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THE ROLE OF AQUATIC PLANTS AND MICROORGANISMS IN DOMESTIC WASTEWATER TREATMENT

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Abstract

This study aimed to assess the ability of microorganism populations and two aquatic plant species (water hyacinth - *Eichhornia crassipes Solms* and water morning glory - *Ipomoea aquatica)* to treat domestic wastewater in Nhue Giang pond, Tay Mo village, Tu Liem District, Hanoi City in Vietnam. The results showed that microorganism populations in the pond water contained all of groups of microorganisms including bacteria, Actinomycetes, mold and yeast. In water inlet and outlet samples, bacteria has the largest number in population ($2.1x10^6$ and $8.7x10^5$ CFU/mL at inlet and outlet), accounting for 99.91% of total microorganisms. Regarding the number of microorganisms attached on roots of aquatic plants, the highest number was recorded for bacteria, while the numbers of Actinomycetes, mold and yeast were quite small. The total number of microorganisms attached on water hyacinth roots is $2.5x10^6$ CFU/g and $1.5x10^6$ CFU/g (at inlet and outlet sample) higher than that on water morning glory roots in both sampling sites.

The wastewater treatment efficiency for TSS, COD, NH_4^+ and PO_4^{3-} parameters at the site without aquatic plants was in the range of 1% to 5% only, while treatment efficiency for those parameters at location with aquatic plants was much higher. Particularly, it was in range of 37.8% - 53.3% for TSS; 44.4% - 53.4% for COD; 56.7% - 61.4% for PO_4^{3-} and 26.8% - 32.6% for NH_4^+. All the lower values belonged to water morning glory sample and the higher values belonged to water hyacinth sample at the outlet.

Key words: aquatic plants, domestic wastewater, microorganisms

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1. Introduction

Water pollution is considered as one of the most pressing environmental concerns. Together with the rapid development in socio-economic, urbanization and high population growth, the problem of domestic wastewater is increasingly serious in Vietnam. The decline in water quality causes detrimental effects not only on aquatic ecosystems but also human health. Water-related diseases such as diarrhea, cholera, typhoid fever account for nearly a half of the total infectious diseases in Vietnam. Therefore the treatment of wastewater is highly needed. Among various technologies for wastewater treatment, biological method using microorganisms and aquatic plants shows many advantages such as low-cost, simple technology and high treatment efficiency. It has been well-documented that aquatic macrophytes and microbial activities can be effectively involved in pollutant transformation and removal in water bodies (Kivaisi 2001; Stottmeister et al., 2003; Vymazal, 1998; Vymazal and Kröpfelová, 2008).

A number of wastewater treatment systems using aquatic plants have been applied in many countries over the world, e.g., the water hyacinth aquatic treatment system for ammonia removal and effluent polishing in Roseville, California (Hauser, 1984), the system using water hyacinth and algae for improving water quality in Varanasi, India (Tripathi and Shukla, 1991), the pilot-scale lotus and *Hydrilla* system for domestic wastewater treatment in Hat Yai,

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Thailand (Kanabkaew and Puetpaiboon, 2004). In Vietnam, many scientists have been also interested in investigating aquatic plants in wastewater treatment, for example, the study on the use of water hyacinth for domestic wastewater treatment in a commune of Vinh Phuc City and the water hyacinth and water dropwort system for treatment of livestock effluents in An Giang Province. Some other researches studied the role of aquatic plants in constructed wetland for wastewater treatment (Loan, 2006; Loan et al., 2010), the results showed high treatment efficiency in organic matters, nitrogen and phosphorus removal.

The research contents of this study are: (i) To assessment of the situation and characteristics of wastewater in the Nhue Giang village pond; (ii) to determine the number of microorganism populations in wastewater and roots of aquatic plants in the pond; (iii) to determine the change of parameters characteristic of wastewater after treatment by aquatic plants and microorganism, which preliminarily evaluate the effectiveness of wastewater treatment capabilities of aquatic plants and microorganism

2. Experimental

2.1. Material

Wastewaters are collected at the Nhue Giang village pond - where the pond water contains the domestic wastewater (about 5.5m^3/day) of 15 households from Nhue Giang village, Tay Mo commune, Tu Liem District, Hanoi city. It has an area of about 1000 m^2, with depth average of 1.5 m. The pond is a man-made, surrounded by a low brick wall and the bottom is clay soil layer.

