JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(4), 111–118
https://doi.org/10.12911/22998993/183822
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.01.22
Accepted: 2024.02.16
Published: 2024.03.01

The Potential of Floating Treatment Wetlands for Pollutant Removal in the Recirculating Aquaculture System of Catfish

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ABSTRACT

Floating treatment wetland (FTW) as a wastewater processing technology in recirculating aquaculture systems (RAS) of catfish is considered to be effective in eliminating the pollutant load of nitrogen, phosphorous, and organic matter. This research aims to reduce the concentration of pollutant loads and obtain an effective ratio between the volume of the FTW and the total water volume of the catfish RAS. The FTW system uses *Vetiveria zizanoides* grown on floating media and equipped with an aerator in the bottom layer of the pond. Several FTW volume ratios were used to determine an FTW system that is effective in reducing pollutant loads according to the mass balance concept. This approach was conducted to maintain acceptable water quality in catfish cultivation ponds. The study results showed that most pollutant load concentrations decreased in all ponds. The largest removal percentage included the parameters TAN, COD, TSS, TP, nitrate, phosphate, and TN, namely 88.54%, 66.17%, 85.68%, 91.30%, 83.85%, 61.46%, and 44.68%, respectively. The effective ratio between the volume of the FTW processing system and the total water volume of 0.543with an age group of fish of 9–12 weeks was able to eliminate the pollutant loads from catfish pond wastewater.

Keywords: floating treatment wetlands, recirculating aquaculture systems, *Vetiveria zizanoides*, effective ratio

INTRODUCTION

Aquaculture offers enormous potential for feeding and nourishing the world's expanding population. Conventional aquaculture takes a considerable amount of water and land space and creates dirty effluent, which has a negative influence on the environment (Somprasert et al., 2021). The accumulation of feed residue and fish excreta frequently causes water quality in fishponds to degrade, further reducing aquaculture production (Lin et al., 2003). The development of sustainable aquaculture is critical to satisfy the growing demand for aquatic food. Recirculating aquaculture system (RAS) is a green and sustainable aquaculture technique that not only boosts farm productivity but also greatly reduces environmental effects. Organic matter, particulate matter, ammonia, nitrate, and phosphor will collect in RAS, causing unfavorable effects on system functioning and production (Satya et al., 2014, Susanti et al., 2019, Colares et al., 2020). As much as 65% of the protein in fish feed can be degraded into the environment, as much as 60% of the organic nitrogen coming from protein is expelled as ammonia, and only 10–15% is discharged as solid waste from fish metabolism (Craig and Kuhn, 2017). The RAS water treatment unit is critical in guaranteeing optimal growth conditions by filtering and degrading contaminants from aquaculture and recycling water, which saves natural resources significantly (Li et al., 2023). RAS has incorporated wastewater treatment procedures into aquaculture production to maintain water quality and is gaining popularity around the world.

In this study, floating treatment wetland (FTW) technology was used as a wastewater processing technology in a recirculation cultivation system. FTW is known to be effective in removing nitrogen, phosphorus, and organic matter pollutant loads. In the FTW system, *Vetiveria zizanoides* is planted which is known to effectively remove pollutants and has a high tolerance to extreme conditions (Chyan et al., 2016; Effendi et al., 2018). *Vetiveria zizanoides* will absorb nutrients from the decomposition process of organic material originating from catfish feed, which is used as nutrition to support the growth of vetiver.

In recirculation systems, technical specifications such as pool size, pool volume, and flow rate influence the contact area and contact time of the pollutant load with the waste treatment system used (Syah et al., 2017), so that information on the ratio between the volume of the wastewater treatment system and the total system volume recirculation is very important to know. This research aims to reduce the concentration of pollutant loads and obtain the effective ratio of the area volume of the FTW wastewater treatment system and the total recirculation volume. The results of this research can be used as an alternative technology to control pollution, especially fishery wastewater pollution.

MATERIALS AND METHODS

The experiment was carried out using experimental methods in the greenhouse at the Research Center for Limnology and Water Resources. The RAS system consists of (1) a water storage tank measuring 300 L, (2) a catfish pond measuring 1.8×0.8×0.5 m^3, (3) a wastewater treatment system with 8 FTW ponds arranged in series with dimensions of 1.8×0.8×0.5 m^3, (4) a holding pond 1.8×0.8×0.5 m^3. The water level is regulated with a pipe, and the height is maintained at 0.4 m. *Vetiveria zizanoides* in the FTW pond are planted in pots containing rock wool media placed in a floating bed that covers the entire surface of the pond. The Resun LP 40 aerator pump with an air output of 60 L/minute is distributed to eight FTW ponds using one aeration stone in each pond.

