	24	15	0.096	0.089	3.03	9.300
	Jun	33.1	7.28	4.69	55	28	17	0.203	0.202	1.94	24,000

Table 5 *(Continue)*

Code	Month	Temperature	pH	DO	TSS	COD	BOD_5	$N\text{-}NO_3^-$	$P\text{-}PO_4^{3-}$	$N\text{-}NH_4^+$	Coliform
		^0C		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	MPN/100 mL
AQ15	Mar	28.7	6.91	4.07	55	30	20	0.08	0.039	1.75	9,300
	Jun	33.3	7.29	4.71	50	29	18	0.117	0.189	2.35	9,300
AQ20	Mar	31.6	7.18	4.54	46	20	13	0.032	ND	0.311	9,300
	Jun	29.6	7.18	4.86	48	14	8	0.208	0.042	0.391	15,000
AQ21	Mar	29.1	6.89	3.13	98	39	25	0.11	0.172	1.74	46,000
	Jun	32.6	7.23	2.12	60	32	21	0.068	0.201	2.72	21,000
AQ22	Mar	30.1	7.19	3.51	48	32	21	0.132	0.516	2.81	15,000
	Jun	32.3	6.97	2.23	56	34	22	0.185	0.279	2.56	7,500
AQ23	Mar	31.2	7.15	4.26	48	21	14	0.192	0.845	3,41	4,300
	Jun	28.9	7.18	5.08	54	15	10	0.327	0.031	0.199	2,300
AQ24	Mar	29.8	7.16	4.18	53	14	9	0.124	0.042	0.459	9,300
	Jun	33.6	7.31	4.81	64	22	14	0.188	0.089	1.25	110,000
AQ25	Mar	29.4	7.36	4.69	45	15	10	0.088	0.041	0.126	2,300
	Jun	31.4	7.18	4.81	59	31	19	0.281	0.243	4.29	1,500
National technical regulation			6-8.5	≥6	20	10	4	2	0.1	0.3	2,500

Notes: "Underline": The value does not meet the standard according to QCVN 08-MT:2015/BTNMT: National technical regulation on surface water quality, column A1; ND = Not detected

Figure 4 displays that the quality of surface water affected by aquaculture areas according to the Water Quality Index in the first six months of 2021 ranged from the level of pollution (water is heavily polluted, needing future treatment) to the good level (water could be used for domestic water supply but requires appropriate treatment measures). Surface water quality was suitable for water transport purposes for the monitoring period. Farmers need to have measures and technology to treat wastewater to meet national standards before discharging it to surface water sources.

Figure 4 shows that AQ5 was the most polluted site. The reason was that this was the site with the largest area of fishpond farming, with a large amount of wastewater discharged to the watercourse. Besides, water samples were collected in the Xang Vinh Tre canal, which has poor circulation, and low self-cleaning ability, leading to the most polluted water quality. The water quality at AQ6, AQ8, AQ23, and AQ25 was much better. Because these sites had a small area of fishpond farming compared to other sites, and the amount of wastewater discharged was small. Water samples were collected in the river with good circulation and self-cleaning ability, so the water quality was less polluted.