The water volume is about 1200 m^3. The pond water is almost stagnant (the speed of water flow is about 0.5 m/day), and water volume is not mixed. In the pond, two species of aquatic plants, that are water morning glory (*Ipomoea aquatica*) and water hyacinth (*Eichhornia crassipes Solms*), were grown in confined areas of about 40m^2 at inlet and outlet area. Figs. 1a and 1b illustrated the two kinds of aquatic plants.

2.2. Methodology

Wastewater samples (1L each) were obtained by collecting at three different sampling points in the depth of 15 cm at pond inlet, then mixing them to get composite samples. The same procedure is applied for collecting wastewater sample at the outlet. The wastewater samples were preserved in crushed ice box and brought immediately to the laboratory for analysis. The composite samples were kept cool with ice or a refrigeration system set at 4°C at laboratory before analysis. Roots of water hyacinth and morning glory were taken from several randomly selected plants. Then they were brought immediately to the laboratory for analysis. In the laboratory, the roots of several plants were cut and mix together and 1 g was taken for counting of microorganism numbers.

Methodology used for the various tests are analysis of chemical and physical parameters in water those defined in "Standard Methods" are as follows:

- Suspended Solids, SS: Method 208D, "Total Non-filterable Residue Dried at l03-l05^{o}C";
- pH: 220 EPA Method 150.1 was used to analyze aqueous samples. In this method, the pH of a sample is determined electrometrically using either a glass electrode in combination with a reference potential or a combination electrode.
- COD: Chemical Oxygen Demand (COD) was measured using EPA Methods 410.1. Organic and oxidizable inorganic substances in the sample are oxidized by potassium dichromate in 50% sulfuric acid solution at reflux temperature. Silver sulfate is used as a catalyst and mercuric sulfate is added to remove chloride interference. The excess dichromate is titrated with standard ferrous ammonium sulfate, using ortho-phenanthroline ferrous complex as an indicator.

Ammonia nitrogen: Method 418D, "Acidimetric Method". Take 5mL of wastewater into test-tube, followed by adding 0.2mL saline ($KNaC_6H_4O_6$) and 0.3mL Nessler reagent mix well and let stand for 10 minutes. Ammonium in alkaline environment reacts with Nessler reagent (K_2HgI_4) forming complexes that are yellow or dark brown.

(a) (b)

Fig. 1. a) Water morning glory (*Ipomoea aquatica*); **b)** Water hyacinth (*Eichhornia crassipes Solms*)

The solution is brought to the absorbance measurements. Ammonium concentration in the sample determined based on the calibration curve. The standard curve of ammonium is prepared by dissolving 14.861mg NH_4Cl, which was dried at 103^0C for about 1 hour, in distilled water as a standard solution concentration of 5 mg /L.

- PO_4^3 Ascorbic Acid-Molybdate Method. Take 10mL sample into 50mL volumetric flask, add about 10 mL of distilled water, 2 mL ammonium molidat 2.5% and 1 mL of ascorbic acid. Boil the solution slightly until blue color appears. Let the solution react for 20 min then measure the absorption at 880nm using distilled water as a blank. The phosphate concentration of sample is determined based on the calibration curve.

- Total coliform: Standard methods 9221 b. Standard total coliform fermentation technique (APHA, 1995). The sample is diluted to 1/100; 1/1000 and 1/10000

Take 1 mL of each diluted sample put into a 3 series of five fermentation tubes. Each tube contains 9 mL lauryl tryptose broth media for the bacteria to thrive on. The group of bacteria (*Escherichia coli, E. Aurescens, E. freundii, E. Intermedia; Aerobacter, Aerogenes, A. Cloacae*) as total coliform fermented lactose with gas formation within 48 hours at 35°C. Tubes with growth and gas production in this media were recorded as positive. Based on positive test-tubes of three series, the probable number of bacteria originally present in the sample can be determined according to result from a 5-tube MPN table.