The source of wastewater originates from the outlet of the catfish rearing pond. The size of the catfish used at the start of the study was 5–6 cm (2 weeks old) with a density of 200 catfish/pond. The fish feed used are commercial pellets with a protein content of 31% and is given at a feeding rate of 5% of the catfish's body weight. Water samples were taken every week until the harvest period in the 12th week with a catfish consumption size of ± 100 grams/fish. The series of experimental devices were arranged to operate in a recirculating system with the water flow in the catfish pond and inlet maintained at 12 liters/hour. The retention time in the research FTW pool was 2 days. The RAS with FTW schematic design can be seen in Figure 1.

Vetiver growth was analyzed for biomass parameters, C, N, P, and K, which were carried out at the beginning and end of the study. Measuring the length and weight of catfish is carried out every two weeks. Water quality parameters were analyzed using the standard methods APHA AWWA (2017), including COD, TSS, pH, dissolved oxygen, total ammonium nitrogen (TAN), nitrate, phosphate, total nitrogen, total phosphorus, and temperature.

The experimental design in the study used a randomized block factorial design (RAKF) with (A) three levels of fish age group: the 0–3 weeks, 4–8 weeks, 9–12 weeks, and (B) the FTW ratio difference factor consists of five levels: catfish ponds as pollutant source ponds; FTW ratio 0.181, 0.362, 0.543 and 0.725. The basis for grouping fish age is the average weight of the fish which influences the amount of feed given (Akbar et al., 2020). The experimental design in this study was used to determine the significance of fish age groups (Factor A) and differences in ratios (Factor B) in each water quality parameter.

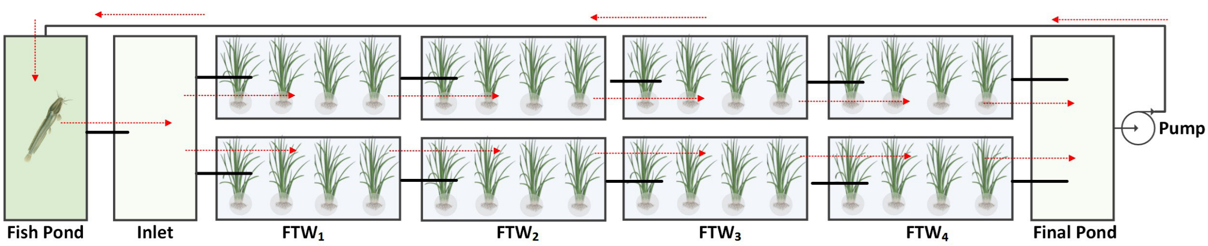

Figure 1. The recirculating aquaculture system with floating treatment wetland schematic design

The input load calculation for each parameter is calculated based on Jörgensen and Vollenweider (1988) as follows:

$$Load = C \cdot Q$$

where: *Load* – input of pollutant loading (mg/h), *C* – concentration (mg/L), *Q* – flow rate (L/h).

The percentage of pollutant load removal for each FTW unit is calculated based on the formula of Wang et al. (2010):

$$RE = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \cdot 100\%$$

where: C_{inlet} – pollutant concentration before entering the FTW (inlet), C_{outlet} – pollutant concentration coming out of the FTW (outlet), *EP* – removal efficiency (%).

The parameters tested statistically were the pollutant load of each water quality parameter, namely COD, TSS, TAN, nitrate, phosphate, TN, TP, DO, temperature, and pH in each FTW pond with various ratios and fish age groups. Data were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) to test the significance of differences in fish age groups (Factor A) and differences in ratios (Factor B) in each water quality parameter. The difference test is carried out using the Tukey test. If the results of the analysis show real significance (95% confidence level), then a further test is carried out using Duncan's Multiple Range Test (DMRT). Presentation of the analysis results using unique notation for each treatment is presented in Table 1.