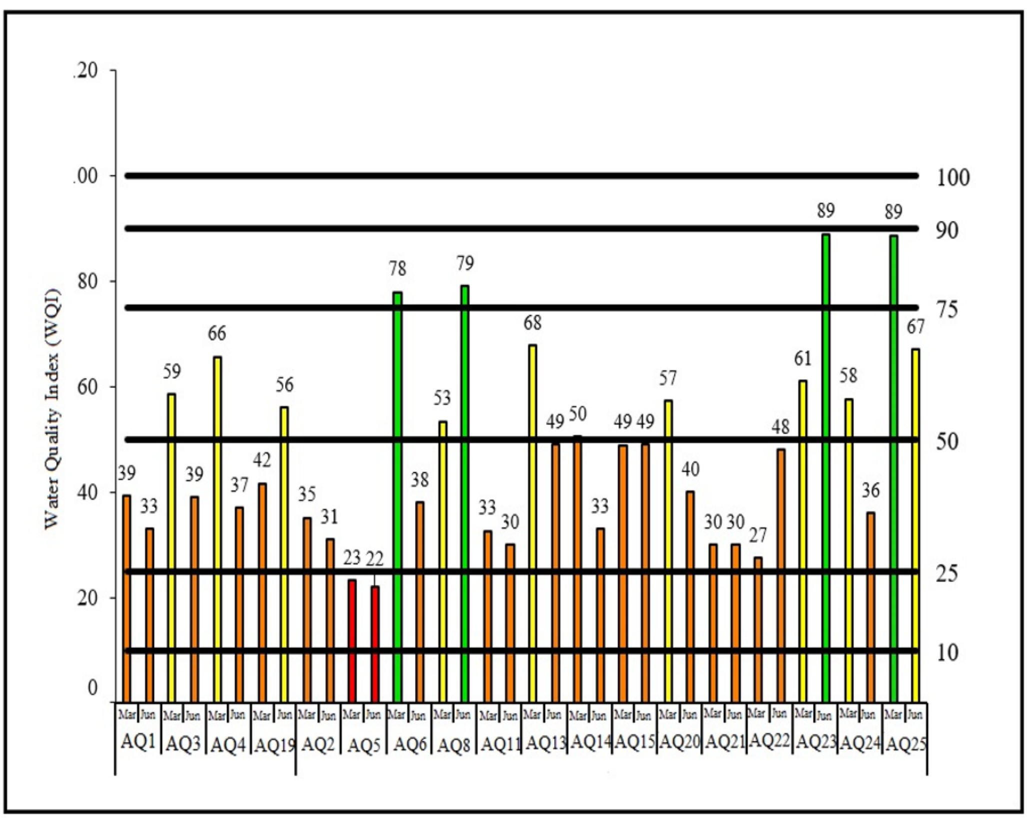

Figure 4. Water Quality Index of surface water

Analytical Results of Wastewater Samples from Pangasius Catfish Fishponds

The results of the wastewater sample analysis of the two catfish ponds are shown in Table 6. The results showed that all parameters have values exceeding the allowable standards according to QCVN 40:2011/BTNMT—National Technical Regulations on industrial wastewater, column A. That means the aquaculture wastewater of these two fish farms needs to be treated before being discharged into the receiving watercourse.

Table 6

Analytical results of two fishponds at two fish farms in Chau Phu district

Location	SS	COD	BOD_5	$N\text{-}NH_4^+$	Total N	Total P
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Treatment 1 (Fish farm 1)	118	106	68	14.80	22.14	2.38
Treatment 2 (Fish farm 2)	76	60	39	8.93	10.23	4.20
National Technical Regulations	50	75	30	5	20	4

The Density of Aquatic Plants

Through the field survey at two wastewater discharge areas of two fish farms in Chau Phu district, An Giang province, three native species of floating aquatic plants have been found. They were Water hyacinth (*Eichhornia crassipes*), Morning Glory (*Ipomoea aquatica*) and Climbing Dayflower (*Commelina diffusa*). Figure 5 shows three native aquatic plants used in the study. Although there was not a great diversity of species in the two survey areas, all three species are valuable species in the treatment of pollutants in water, which has been proven through many studies (Viet & Hoang, 2004; Nguyen et al., 2020).

Water hyacinth (*Eichhornia crassipes*) | Morning glory (*Ipomoea aquatica*) | Climbing dayflower (*Commelina diffusa*)

Figure 5. Native aquatic plants used in the study

Climbing Dayflower (*Commelina Diffusa*) has the characteristics of Herbaceous creeping, with roots at the nodes, almost hairless, with a soft stem 0.5– l.5 m long. Leaves are slender or oval, 2–6 cm long, 1–2 cm wide, pointed apex, and sheath with hairy margins. The flowers are small, blue, and 1 cm wide. Morning Glory (*Ipomoea aquatica*) is a semi-aquatic tropical plant, a leafy vegetable with a crawling stem on land or in water. Stems are hollow, thick, eye-rooted, usually hairless in the hot season, and hairy in the cold. Leaves are triangular, pointed, sometimes narrow, and long. Flowers are large, white, or purple-pink, light purple flower tubes, and 1–2 flowers on a stalk. Water hyacinth (*Eichhornia crassipes*) is an aquatic herbaceous floating in the water, growing about 30 cm high with round, green, smooth, and smooth leaves and long and narrow arched veins. Leaves entwined like petals. The petiole expands like a porous bubble to help the plant float on the water. The three sepals are like three petals. Water hyacinth roots look like black feathers falling into the water, up to 1 m long. Water hyacinth reproduces very quickly, so it is easy to clog ponds, lakes, and canals (Ho, 1999a, 1999b, 1999c).