The medium for microorganism isolation are:

- MPA medium for bacteria (Pepton: 10 g, NaCl: 10 g, Agar: 15 g, H_2O: 1L)
- Hansen medium for yeast (Starch: 50 g, Pepton: 5 g, $MgSO_4.7H_2O$: 3 g, KH_2PO_4: 3 g, K_2HPO_4: 3g, Agar: 20 g, H_2O: 1L);
- Czapecdox medium for mold (Starch: 30 g, $NaNO_3$: 3g, KH_2PO_4:1g, $MgSO_4.7H_2O$: 0.5 g, KCl: 0.5 g, $FeSO_4$: 0.01 g, Agar: 20 g, H_2O: 1L);
- Gause medium for *Streptomyces* (Starch: 20 g, KNO_3: 1g, K_2HPO_4: 0.5 g, $MgSO_4.7H_2O$: 0.5 g, NaCl: 0.5 g, $FeSO_4$: 0.01 g, Agar: 20 g, H_2O: 1L).

Isolation of microorganism in wastewater: 1 mL of wastewater was taken and diluted in a test tube containing 9mL of sterile distilled water to get the dilution of 10^{-1}. The dilution procedure was continued until it reached the appropriate dilution. Isolation of microorganism in plant roots: 1 gram of root sample was crushed in sterile porcelain cup, and then it was put into a flask containing 100mL of distilled water, from that 1mL of the diluted sample was taken and put into a test tube containing 9mL of sterile distilled water to get the dilution 10^{-3}. The dilution procedure was continued until it reached the appropriate dilution.

After the dilution, one water drop of diluted samples was taken and put into the middle of the agar plates, that were prepared with different kind of media for different kind of microorganisms, and the inoculum was spread over the whole disk area. Then, the agar plates were covered and placed in an incubator at 28 - 30^0C. After 2-5 days the agar plates were removed and the numbers of grown colonies were counted. The number of microorganisms was determined by Eq. (1).

$$X = a \times b \times c \qquad (1)$$

where:• X - number of CFU (colony forming unit) in 1 g sample

a - number of colonies on agar plates

b - the inverse of the dilution

c - number of water drop/1mL

2.3. Experimental design

Two water samples from inlet (W1) and outlet (W2) were taken to analyze the water quality of the pond. Wastewater samples were taken from water hyacinth area (E1 and E2) and water morning glory (I1 and I2) at inlet and outlet every 4 days for 6 times. The water samples were analyzed three times, and the presented results were mean values with standard deviations. The experiment was conducted in dry season (April 2012) when no raining was occurred during experimental period. Fig. 2 shows a pond shape and the sampling points.

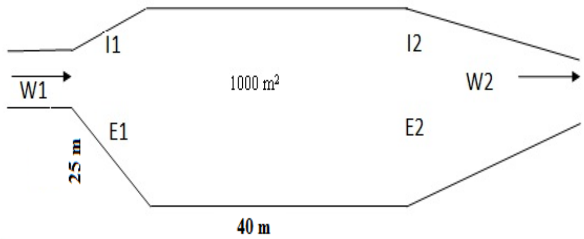


Fig. 2. Sketch map of sampling points on Nhue Giang pond

where: W1 - the wastewater was collected from inlet area; W2 - the wastewater was collected from outlet area; I1 - the wastewater was collected from area of water morning glory (*Ipomoea aquatica)* in the inlet area; I2 - the wastewater was collected from area of water morning glory (*Ipomoea aquatica)* in the outlet area; E1 - the wastewater was collected from area of water hyacinth (*Eichhornia crassipes Solms)* in the inlet area; E2 - the wastewater was collected from area of water hyacinth (*Eichhornia crassipes Solms)* in the outlet area.

3. Results and discussion

3.1. Assessment of the status and typical parameters of domestic wastewaters in Nhue Giang pond

The mean concentrations of parameters in Nhue Giang pond are shown in Table 1 (samples taken at two points: W1 and W2). The results showed that the pond water is contaminated; almost all the parameters exceeded the Vietnamese standards, except pH and PO_4^{3-}. The concentration of ammonium was about 2.1 times higher than the Vietnamese standard. The concentrations of COD were high, 168 mg/L in sample W1 and 165 mg/L in sample W2. The concentration of coliforms in W1 and W2 was 3.4 times and 2.3 times higher than the Vietnamese standard. It can be concluded that the pond is contaminated by domestic wastewater.