Determining the most effective ratio of FTW volume to total recirculation system volume is carried out using a decision matrix based on Brown (2007). The matrix column is a variation of the FTW ratio, namely FTW_1 (R 0.181), FTW_2 (R 0.362), FTW_3 (R 0.543), and FTW_4 (R 0.725). The matrix rows are water quality parameters. The matrix is created by assigning weights and scores to each water quality parameter. Weight is the assignment of a value to each parameter that changes based on the observation group. Weighting is done by differentiating each parameter into five observation groups. This group is the group that is the main parameter, namely TAN, COD, and TSS (weights 5, 4, and 3). The supporting parameter group is DO (weight 2) and the supporting parameter group is temperature and pH (weight 1) (Emerson et al. 1975). The scoring is determined based on the level of removal efficiency of each FTW system in eliminating pollutants. Determination of the category of removal efficiency level refers to Tchobanoglous et al. (2004). The total value calculation is the product of the weight and score values, with the maximum value of the product of the weight and score being 100 (Table 2). Next, the total matrix value is calculated using the formula (Song and Kang 2016) as follows:

$$Matrix\ decision\ value =$$

$$= max \sum_{parameter-i}^{the\ value\ of\ parameter-i} weight \cdot score$$

Table 1. Notation for each treatment for visualization of analysis results

Fish age (factor A)	Ratio FTW (factor B)				
	Source of pollutant (control)	FTW_1 (ratio 0.181)	FTW_2 (ratio 0.362)	FTW_3 (ratio 0.543)	FTW_4 (ratio 0.725)
a (0–3)	aSP	$aFTW_1$	$aFTW_2$	$aFTW_3$	$aFTW_4$
b (4–8)	bSP	$bFTW_1$	$bFTW_2$	$bFTW_3$	$bFTW_4$
c (9–12)	cSP	$cFTW_1$	$cFTW_2$	$cFTW_3$	$cFTW_4$

Table 2. Decision-making matrix

Parameter	Reference	Limit	Weight	Score		
				50	25	10
TAN	Zang (2015)	≤ 0.5 (mg/L)	5	Pollutant removal efficiency ≥ 80%	Pollutant removal efficiency 50–80%	Pollutant removal efficiency ≤ 50%
COD	Wang & Sample (2014)	≤ 40 (mg/L)	4			
TSS	Tourcious & Papenbrock (2014)	≤ 100 (mg/L)	3			
DO	Effendi (2020)	≥ 4 mg/L	2			
pH	Emmerson et al. (1975)	6–9	1			
Temperature	Emmerson et al. (1975)	deviation 3 °C	1			

The decision matrix value is seen based on the results of measuring water quality parameters at each FTW ratio and observation time group. Rank one is determined based on the highest total score.

RESULTS AND DISCUSSION

Source of pollution

Fish weight gain increases with age and increasing amount of feed (Table 3) which has implications for increasing the pollutant load of ammonia and COD originating from the decomposition of residual protein (organic nitrogen) in feed in catfish ponds.

The wastewater treatment system uses FTW

The average length of vetiver before and at the end of the study ranged from 56.60 to 154.80 cm. The increase in vetiver biomass was 71.26%. Plant growth in FTW proves that plants effectively absorb and remove nutrients (Chance et al., 2019). The C, N, P, and K contents analyzed before and after the experiment (Table 4), showed an increase in FTW^4 which is in line with research conducted by Lincoln and Zeiger (2002).

Water quality of the wastewater treatment system

The characteristics of the RAS pond wastewater quality were observed in situ as in Table 5. Dissolved oxygen (DO) at the end of observation (fish age group 9–12 weeks) in FTW_3 and FTW_4 pond was above 4.00 mg/L. In fish ponds, DO has decreased due to increasing feed input given over time. The decrease in DO is caused by microbiological activities, especially nitrification and decomposition of organic compounds (Kadlec and Wallace, 2008). The temperature of the research pool ranged from 25.00–25.20 °C. These conditions are optimal for vetiver growth, namely in the temperature range of 17–27 °C (Rahmawan et al., 2019) and pH 6–9 (Singh et al., 2014). Optimum pH conditions can increase plant growth and production (Torres et al., 2010). The decrease in pH is influenced by the decomposition process of organic material originating from food waste and feces resulting from fish metabolism (Wulandari et al., 2014, White and

Table 3. The average weight of fish, amount of feed, TAN, and COD

Time (week)	The average weight of fish (g)	Feed (5% of fish weight) (g/day)	TAN (g/day)	COD (g/day)
0	2.47	29	0.061	11.04
2	5.36	57	0.188	22.32
4	11.32	133	0.310	29.28
6	22.89	267	0.423	51.84
8	63.02	747	0.492	59.52
10	95.34	1096	1.307	64.32
12	102.34	1096	5.606	124.80