The Quadrat method is applied to determine the density of aquatic plants in the survey areas (Dan et al., 2012; Rastogi, 1999). According to the calculation Equations 4 and 5, the frequency of occurrence and density of aquatic plants at each survey area are shown in Table 7.

Table 7
Frequency of occurrence of aquatic plants in the survey areas

Area	Aquatic plants	Frequency of occurrence (%)	Density (plants/m^2)
Area of fish farm 1	Water Hyacinth (*Eichhornia crassipes*)	90	13
	Morning Glory Plants (*Ipomoea aquatica*)	85	10
	Climbing dayflower (*Commelina diffusa*)	80	8
Area of fish farm 2	Water Hyacinth (*Eichhornia crassipes*)	100	15
	Morning Glory Plants (*Ipomoea aquatica*)	30	1
	Climbing dayflower (*Commelina diffusa*)	45	8

The growth ability of water hyacinth, morning glory, and climbing dayflower was shown by the increased number of plants and the stem length during the experiment. From Table 8, the length of the stem and the number of water hyacinths in T1 change from 20 cm to 32 cm and from 13 to 62, respectively. The stem length and the number of morning glory plants in T1 change from 20 cm to 28 cm and from 10 to 43, respectively. The stem length and the number of climbing dayflowers in T1 change from 20 cm to 36 cm and 15 to 71, respectively. The length of the stem and the number of water hyacinths in T2 change from 20 cm to 36 cm and from 15 to 71, respectively. The length of the stem and the number of morning glory Plants in T2 change from 20 cm to 32 cm and from 1 to 5, respectively. The length of the stem and the number of climbing dayflowers in T2 change from 20 cm to 28 cm and from 8 to 49, respectively. The results showed that, in general, the aquatic plants, including water hyacinth (*Eichhornia crassipes*), morning glory plants (*Ipomoea aquatica*), and climbing dayflower (*Commelina diffusa*), grow and develop well in the aquaculture wastewater. The optimum growth rate of water hyacinth greatly affects wastewater purification efficiency in a continuous system, and nutrient removal was successfully achieved (Rezania et al., 2016). Regarding removal mechanisms, the removal of nitrogen and phosphorus by water hyacinth primarily depended on plant adsorption (Bin et al., 2018).

Table 8
Length of aquatic plants before and after the experiment

Treatment	Aquatic plant	Plant morphology	Before the experiment	End of experiment
T1	Water hyacinth (*Eichhornia crassipes*)	Length of the stem (cm)	20	32
		The number of plants	13	62
		Number of dead plants		13
	Morning Plory plants (*Ipomoea aquatica*)	Length of the stem (cm)	20	28
		The number of plants	10	43
		Number of dead plants		3
	Climbing dayflower (*Commelina diffusa*)	Length of the stem (cm)	20	30
		The number of plants	8	27
		Number of dead plants		4
T3	Water hyacinth (*Eichhornia crassipes*)	Length of stem (cm)	20	36
		The number of plants	15	71
		Number of dead plants		15
	Morning Glory plants (*Ipomoea aquatica*)	Length of the stem (cm)	20	32
		The number of plants	1	5
		Number of dead plants		0
	Climbing dayflower (*Commelina diffusa*)	Length of the stem (cm)	20	28
		The number of plants	8	49
		Number of dead plants		0

The experimental results in Table 8 show that after 28 days of the experiment, there were 13 dead plants of water hyacinth, three dead plants of morning glory, and four dead plants of climbing dayflower in tank T1. There were only 15 plants of water hyacinth, no dead plants of morning glory, and a climbing dayflower in tank T3. Some plants of water hyacinths died in tank T1 and tank T3, possibly due to the competition for nutrients between species at the end of the experiment and the growth cycle of the plants. There were dead plants of morning glory and climbing glory in tank T1 in the first phase of the experiment, possibly because the plants had not yet adapted to the new environment.