3.2. Microbial populations in wastewaters and in roots of aquatic plants in Nhue Giang pond

3.2.1. Microbial populations in wastewaters in Nhue Giang pond

The mean microbial populations in wastewater of Nhue Giang pond are shown in Table 2: the results showed that the microbial communities in the pond are diverse, with four groups of microorganisms including bacteria, actinomycetes, mold and yeast.

In both samples, the number of bacteria was the largest: in W1 sample, the number of bacteria was 2.1x 10^6 CFU/mL, accounting for 99.91% of the total number of microorganisms. In W2 sample, the number of bacteria was 8.7x 10^5 CFU/mL, accounting for 92.02% of total microorganisms.

3.2.2. Microbial populations in roots of aquatic plants in Nhue Giang pond

The mean microbial populations in roots of aquatic plants (water hyacinth and water morning glory) in Nhue Giang pond are shown in Table 3.

The results showed that the major population in roots is bacteria. Mold and yeast occupy only a small amount. The number of aerobic microorganisms on water hyacinth roots is higher than that on morning glory roots in both sampling sites, this can be explained by the structures of the roots: water hyacinth roots are branching cluster, thus the number of bacterial adhesion per unit weight (g) is much more.

Root structures in different aquatic plants can affect nutrient removal because there are different oxidic environment provided in the rhizosphere (Gersberg et al., 1986). Compared to water morning glory roots, water hyacinth roots have higher number of attached aerobic microorganisms. It suggests that water hyacinth can offer more oxic conditions which stimulate aerobic processes in decomposition of organic matters and other nutrients such as nitrogen and phosphorus. Pictures of microorganisms isolated from the roots of aquatic plants are shown in Fig. 3.

3.3. The changes in concentrations of parameters of wastewaters after treated by aquatic plants and microorganisms

Samples were taken every 4 days in the areas, where water hyacinth and water morning glory were present to determine the changes of wastewater parameters and compare the treatment ability of each aquatic plant. The analyzed parameters were total suspended solid (TSS), COD, NH_4^+ and PO_4^{3-}.

Table 1. The mean concentrations of parameters in wastewater from Nhue Giang pond

Parameter	***Unit***	***Sampling points***		***Type B****
		W1	***W2***	
Odour	-	Unpleasant		Unpleasant
TSS	mg/L	140.9±1.31	139.4±1.15	100
pH	-	6.8±0.27	7.2±0.46	5 – 9
COD	mg/L	168±1.73	165±13.23	-
NH_4^+	mg/L	21.3±1.06	20.17±1.19	10
PO_4^{3-}	mg/L	2.1±0.17	1.07±0.23	10
Coliforms	MPN/mL	17,000±866	11,500±2,500	5.00

*Note: *QCVN 14, (2008), (2008), Vietnamese national technical regulation on domestic wastewater, applied to domestic wastewater discharged into the receiving sources not used for drinking water supply.*

