Investigation of the Nutrient and Organic Matter Removal in Surface Water by Aquatic Plants: A Laboratory Scale Study

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ABSTRACT

The intensification of urbanization and industrial activities has precipitated a substantial influx of nutrients and organic pollutants into surface water systems, thereby exacerbating water quality degradation and posing significant threats to aquatic ecosystems and human health. Phytoremediation, characterized by the use of aquatic plants to sequester, metabolize, and remove contaminants from water bodies, emerges as a compelling, eco-friendly method. In this study, individual and combined cultivation experiments of three aquatic plants, including *Microsorum pteropus "Narrow"* (AQ1), *Cyperus haspan L.* (AQ2), and *Salvinia cucullata* (AQ3), in different water samples collected from landscape lakes were conducted. This study aimed to quantify the ability of these plants to enhance water quality by reducing nutrients (measured as Total Nitrogen - TN and Total Phosphorous - TP) and organic pollutant levels (measured as biological oxygen demand BOD_5), while also assessing their growth and adaptation during the experiment. Results showed that highest removal efficiencies of nutrients and organic matter were obtained in the case of AQ2. The combined cultivation ratio between AQ1 and AQ2 of 1:2 based on weight percentage (% w.t.) was also determined as the most appropriate design, since relatively similar removal efficiencies were found in both water samples: BOD_5 (29.8%), TN (66.7%), TP (91.7%), Coliform (64.9%) with internal landscape lake (TDT water sample) and BOD_5 (32.1%), TN (60.0%), TP (92.9%), Coliform (16.7%) with external landscape lake (HBN water sample). This study not only deepened the scientific understanding of plant-based water purification processes but also demonstrates their practical applications in enhancing urban water management practices sustainably.

Keyword: *Microsorum pteropus "Narrow"*/ *Cyperus haspan L.*/ *Salvinia cucullata*, aquatic plant/ Removal of nutrients and organic matter

1. INTRODUCTION

Surface water pollution in big city is a current concern since it affects the urban landscape and life quality of citizen. Ho Chi Minh city (HCMC), one of the largest cities in Vietnam, is also suffering from the negative impacts of water pollution. Due to the population growth of about 9 million people and a rapid urbanization, the nutrients and organic pollutants occurring in surface water systems are posing significant threats to aquatic ecosystems and human health. Thus, the treatment and regeneration of surface water resources has become an urgent priority in HCMC.

Traditional water treatment technologies, while effective, often entail the use of chemical agents that can disrupt aquatic life and lead to secondary pollution. Phytoremediation, characterized by the use of aquatic plants to sequester, metabolize, and remove contaminants from water bodies, emerges as a compelling, eco-friendly alternative [1-3]. During the phytoremediation, the organic matters and nutrients can be eliminated through different mechanisms including biological degradation by microorganism, settling, and filtration in which biological activities play the most important role [4]. Furthermore, heavy metals removal by phytoremediation have been reported by many studies [5-7]. In addition, aquatic plants also contribute on the environmental protection and increase urban aesthetics [2, 8]. Specifically, aquatic plants increase the habitat for aquatic animals, enhancing biodiversity and balancing the ecosystem.

Several common aquatic plants have been investigated by recent studies for the treatment of organic and nutrient pollutants in surface water systems, domestic and industrial wastewater sources, such as water hyacinth (*Eichhorina crassipes*) [9, 10], vetiver grass (*Vetiver zizanioides*) [11, 12], reed

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grass (*Phragmites australis*) [13, 14]. Among them, narrow-leaf fern (*Microsorum pteropus "Narrow"*), haspan plant (*Cyperus haspan L.*) and *Salvinia cucullata* are also capable of removing nutrients and organic matter from surface water [2, 8]. Specifically, study found that Cadmium could be accumulated by *Microsorum pteropus "Narrow"* with high capacity (i.e., 400 mg Cd/1kg dry mass) [15]. *Salvinia sp.* was reported to treat domestic wastewater during the phytoremediation process with high performance in removal of organic matters [16]. Although there are several artificial aquarium models using these three aquatic plants for the landscaping purposes, few experimental studies examined to demonstrate their capacity and practical applicability for treatment of organic and nutrients pollutants in surface water.