Table 4. Concentrations of C, N, P, and K in Vetiver

Specification	%C	%N	%P	%K
Vetiver in t = 0	35.75	0.54	0.21	1.57
Vetiver in FTW_1	41.13	1.28	0.39	1.77
Vetiver in FTW_2	40.46	1.28	0.40	1.71
Vetiver in FTW_3	41.63	1.07	0.38	1.79
Vetiver in FTW_4	42.78	0.87	0.33	1.96
Lincoln dan Zeiger (2002)*	45.00	1.50	0.20	1.00

Table 5. The values of pH, DO, and temperature

Specification	pH	DO (mg/L)	Temperature (^{0}C)
The average	7.38 ± 0.32	6.27 ± 1.87	25.10 ± 0.07
Range	6.62 – 8.07	2.26 – 8.85	25.00 – 25.20

Cousins, 2013). The stability of the water temperature, the level of light penetration, the water flow rate, and the amount of organic material in the ponds will influence the DO concentration.

Removal efficiency of pollutant

The FTW wastewater treatment system effectively removes the pollutant load of TAN, COD, TSS, TP, nitrate, phosphate, and TN respectively by 88.54%, 66.17%, 85.68%, 91.30%, 83.85%, 61.46%, and 44.68% (Figure 2). The pattern of decreasing pollutant load for each parameter shows almost similar results, respectively, pollutant load in fish ponds > Inlet > FTW_1 > FTW_2 > FTW_3 > FTW_4 (Figure 2). The presence of ammonia and ammonium ions quickly forms an equilibrium in water which is greatly influenced by pH and water temperature. Ammonia that ionizes to form ammonium ions (NH_4^+) tends to be almost less dangerous than free unionized ammonia (NH_3).

The toxicity of NH_3 tends to increase with decreasing DO, pH, and temperature (Effendi, 2003). If the pH and temperature values tend to increase, the ammonia concentration will increase while the ammonium ion concentration will decrease (Emerson et al., 1975). Average TAN results in each consecutive pond for catfish ponds; inlet: FTW_1, FTW_2, FTW_3, and FTW_4 of 3.565 mg/L, 2.882 mg/L, 2.117 mg/L, 1.014 mg/L, 0.757 mg/L and 0.331 mg/L. The relatively high TAN, but with a neutral pH and stable temperature, causes most of the ammonia to be in the form of ammonium ions, this is what resulted in research, the condition of the fish still growing well (Trussel, 1972). After going through the wastewater treatment process, the final average TAN of observations at FTW_4 has met the quality