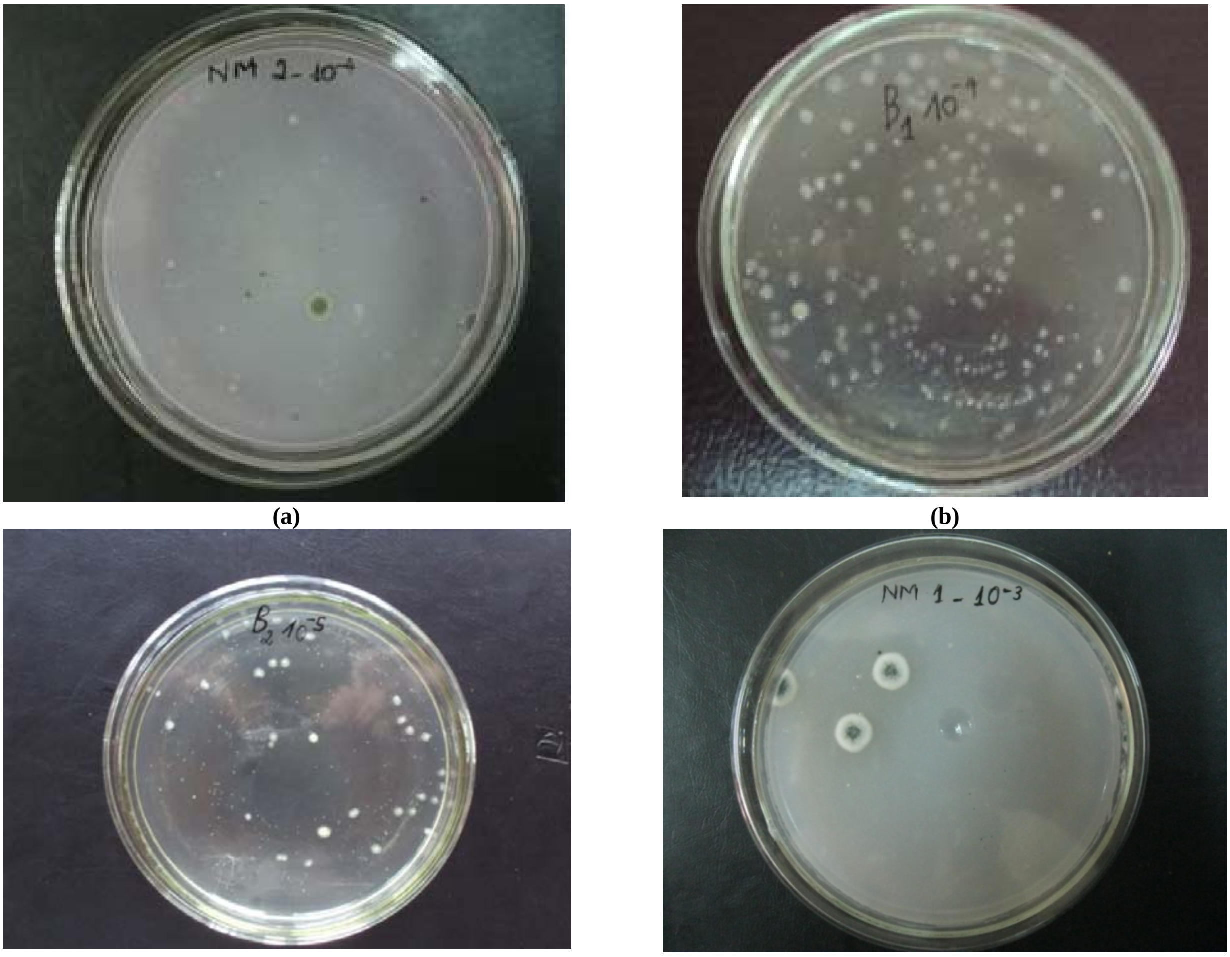
Table 2. The mean microbial populations in wastewater in Nhue Giang pond (CFU/mL)

Sample	***Bacteria***	***Streptomyces***	***Mold***	***Yeast***	***Total microorganisms***
W1	$2.1x10^6±0.13x10^6$	790±13.23	$504x10^2±0.78x10^2$	$560x 10^2±62.6x10^2$	$2.2x 10^6$
W2	$8.7x10^5±0.05x10^5$	410±6.24	$323x10^2±1.17x10^2$	$367x10^2±1.8x10^2$	$9.4x 10^5$

Table 3. The mean microbial populations in roots of aquatic plants (Water hyacinth and water morning glory) in Nhue Giang pond (CFU/g)

Sample	***Bacteria***	***Streptomyces***	***Mold***	***Yeast***	***Total microorganisms***
RI1	$13x10^5±0.38x10^5$	450±2.65	$270x10^2±2.64x10^2$	$490x10^2±4.58x10^2$	$1.4x 10^6$
RI2	$7x10^5±0.26x10^5$	380±5.29	$160x10^2±2.45x10^2$	$430x10^2±1.73x10^2$	$7.6x 10^5$
RE1	$24x10^5±0.44x10^5$	870±6.24	$410x10^2±7x10^2$	$500x10^2±0.45x10^2$	$2.5x 10^6$
RE2	$14x10^5±0.12x10^5$	640±9.54	$280x10^2±4.35x10^2$	$600x10^2±0.6x10^2$	$1.5x 10^6$

RI1: water morning glory roots at the inlet area; RI2: water morning glory roots at the outlet area; RE1: water hyacinth roots at the inlet area; RE2: water hyacinth roots at the outlet area



(a) (b) (c) (d)

Fig. 3. a) Mold colonies isolated from sample RI1; b) Bacterial colonies isolated from samples RE1; c) Yeast colonies isolated from samples RE2; d) Mold colonies isolated from samples RI2