Therefore, in this study, three above aquatic plant species, including *Microsorum pteropus "Narrow", Cyperus haspan L., and Salvinia cucullata*, are employed in experimental designs in lab-scale, aiming to quantify the ability of these plants to enhance water quality by reducing nutrients and organic pollutant levels while also assessing their growth and adaptation during the experiment. The actual surface water samples are collected from landscape lakes in Ho Chi Minh City to stimulate the natural water sources. The results and findings are expected to contribute on the scientific database of aquatic organisms for surface water treatment. Therefore, this study not only deepened further understanding of plant-based water purification processes but also demonstrates their practical applications in enhancing urban water management practices sustainably.

2. METHODOLOGY

2.1 Raw surface water sampling

Two surface water sources in District 7, HCMC were investigated in this study, including (1) the TDTU water samples collected from the internal lake of a university campus and (2) the HBN water samples from a landscape external lake. For each water source, the sampling was conducted at 3 different positions as illustrated in Figure 1. Water samples collected were then mixed together to obtain the representative samples. The sampling was conducted in two batches for two different experiments. All samples before analysis were preserved according to the standard methods.

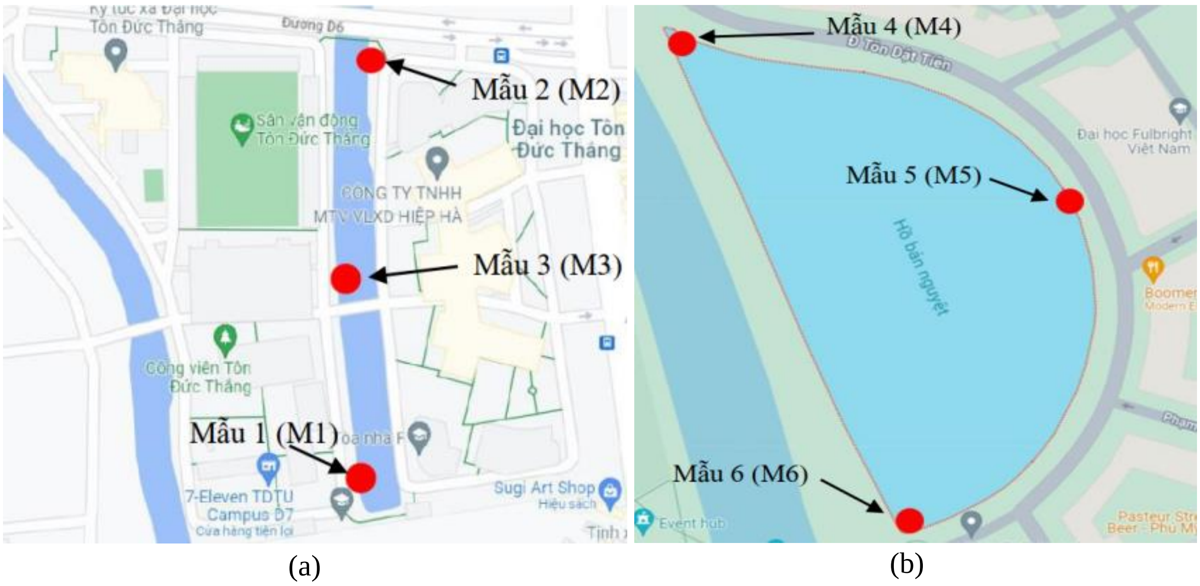

Figure 1. Raw water sampling locations: (a) the TDTU and (b) the HBN water samples

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2.2 Water characterization

Water quality was analyzed and characterized by considering pH, BOD_5, total nitrogen (TN), total phosphorus (TP) concentration, and total coliform. All parameters were determined according the Vietnam national standards and specific analytical laboratory instruments (Table 1).

Table 1. Analytical methods and instruments

No	Parameters	Values (before experiment)		National analytical methods	Analytical instruments
		TDTU sample	HBN sample		
1	pH	7.48	7.66	TCVN 6492:2011	pH meter, model AD12 Adwa Instruments
2	DO	3.48	4.38	TCVN 7325:2015	DO Extech DO600-K
3	BOD_5	8.96	6.26	SMEWW 5210 B : 2005	
5	TN	3.26	3.36	TCVN 6638:2000	KjelMaster K-375, BUCHI
7	TP	0.27	0.21	SMEWW 4500 – P.D :20017	Genesys 10S UV-VIS
8	Total coliform	8600	5600	AOAC Official Method 991.14	Petrifilm plate E.Coli/Coliform Count (EC) 3M, code: 6404

2.3 Aquatic plant experimental cultivation

- *Aquatic plant sampling*

Three aquatic plant samples, including *Microsorum pteropus "Narrow"* (AQ1), *Cyperus haspan* (AQ2), *and Salvinia cucullata* (AQ3), were natural and collected from suburban areas of Ho Chi Minh City. After removing the impurities on the branches and leaves, these aquatic species were grown individually for 07 days in clean water tanks to remove the remaining dirt and increase the ability to adapt to the water environment before moving to the experimental cultivation step.