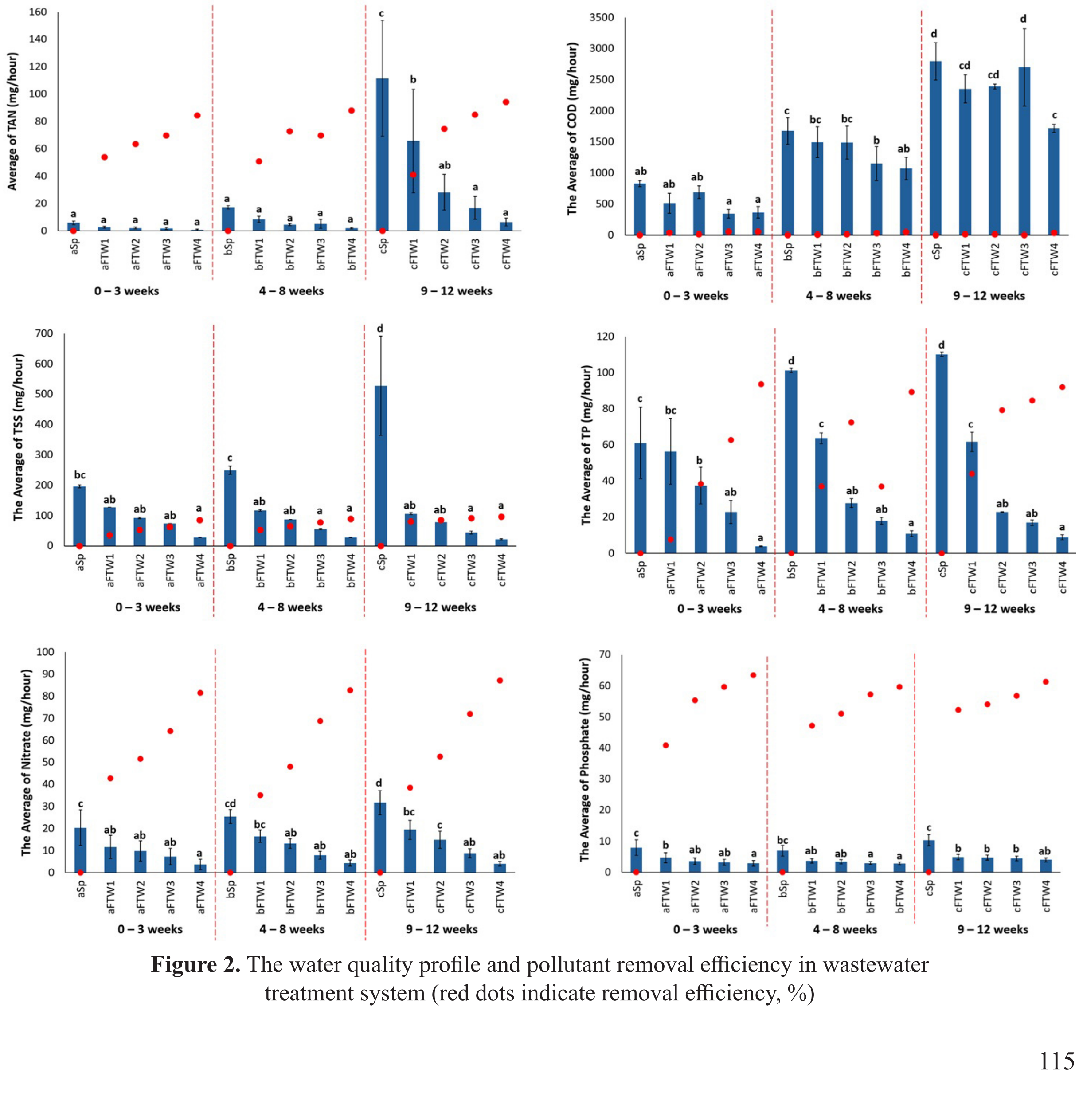

Figure 2. The water quality profile and pollutant removal efficiency in wastewater treatment system (red dots indicate removal efficiency, %)

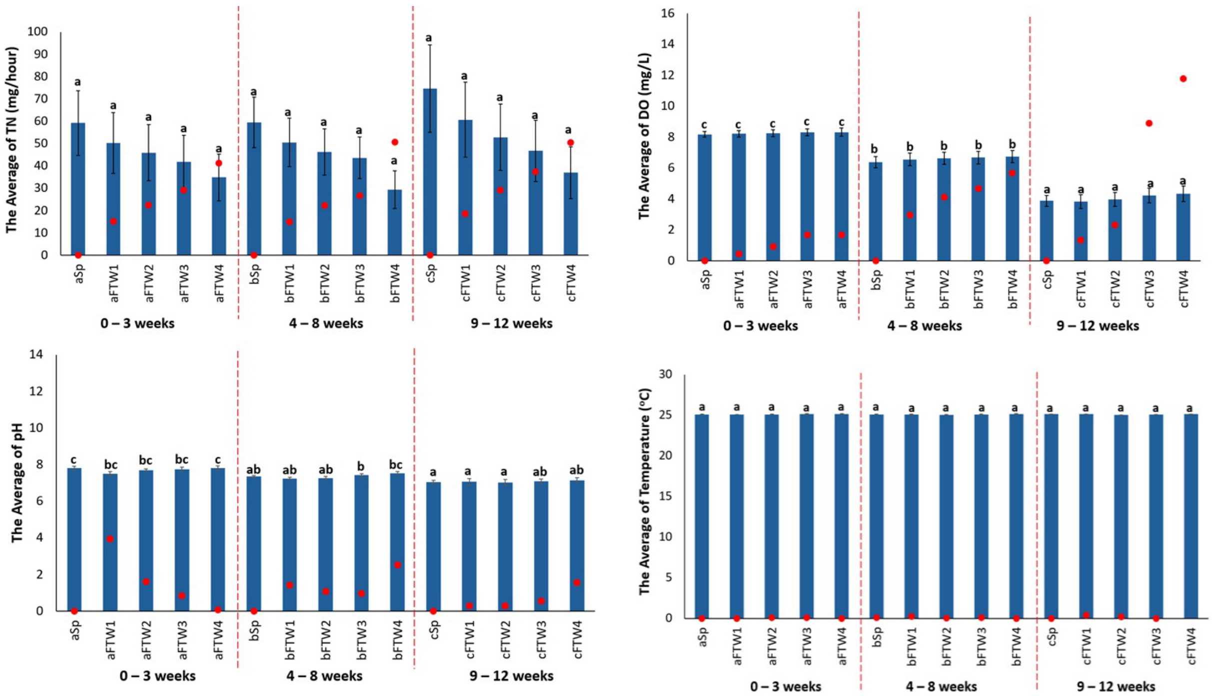

Figure 2 Cont. The water quality profile and pollutant removal efficiency in wastewater treatment system (red dots indicate removal efficiency, %)

standard value, namely <0.5 mg/L. The treatment of fish age group, volume ratio in FTW and the interaction between the two had significantly different effects on TAN (P<0.05), especially in fish over 8 weeks old. The ammonia toxicity threshold is highly dependent on the species and size of the fish (Colt, 2006). Fish cannot tolerate high concentrations of ammonia because it interferes with the binding of oxygen by the blood which results in suffocation (Effendi, 2003).