The Efficiency of Floating Raft of Native Aquatic Plants on Aquaculture Wastewater Improvement

Variation of Suspended Solids (SS). Figure 6 shows that the concentration of SS in the wastewater in the experimental tanks decreased sharply during the first three months of farming and in the fourth month until harvest. The concentration of SS in the treatment T1 and treatment T2 met the standards for seven days when compared with the National technical regulation on industrial wastewater of Vietnam. During the first three months of the farming, SS removal efficiency was 92.6% in the tanks treated by plants and 83% in the control tanks until the day of 28. In the fourth month until harvest, SS removal efficiency reached 92.7% in the tank-treated plants and 82.8% in the control tank until day 28.

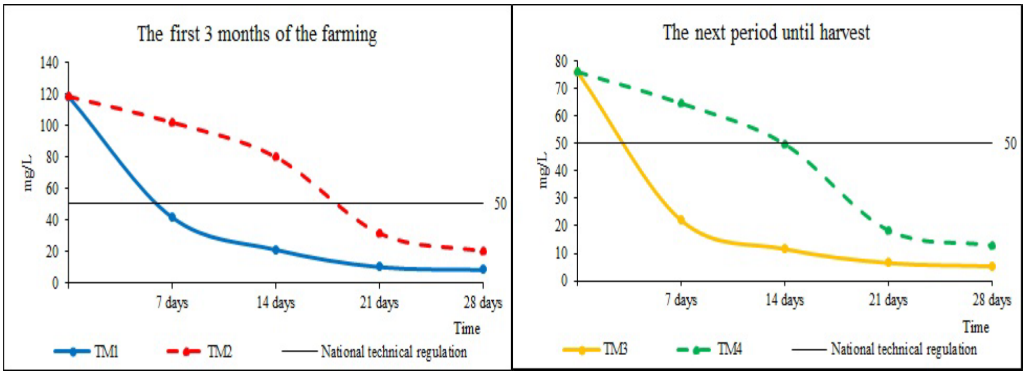

Figure 6. Variation of suspended solids (SS)

Variation of Chemical Oxygen Demand (COD). Figure 7 shows that the concentration of COD in the wastewater in the experimental tanks decreased sharply during the first three months of farming and in the fourth month until harvest. The concentration of SS in the treatment T1 and treatment T2 met the standards for seven days when compared with National technical regulations. During the first 3three months of the farming, COD removal efficiency was 89.6% in the tanks treated by plants and 78.7% in the control tanks until the day of 28. In the fourth month until harvest, COD removal efficiency reached 89.9% in the tank-treated plants and 78.3% in the control tank until day 28.

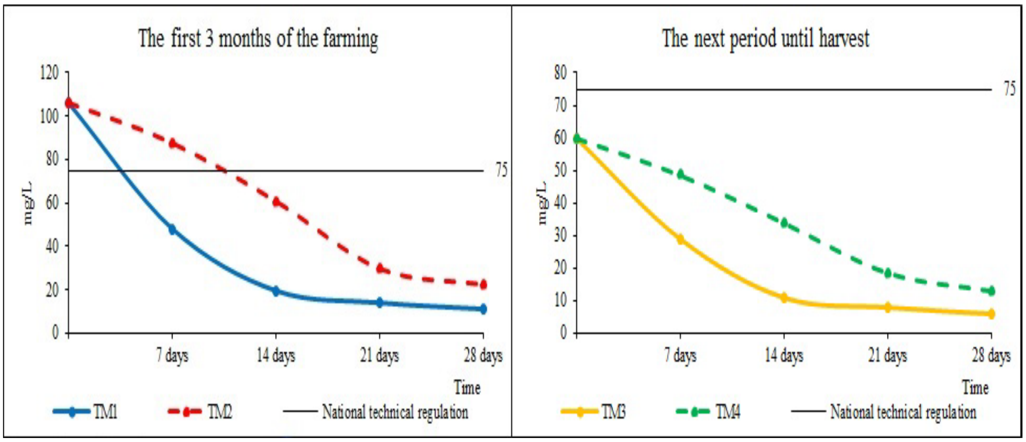

Figure 7. Variation of chemical oxygen demand (COD)

Variation of Biological Oxygen Demand (BOD_5). Figure 8 shows that the concentration of BOD_5 in the wastewater in the experimental tanks decreased sharply during the first three months of the farming and in the fourth month until harvest. The BOD_5 in the treatment T1 and treatment T2 met the standards for seven days compared to National technical regulations. During the first three months of the farming, the BOD_5 removal efficiency was 93.9% in the tanks treated by plants and 82.5% in the control tanks until the day of 28. In the fourth month until harvest, SS removal efficiency reached 91.5% in the tank-treated plants and 79.7% in the control tank until day 28.