- *Experimental cultivation design*

Eight plastic reactors (53 x 37 x 29 cm in size, weight of 150 g, with a capacity of 25 liters) were used for each cultivation experiment, in which 6 reactors were used for cultivation of 3 aquatic plants with 2 surface water samples taken from landscape lakes as described in section 2.1 and 2 reactors were employed as control samples (without aquatic plants) (Table 2). Depending on the experiment, individual or mixed aquatic plant species were cultivated in each reactor accordingly. The aim of experiment 1 is to assess the capacity of individual plant species for removal of nutrient and organic matter, while experiment 2 is designed to explore synergistic effects in mixed plant cultures and determine the most effective ratios (by mass) for pollutant removal.

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Table 2. Experimental cultivation design

No.	Reactor ID	Type of aquatic plant (Total fresh weight, gram[(a)])	Type of surface water	Remark
Experiment 1 - individual aquatic plant cultivation				
1	TDT1_0	No aquatic plant	TDTU water samples (mixed samples obtained from 3 sampling sites M1, M2, M3_phase 1)	Control sample
2	TDT1_1	AQ1 (162.72 gram)		Reactor 1
3	TDT1_2	AQ2 (164.82 gram)		Reactor 2
4	TDT1_3	AQ3 (153.0 gram)		Reactor 3
5	HBN1_0	No aquatic plant	HBN water samples (mixed samples obtained from 3 sampling sites M4, M5, M6_phase 1)	Control sample
6	HBN1_1	AQ1 (157.62 gram)		Reactor 4
7	HBN1_2	AQ2 (159.34 gram)		Reactor 5
8	HBN1_3	AQ3 (145.0 gram)		Reactor 6
Experiment 2 - Combined aquatic plant cultivation at different mass ratio, based on results of Experiment 1				
1	TDT2_0	No aquatic plant	TDTU water samples (mixed samples obtained from 3 sampling sites M1, M2, M3_phase 2)	Control sample
2	TDT2_1	AQ1 and AQ2[(b)]		Ratio of 2:1
3	TDT2_2			Ratio of 1:2
4	TDT2_3			Ratio of 1:1
5	HBN2_0	No aquatic plant	HBN water samples (mixed samples obtained from 3 sampling sites M4, M5, M6_phase 2)	Control sample
6	HBN2_1	AQ1 and AQ2 [(b)]		Ratio of 2:1
7	HBN2_2			Ratio of 1:2
8	HBN2_3			Ratio of 1:1

[(a)]*Total fresh weight of aquatic species was determined on the first day of the cultivation experiment.*
[(b)]*The selection of combined aquatic plant in experiment 2 was determined based on the results of experiment 1.*

Each experiment was performed with a water loading of 23 liters/first day of the experiment. During the experiment (30 days), surface water was not supplemented in the reactors in order to accurately determine the treatment efficiency of the investigated aquatic species during the experimental period. The sampling and analysis of water quality parameters, including pH, dissolved oxygen (DO), BOD_5 concentration, total nitrogen (TN), total phosphorus (TP) and total coliform, were carried out sequentially at specific time to evaluate the treatment efficiency. The analytical method is presented in Table 1.

In addition, study also monitored the growth performance, biomass accumulation, and health of the plants over the experimental period to determine their resilience and adaptability to urban water conditions. For this, several parameters, such as the total weight, root length, leaf size, and biomass of aquatic plants were monitored and considered.

3. RESULTS AND DISCUSSION

3.1 Changes of water quality in individual aquatic plant cultivation (Experiment 1)

The results of the individual cultivation experiments for 03 types of aquatic plants during 30 days showed that each aquatic plant has different ability in the removal of nutrients and organic matter, depending on their biological characteristics.