The presence of ammonium and nitrate ions in the FTW pool water are nutrients that the vetiver absorbs. Nitrate is a product of ammonia nitrification by nitrifying bacteria under aerobic conditions (Montoya and Velasco, 2000), which is not toxic to aquatic organisms (Effendi, 2003). Nitrates in waters are expected to be no more than 20 mg/L. Different plant types will absorb different nitrogen nutrients based on the N sources available in the wetland (Garnett et al., 2003). Plants will absorb N nutrients through the roots. If the available nitrogen sources are ammonium ions and nitrate ions, plants will prefer to absorb ammonium ions (Fang et al., 2007). This is because the energy required to assimilate ammonium ions is lower than nitrate (Wetzel, 2001).

Total nitrogen (TN) is the sum of inorganic nitrogen in the form of nitrate, nitrite, ammonia, and organic nitrogen (Effendi, 2003, Zhang et al., 2016). The TN results from the study tended to decrease with an average TN of 5.338 mg/L to 3.71 mg/L. This value meets the quality standard of 25 mg/L. The highest percentage of TN removal occurred in FTW_4 at 44.68%, relatively lower than the percentage of other parameters. Percentage results of removal efficiency using FTW on TN parameters; ammonia, TP, and phosphate respectively 60%, 85.2%, 82.7%, and 82.5%.

The removal of organic matter is influenced by the organic substrate, pH, temperature, and biological decomposition processes (Kataki et al., 2021). The average COD ranges from 72.47 mg/L to 175.96 mg/L, which is still above the quality standard value of 40 mg/L. The percentage of COD removal ranges from 15.38–49.35%, it can be said that FTW is quite efficient in removing organic pollutant loads (Tchobanoglous et al., 2004). Statistically, different age groups of fish and FTW ratios had a significant effect (P<0.05).

Phosphorus in cultivation ponds comes from leftover feed not consumed by fish, fish feces, and fish metabolic waste in the form of phosphate. Fish feed releases 71.4% of P, the remainder is eaten by the fish (Price and Morris, 2013). Approximately 81% of P absorption in plants depends on the type of plant, plant absorption capacity, and plant surface area (White and Cousins, 2013). Phosphorus in wetlands is usually

Table 6. Matrix calculation results for COD, TAN, TSS, DO, and pH in the treatment system

Parameter	Matrix decision value											
	FTW_1			FTW_2			FTW_3			FTW_4		
	0–3	4–8	9–12	0–3	4–8	9–12	0–3	4–8	9–12	0–3	4–8	9–12
TAN	125	125	50	125	125	50	125	125	250	250	250	250
COD	40	40	40	40	40	40	40	40	40	40	40	40
TSS	30	150	75	30	30	30	30	30	30	30	30	30
DO	20	20	20	20	20	20	20	20	20	20	20	20
pH	10	10	10	10	10	10	10	10	10	10	10	10
Temperature	10	10	10	10	10	10	10	10	10	10	10	10
Total score of matrix	235	355	205	235	235	160	235	235	360	360	360	360
Rank	3	2	4	3	3	5	3	3	1	1	1	1

in the form of dissolved orthophosphate (PO_4^{3-}) or organic phosphorus (Masters, 2012). TP and phosphate during observations ranged between 0.886–7.638 mg/L and 0.338–0.693 mg/L. TP and phosphate during the experiment tended to decrease, although, at the end of the observation period, only TP in FTW_4 had reached < 1 mg/L. The percentage of TP removal in the FTW system is 91.30%, a higher value than Vymazal's (2010) study which ranged from 40–60%.