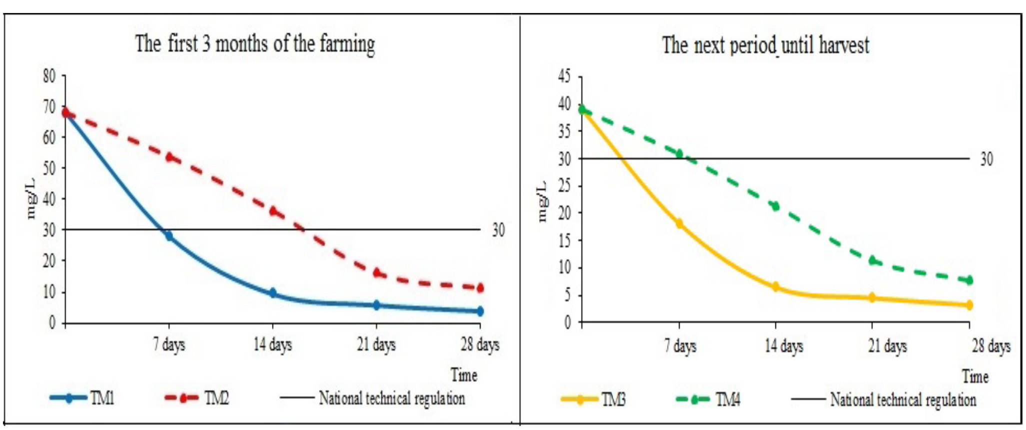

Figure 8. Variation of Biological oxygen demand (BOD_5)

Variation of Ammonium (N-NH_4^+). Figure 9 shows that the concentration of N-NH_4^+ in the wastewater in the experimental tanks decreased sharply during the first three months of the farming and in the fourth month until harvest. The concentration of N-NH_4^+ in the treatment T1 and treatment T2 met the standards for seven days compared with National technical. During the first three months of the farming, the N-NH_4^+ removal efficiency was 93.4% in the tanks treated by plants and 69.4% in the control tanks until the day of 28. In the fourth month until harvest, N-NH_4^+ removal efficiency reached 93.6% in the tank-treated plants and 69.5%; in the control tank until day 28.

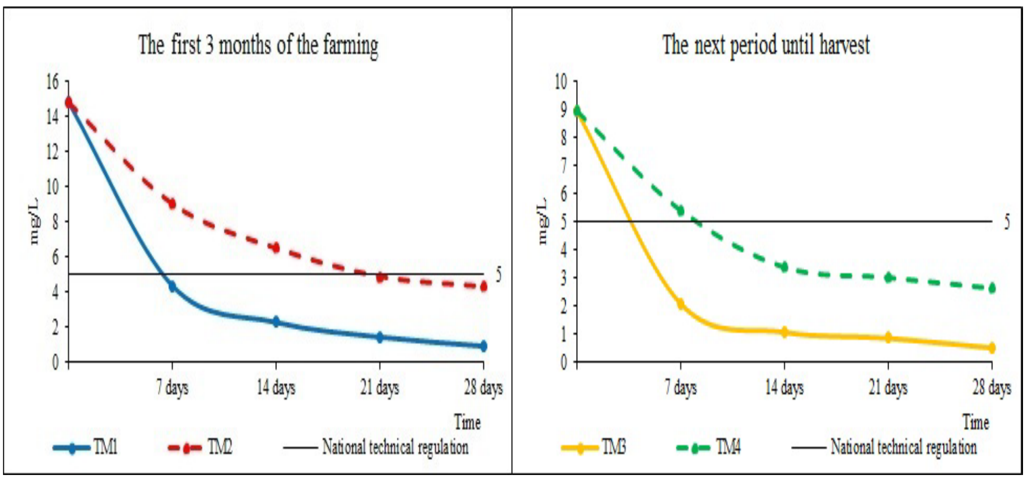

Figure 9. Variation of Ammonium (N-NH_4^+)

Variation of Total Nitrogen. Figure 10 shows that the concentration of Total Nitrogen in the wastewater in the experimental tanks decreased sharply during the first three months of farming and in the fourth month until harvest. The concentration of SS in the treatment T1 and treatment T2 met the standards for seven days when compared with National technical regulations. During the first three months of the farming, Total Nitrogen removal efficiency was 64.3% in the tanks treated by plants and 34.8% in the control tanks until the day of 28. In the fourth month until harvest, TN removal efficiency reached 67.8% in the tank-treated plants and 32.8% in the control tank until day 28.