Specifically, for organic matter measured by BOD_5 concentration, all three AQ1, AQ2, and AQ3 species, in general, did not show high efficiency. After 30 days of cultivation, the highest BOD_5 removal efficiency was found in the AQ3 case (13.9% - reactor TDT1_3 and 14.0% - reactor HBN1_3, Table 3). The biodegradation of organic matter in cultivation experiments basically removes dissolved organic compounds. The remaining organic matter and settled solids can be only removed through sedimentation. This biodegradation mechanism occurs when dissolved organic compounds are carried into the biofilm layer attached to the submerged part of the plant and decomposed by microorganisms, mainly bacteria and fungi, living in the roots. The high-density root system is the adhesion medium of the microorganisms growing in water; increasing the contact density between microorganisms and the

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water source. Accordingly, aquatic plants facilitate microorganisms to carry out the biodegradation process. They also help transport oxygen into the root zone through diffusion [3].

Table 3. Water treatment efficiency of individual aquatic plant cultivation (Experiment 1)

Parameters	Treatment efficiency (%) of different reactors, corresponding to specific aquatic plant					
	AQ1 plant		AQ2 plant		AQ3 plant	
	Reactor TDT1_1	Reactor HBN1_1	Reactor TDT1_2	Reactor HBN1_2	Reactor TDT1_3	Reactor HBN1_3
BOD_5	13.9%	14.0%	KĐ	KĐ	11.2 %	14.8 %
TN	60.7%	50.0 %	82.1 %	66.7%	36.9 %	44.4 %
TP	76.0 %	72.2 %	92.3%	86.9%	22.0 %	26.0 %
Coliform	Not satisfy	Not satisfy	Not satisfy	Not satisfy	Not satisfy	Not satisfy

Regarding nutrient parameters (i.e., TN and TP), the highest TN removal (82.1% - TDT12 and 66.7% - HBN12) and TP removal (92.3% - TDT1_2 and 86.9% - HBN1_2) were found in the case of AQ2 (Table 3). The nutrient treatment efficiency of aquatic plants has been report by several studies due to following mechanisms: (i) simple amino acids can be absorbed directly by plant roots, (ii) aquatic plants secrete some specific enzymes to break down organic N, P compounds into simple compounds that they can absorb, and (iii) the microbial community living in the root zone of plants has the ability to mineralize organic compounds to provide mineral nutrients for plants [1, 17].

However, in term of Coliform reduction, none of investigated aquatic plants showed positive results since the analysis found that the number of Coliform did not change much during the 30 days of experiments. This indicates that the phytoremediation mechanism activated by these aquatic plants may not be efficient for Coliform removal.

3.2 Growth performance of aquatic plants

In order to evaluate the growth and biomass increase of aquatic plants during the 30 days experimental cultivation, the study consider the changes of total weight, the length of leave/ branch/ petiole diameter, and the length of root (Table 4).

Results showed that three aquatic plants have adapted and grown strongly with the experimental conditions. The plant morphology and pigmentation were well developed based on the actual observation. Most of criteria monitored during 30 days of cultivation were increased positively, indicating the growth of aquatic plants to biodegrade organic matter and nutrients in water. The cultivation was carried out in static condition of laboratory, where the effects of other environmental factors (e.g., water flow, air, light, temperature, and other recalcitrant pollutants) were ignored. The actual conditions of environment may affect the growth rate and treatment efficiency of plants.

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Table 4. Evaluation of the growth and biomass increase of aquatic plants

Criteria	AQ1 plant				AQ2 plant				AQ3 plant			
	TDT water		HBN water		TDT water		HBN water		TDT water		HBN water	
	1st day	30th day	1st day	30th day	1st day	30th day	1st day	30th day	1st day	30th day	1st day	30th day
Total weight (g)	162.72	186.68	157.62	179.07	164.82	169.82	159.34	170.31	153.00	132.70	145.00	122.98
Length of leave/ branch/ petiole diameter (cm)	13.8	15.5	11.75	14.63	82.2	100.4	88.6	97/7	1.6	2.5	1.5	2.5
Length of root (cm)	-	-	-	-	18.9	22.9	22.1	25.6	2.6	3.3	2.9	3.5
Number of branches	22	30	25	32	-	-	-	-	-	-	-	-

3.3 Changes of water quality in combined cultivation at different mass ratio (Experiment 2)

Based on the resulted obtained in Experiment 1 (Table 3), the AQ1 and AQ2 were chosen for the combined aquatic plant cultivation experiment (Experiment 2). The cultivation was carried out at different mass ratios of 1:2, 2:1 and 1:1 as shown in Table 2. Results showed that each ratio had different treatment efficiency of nutrient and organic matter, depending on the biological characteristics of the dominant species during the cultivation (Table 5 and 6).