The matrix calculation results are presented in Table 6. It shows that the FTW_3 with a ratio of 0.543 in the 9–12 weeks fish age group has the highest total value, amounting to 360, and is first ranked. Thus, the FTW ratio of 0.543 at 9–12 weeks is determined to be the most effective ratio in reducing the pollutant load of catfish wastewater. This is due to the greater amount of vetiver in FTW_3 (R 0.543) compared to FTW with a lower ratio, causing vetiver to be able to absorb nutrients in wastewater optimally (Danh et al., 2009). Based on the total value of the weighting matrix calculation, the elimination ability of FTW_3 with a ratio of 0.543 is equivalent to FTW_4 with a ratio of 0.725 at ages of fish 0–3, 4–8, and 9–12 weeks.

CONCLUSIONS

FTW can be a treatment system in recirculating aquaculture systems as a water conservation effort. The decrease in pollutant concentration occurred in all FTWs. The highest removal percentage for TAN, COD, TSS, TP, nitrate, phosphate, and TN was 88.54%; 66.17%; 85.68%; 91.30%; 83.85%; 61.46%; 44.68% respectively, in FTW_4 with a ratio of 0.725. The effective ratio between the volume of the FTW processing system and the total volume of RAS water was 0.543 (FTW_3) in the fish age group 9–12 weeks can eliminate the pollutant of TAN, COD, TSS, TP, nitrate, and phosphate from catfish rearing wastewater.

REFERENCES

1. Chance LMG, Brunt SC Van, Majsztrik JC, White SA. 2019. Short- and long-term dynamics of nutrient removal in floating treatment wetlands. Water Res. 159:153–163. doi:10.1016/j.watres.2019.05.012.
2. Chyan JM, Lin CJ, Lin YC, Chou YA. 2016. Improving removal performance of pollutants by artificial aeration and flow rectification in free water surface constructed wetland. Int Biodeterior Biodegrad. 113:146–154. doi:10.1016/j.ibiod.2016.04.034.
3. Colares GS, Dell'Osbel N, Wiesel PG, Oliveira GA, Lemos PHZ, da Silva FP, Lutterbeck CA, Kist LT, Machado ÊL. 2020. Floating treatment wetlands: A review and bibliometric analysis. Sci Total Environ. 714:136776. doi:10.1016/j.scitotenv.2020.136776.
4. Colt J. 2006. Water quality requirements for reuse systems. Aquac Eng. 34(3):143–156. doi:10.1016/j.aquaeng.2005.08.011.
5. Craig S, Kuhn DD. 2017. Fish Feed. Virginia Coop Ext. 420–256 Unesco 2015:420–256.
6. Effendi H, Margaretha JA, Krisanti M. 2018. Reducing ammonia and chromium concentration in batik wastewater by vetiver (*Chrysopogon zizanioides* L.) grown in floating wetland. Appl Ecol Environ Res. 16(3):2947–2956. doi:10.15666/aeer/1603_29472956.
7. Emerson K, Russo RC, Lund RE, Thurston R V. 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. J Fish Res Board Canada. 32(12):2379–2383. doi:10.1139/f75-274.
8. Fang YY, Babourina O, Rengel Z, Yang XE, Pu PM. 2007. Ammonium and nitrate uptake by the floating plant Landoltia punctata. Ann Bot. 99(2):365–370. doi:10.1093/aob/mcl264.