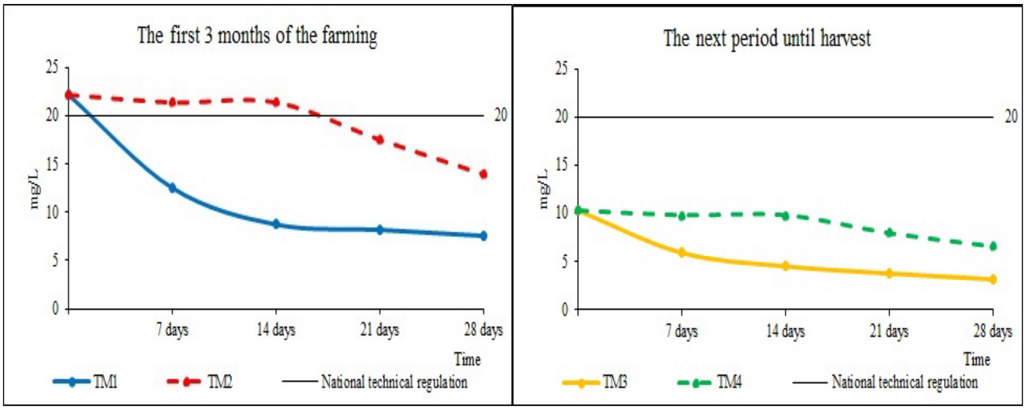

Figure 10. Variation of Total Nitrogen (TN)

Variation of Total Phosphorus. Figure 11 shows that the concentration of TP in the wastewater in the experimental tanks decreased sharply during the first three months of farming and in the fourth month until harvest. The concentration of SS in the treatment T1 and treatment T2 met the standards for seven days when compared with National technical regulations. During the first three months of the farming, TP removal efficiency was 94.6% in the tanks treated by plants and 33.5% in the control tanks until the day of 28. In the fourth month until harvest, TP removal efficiency reached 94% in the tank-treated plants and 35.3% in the control tank until day 28.

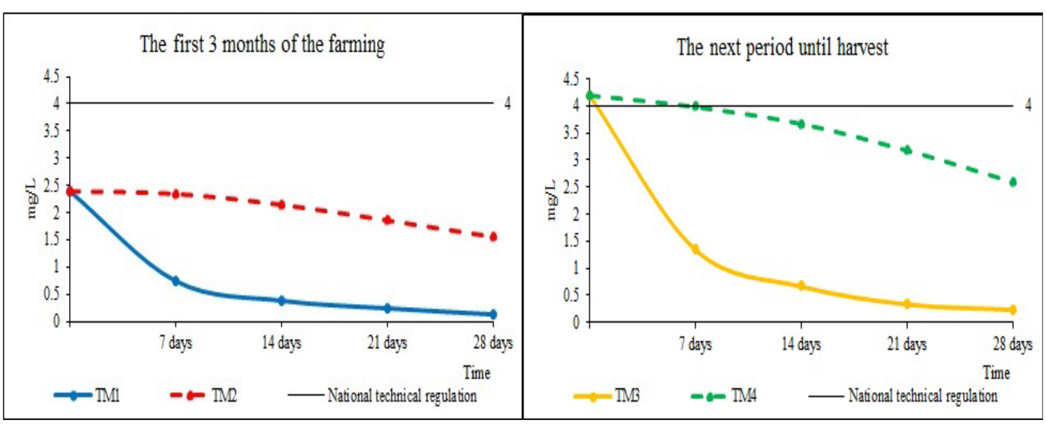

Figure 11. Variation of Total Phosphorus (TP)

In general, using a floating raft of native aquatic plants in the wastewater discharged area to treat aquaculture wastewater is effective. Water Hyacinth (*Eichhornia crassipes*), Morning Glory Plants (*Ipomoea aquatica*), and Climbing dayflower (*Commelina diffusa*) have strong absorption capacity for nutrients and quickly remove pollutant components in aquaculture wastewater. The quality of wastewater after treatment was significantly improved.