Table 5. Treatment efficiency of nutrient and organic matter of combined cultivation at different mass ratio (Experiment 2)

Parameters	Treatment efficiency of combination of AQ1 and AQ2 plant, (%)					
	Mass ratio of 2:1		Mass ratio of 1:2		Mass ratio of 1:1	
	Reactor TDT2_1	Reactor HBN2_1	Reactor TDT2_2	Reactor HBN2_2	Reactor TDT2_3	Reactor HBN2_3
BOD_5	19.6 %	17.9 %	29.8 %	32.1 %	17.9 %	0.5 %
TN	66.7 %	78.6 %	66.7 %	60.0 %	74.4 %	63.6 %
TP	69.9 %	75.0 %	91.7 %	92.9 %	86.1 %	85.7 %
Coliform	Not satisfy	Not satisfy	14.9 %	16.7 %	16.2 %	Not satisfy

Specifically, all 03 combination ratios of AQ1 and AQ2 plants have relatively low BOD_5 treatment efficiency (i.e., < 35%, Table 5). A similar trend for both water samples investigated were found in the combination ratio of 2:1 since the BOD_5 treatment efficiency is about 17 - 19%. In contrast, there was a significant difference in BOD5 treatment efficiency with the combination ratio of 1:1, in which an efficiency of 17.9% was obtained with reactor TDT2_3 and only 0.5% was found with reactor HBN2_3. The combination ratio of 1:2 has the best BOD_5 treatment efficiency (i.e., 29.8% with reactor TDT2_2 and 32.1% with reactor HBN2_2). Overall, the results of individual cultivation in experiment 1 and combined cultivation in experiment 2 indicated that the treatment efficiency organic matter of AQ1 and AQ2 in surface water was actually not high as expected.

However, for the nutrients removal, all combined ratios of AQ1 and AQ2 showed better results since the treatment efficiency of TN and TP were over 60% (Table 5). Especially, a very high treatment efficiency of TP (i.e., over 90%) was achieved with the combination ratio of 1:2 for both water samples (i.e., TDT2_2 and HBN2_3).

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In term of Coliform removal, different results were found in each reactor. The most positive response (i.e., 14.9% at reactor TDT2_2 and 16.7% at reactor HBN2_2) was also obtained with the combination ratio of 1:2. Other investigated ratios of AQ1 and AQ2 did not demonstrate the ability to remove bacteria in both water samples.

The changes of organic matter and nutrients concentrations along with total coliform over time in 02 combined cultivating reactors of AQ1 and AQ2 species at the ratio of 1:2 (i.e., reactor TDT2_2 and HBN2_2) are shown in Figure 2.