9. Garnett TP, Shabala SN, Smethurst PJ, Newman IA. 2003. Kinetics of ammonium and nitrate uptake by eucalypt roots and associated proton fluxes measured using ion-selective microelectrodes. Funct Plant Biol. 30(11):1165–1176. doi:10.1071/FP03087.
10. Grosshans R, Lewtas K, Gunn G, Stanley M. 2019. Floating treatment wetlands and plant bioremediation: nutrient treatment in eutrophic freshwater lakes. Int Inst Sustain Dev.(1):1–37.
11. Jörgensen SE, R.A. Vollenweider. 1988. Guidelines of Lake Management: Vol. 1 Principles of Lake Management. Rep 1:193.
12. Kadlec RH, Wallace S. 2008. Treatment Wetlands Second Edition. Second. London: CRC Press.
13. Kataki S, Chatterjee S, Vairale MG, Dwivedi SK, Gupta DK. 2021. Constructed wetland, an eco-technology for wastewater treatment: A review on types of wastewater treated and components of the technology (macrophyte, biofilm, and substrate). J Environ Manage. 283 January:111986. doi:10.1016/j.jenvman.2021.111986.
14. Li H, Cui Z, Cui H, Bai Y, Yin Z, Qu K. 2023. Hazardous substances and their removal in recirculating aquaculture system: A review. J. Aquaculture 569: 739399. https://doi.org/10.1016/j.aquaculture.2023.739399.
15. Lin YF, Jing SR, Lee DY. 2003. The potential use of constructed wetlands in a recirculating aquaculture system for shrimp culture. J. Environmental Pollution 123(1):107-113. https://doi.org/10.1016/S0269-7491(02)00338-X.
16. Lincoln T, Zeiger E. 2002. Plant Physiology. 3rd ed. Volume 34th. doi: 10.1093/aob/mcg079
17. Masters B. 2012. The ability of vegetated floating Islands to improve water quality in natural and constructed wetlands: A review. Water Pract Technol. 7(1). doi:10.2166/wpt.2012.022.
18. Montoya R, Velasco M. 2000. Role of bacteria on nutritional and management strategies in aquaculture systems. Glob Aquac Alliance- Advocate. April:35–36.
19. Price CS, Morris JA. 2013. Marine cage culture and the environment: Twenty-first-century science informing a sustainable industry. Mar Finfish Aquac Environ.
20. Rahmawan AJ, Effendi H, Suprihatin S. 2019. Potensi rumput vetiver (*Chrysopongon zizanoides* L.) dan kangkung (*Ipomoea aquatica* Forsk.) sebagai agen fitoremediasi limbah industri kayu. Journal Nat Resour Environ Manag. 9(4):904–919. doi:10.29244/jpsl.9.4.904-919.
21. Satya A, Chrismadha T, Sulawesty F, Yoga GP, Mardiyati Y. 2014. Penyisihan nutrien dengan kultur *Eichornia crassipe*s dalam air limbah kolam ikan resirkulasi semi tertutup pendahuluan. 2014(2):157–167.
22. Singh V, Thakur L, Mondal P. 2014. Removal of lead and chromium from synthetic wastewater using *vetiveria zizanioides*. Clean - Soil, Air, Water. 43(4):538–543. doi:10.1002/clen.201300578.
23. Somprasert S, Mungkung S, Kreetachat N, Imman S, Homklin S. 2021. Implementation of an integrated floating wetland and biofilter for water treatment in Nile tilapia aquaculture. J Ecol Eng. 22(8):146–152. doi:10.12911/22998993/140267.
24. Susanti E, Wulandari S, Henny C, Melati I. 2019. Pengolahan air limbah budidaya berbasis IMTA (integrated multi trophic aquaculture) menggunakan constructed treatment wetland – surface flow system. Pros Pertem Ilm Tah Ke-1V MLI 2019.
25. Syah R, Fahrur M, Suwoyo HS, Makmur M. 2017. Performance of intensive shrimp pond wastewater treatment plant. Media Akuakultur. 12(2):95. http://ejournal-balitbang.kkp.go.id/index.php/ma/article/view/6140.
26. Tchobanoglous G, L. Burton F, Stensel DH. 2004. Metcalf & Eddy: Wastewater Engineering: Treatment and Reuse. McGraw Hill Companies, Inc.(7):421.
27. Timmons MB, Ebeling J, Wheaton F, Summerfelt S, B. Vinci. 2002. Mass Balances, Loading Rates, and Fish Growth.
28. Torres AP, Mickelbart M V., Lopez RG. 2010. Leachate volume effects on pH and electrical conductivity measurements in containers obtained using the pour-through method. Horttechnology. 20(3):608–611. doi:10.21273/horttech.20.3.608.
29. Truong P, Carlin G, Cook F, Thomas E. 1996. *Vetiver* grass hedges for water quality improvement in acid sulfate soils, Queensland, Australia.
30. Trussel R. 1972. The percent un-ionized ammonia in aqueous ammonia solutions at different pH levels and temperatures un-ionized ammonia. J Fish Res Board Canada, 29(10), 1972(4):1505–1507. doi:10.11.1139/f72-236
31. Turcios AE, Papenbrock J. 2014. Sustainable treatment of aquaculture effluents- What can we learn from the past for the future? Sustain. 6(2):836–856. doi:10.3390/su6020836.
32. Vymazal J. 2010. Constructed wetlands for wastewater treatment. Water (Switzerland). 2(3):530–549. doi:10.3390/w2030530.
33. Wang W, Yang H, Wang X, Jiang J, Zhu W. 2010. Factors affecting aluminum speciation in drinking water by laboratory research. J Environ Sci. 22(1):47–55. doi:10.1016/S1001-0742(09)60073-5.
34. White SA, Cousins MM. 2013. Floating treatment wetland aided remediation of nitrogen and phosphorus from simulated stormwater runoff. Ecol Eng. 61:207–215. doi:10.1016/j.ecoleng.2013.09.020.