After 28 days of the experiment, the treatment efficiency of SS was 92.6%, COD was 89.6%, BOD_5 was 93.9%, N-NH_4^+ was 93.4%, TN was 64.3%, TP reached 94.6% in the T1, and the treatment efficiency of SS was 92.7%, COD was 89.9%, BOD_5 was 91.5%, N-NH_4^+ was 93.6%, TN was 67.8%, TP was 94% in the T3. In order to ensure that aquaculture wastewater meets the standards of National Technical Regulation on industrial wastewater before being discharged to the receiving source with the most optimal time for fish farms, the hydraulic retention time in the wastewater treatment tank must be seven days in both stages.

Water hyacinth, morning glory plants, and climbing dayflowers used in the study are common plants in the Mekong Delta, with diverse uses. Utilizing biomass of these plants after wastewater treatment brings economic value and can increase income for farmers. Morning glory plants and climbing dayflowers can be used as human food in Vietnam. The current price of morning glory plants in Vietnam is about 30,000–40,000 VND/kg. Climbing dayflower is also a medicinal herb that is used in the treatment of many different diseases in humans. All plants can be used as animal feed for poultry and livestock. Water hyacinth is used to make handicraft products. The price of dried water hyacinth on the Vietnamese market currently ranges from 20,000–30,000 VND/kg. In addition, much previous research showed that aquatic plants can be used for bioenergy production and organic fertilizer. By integrating the growth of aquatic plants in a water recycling system to produce biomass, power can be produced from that biomass (Fedler et al., 2007). Water hyacinth is a more promising aquatic plant biomass for bioenergy production (Fedler & Duan, 2011). Farmers in the Mekong Delta can apply water hyacinth and rice straw as additional feeding material for biogas digester in case of pig manure shortage (Ngan et al., 2012; Nam et al., 2017). Silaging and composting water hyacinth plants generated from ponds treating pig farm wastewater were technically and economically feasible to implement at farm scale levels (Polprasert et al., 1994). The study by Vidya and Girish (2014) signified using Water Hyacinth (*Eichhornia crassipes*) as the organic manure. Water Hyacinth can be brought to make compost, mulch, and clean the sewage. The study by Trang et al. (2018) showed that the water hyacinth was suitable for testing the production of microbial organic fertilizers.

Wastewater treatment using aquatic plants does not require much initial construction cost compared to conventional treatment systems, does not require complicated and expensive machinery and equipment, has low operating and maintenance costs, and is easy to manage. Aquatic plants are widely distributed throughout the Mekong Delta. They are easy to collect in many places of the natural environment as riversides, canals, and ponds, which do not cost much for starting materials. After treatment, the biomass of aquatic plants can be used for many different purposes, bringing economic value. Wastewater treatment by aquatic plants is suitable in rural conditions. The development of vegetation has contributed to bringing landscape value.

CONCLUSION

Surface water quality affected by aquaculture areas in An Giang province did not meet the standards according to QCVN 08-MT: 2015/BTNMT - National technical regulation on surface water quality. The DO content was lower than the allowable standards, and surface water was polluted mainly by suspended solids, organic matter (COD, BOD), nutrients (N, P), and micro-organisms. Using a floating raft of native aquatic plants, including Water hyacinth (*Eichhornia crassipes*), Morning glory plants (*Ipomoea aquatica*), and Climbing dayflower (*Commelina diffusa*) for aquaculture wastewater treatment can improve the wastewater quality. These three species grow and develop well in aquaculture wastewater. After the experiment of 28 days, the removal percentages of SS, COD, BOD_5, N-NH_4^+, Total N, and Total P were 92.6%, 89.6%, 93.9%, 93.4%, 64.3%, 94.6%, respectively, in the first three months of the farming season. The removal percentages after 28 days of SS, COD, BOD_5, N-NH_4^+, Total N, and Total P were 92.7%, 89.9%, 91.5%, 93.6%, 67.8%, 94%, respectively, in the fourth month until fish harvest. In order to ensure that the outlet wastewater meets the national standards on industrial wastewater before being discharged into the receiving water source, the most optimal retention time in the wastewater treatment tank is seven days for two stages.

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