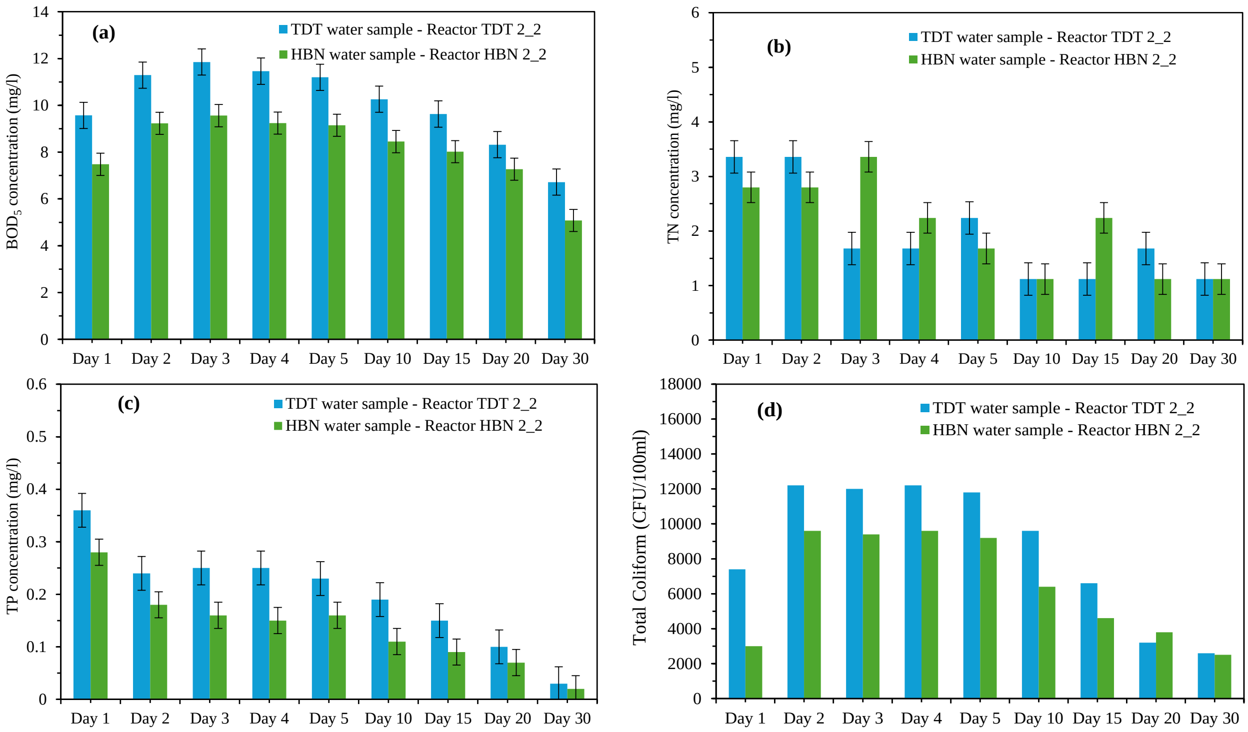

Figure 2. Changes in (a) BOD_5, (b) TN, (c) TP concentration and (d) total coliform in 02 combined cultivation reactors (TDT2_2 and HBN2_2) at the mass ratio of 1:2)

Table 6. Evaluation of water quality after 30 days of combined cultivation of AQ1 and AQ2

Parameters	TDT water sample			HBN water sample		
	Ratio 2:1, TDT2_1	Ratio 1:2 TDT2_2	Ratio 1:1 TDT2_3	Ratio (2:1) HBN2_1	Ratio (1:2) HBN2_2	Ratio (1:1) HBN2_3
pH	7.07±0.19	6.17±0.16	7.61±0.15	6.92±0.12	6.24±0.13	7.35±0.16
BOD_5 (mg/l)	7.93±0.42	6.72±0.49	8.16±0.58	6.01±0.62	5.08±0.46	7.23±0.67
DO (mg/l)	5.86±0.20	4.57±0.20	4.97±0.28	6.43±0.21	5.41±0.11	5.76±0.13
TP (mg/l)	0.11±0.01	0.03±0.01	0.05±0.02	0.07±0.02	0.02±0.01	0.04±0.02
TN (mg/l)	1.12±0.05	1.12±0.03	0.86±0.02	0.60±0.02	1.12±0.02	1.02±0.04
Total coliform (CFU/100 ml)	12.800	2.600	6.200	12.000	2.500	8.400
Classify of water quality based on national standard QCVN 08:2023/ BTNMT	Level D	Level B	Level C	Level D	Level B	Level D

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Water quality in cultivation reactors at different combination ratios was then compared with QCVN 08:2023/BTNMT - the national technical regulation on surface water quality in Vietnam. The results showed that the combined cultivating reactor of AQ1 and AQ2 at the mass ratio of 1:2 helped improve the quality of both surface water samples. Specifically, the water quality can reach level B according to QCVN 08:2023/BTNMT - Table 6). This is an important result to affirm the applicability of this study to implement the cultivation in the actual situation.

4. CONCLUSIONS

Based on laboratory experiments and data analysis in this study, some conclusions were drawn as follows:

1. The study demonstrated successfully the ability of *Microsorum pteropus "Narrow" (AQ1), Cyperus haspan L. (AQ2),* and *Salvinia cucullata (AQ3)* to reduce the organic matter and nutrients through phytoremediation, in which *Cyperus haspan L. (AQ2)* showed better performance.

2. The combination of *Microsorum pteropus "Narrow" (AQ1), Cyperus haspan L. (AQ2)* with a mass ratio of 1:2 in cultivation reactor could help to improve the surface water quality and reach the level B of the national standard QCVN 08:2023/BTNMT of surface water, which confirms the roles of aquatic plant to enhance urban water treatment and management.

3. Results from the study promote the development of a scalable phytoremediation model that can be integrated into urban water management strategies, emphasizing sustainability and ecological benefits.

4. However, the study was conducted in a laboratory scale to mitigate the effects of natural factors. Therefore, it is suggested that further work should be carried out in the scale of natural lakes to consider the effects of dynamic water flow and pollution load to more accurately determine the ability of these aquatic species for treatment of organic matter and nutrients. This helps to demonstrate the practical applicability of this method to improve the quality of urban surface water sources.

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