3.3.1. Total suspended solid

The change in TSS concentrations over time in samples I1, I2 and E1, E2 are shown in Table 4. The results showed that the TSS concentration was decreased over time. After 21 days, at the inlet area, TSS concentration in I1 decreased 1.34 time (from 133.3 mg/L to 99.3 mg/L); in E1, TSS concentration decreased 1.59 time (from 124.1 mg/L to 78 mg/L). At the outlet area, TSS concentrations decreased 1.39 time (from 122 mg/L to 87.7 mg/L) in I2; in E2, TSS concentrations decreased 2.16 times (from 113.2 mg/L to 52.5 mg/L).

The TSS concentrations of samples were all quickly decreased and it is clear to see that TSS concentrations in water hyacinth regions in both inlet and outlet (E1, E2) are decreased faster than that in water morning glory areas (I1, I2). Gersberg et al. (1986) reported that physical processes such as sedimentation and filtration play the most crucial role in the removal of TSS in artificial wetlands. Besides, it has been documented that slightly better TSS removal efficiency can be gained by aeration (Ouellet-Plamondon et al., 2006).

The decrease in TSS concentrations in all samples and the higher TSS removal efficiency in water hyacinth regions in this study might be mostly due to both physical processes and the microbial degradation of organic particles.

The TSS concentrations of all samples after the sixth sampling times (after 21 days) meet the QCVN 14: 2008/BTNMT type B.

3.3.2. COD

The results of COD concentrations in I1, I2, E1 and E2 were shown in Table 5. After 21 days, at the inlet area, COD concentration in both E1 and I1 decreased about 1.5 times. However, the concentration in E1 was lower than that in I1 (93.4 as compared to 105.9 mg/L). At the outlet area, COD concentrations in both E2 and I2 decreased about 1.6 times and the concentration in E2 was lower than that in I2 (78.3 mg/L against 87.5 mg/L).

In both samples, there was a rapid decline in COD concentrations after the fourth time of sampling (after 13 days) and then COD concentrations were gradually decreased and reached the lowest value of 78.3 mg/L in E2. The main mechanisms of COD removal by wetland plants may involve aerobic and anaerobic degradation processes, sedimentation and filtration (Bulc et al., 2006). The samples in this study were taken during summer time and one reason for the rapid reduction in COD concentrations in E2 may be due to the rapid growth of water hyacinth in favorable weather conditions, thus enhancing the reduction of COD concentration. Effective performance in COD removal by water hyacinth in treating dairy wastewater (Munavalli and Saler, 2009) and wastewater from duck farm (Lu et al., 2008) has been reported.

The higher COD removal efficiency in water hyacinth regions than in water morning glory regions in the study is expected because the more extensively in root system of water hyacinth create larger area for microorganisms and therefore organic matters can be degraded more effectively.

3.3.3. Ammonium

The mean ammonium concentrations in I1, I2, E1 and E2 were also measured and the results were shown in Table 6.

Ammonium is considered as one of the major pollutants in domestic wastewaters and of greatly environmental concern because it causes eutrophication in water bodies and its toxicity to aquatic organisms. The capacity of wetland plants in treatment of ammonium has been well-documented (Gersberg et al., 1986; Tanner et al., 1994). Microbial nitrification and denitrification may act as a main removal mechanism and plant uptake only plays a minor role in ammonium removal (Gersberg et al., 1983, Stottmeister et al., 2003). The results in this study showed that ammonium concentrations were decreased, however these decreases were not significant, only about 1.2 times in all samples after 21 days. Better performance in ammonium removal was again recorded for E2 - the wastewater sample in the water hyacinth area. It has been reported that the oxic conditions in the rhizophere of aquatic plants strengthen activities of nitrifying bacteria and hence nitrification is stimulated (Gersberg et al., 1986). With the study on the ability of three different aquatic plants: *Scirpus validus* (bulrush), *Phragmites communis* (common reed) and *Typha latifola* (cattail) in nitrogen removal, Gersberg et al. (1986) pointed out that the cattail has the lowest performance in ammonium removal because of its shallowest rhizophere.

The result on ammonium removal in our study is accordance with the hypothesis of Gersberg et al. (1986), which showed that water morning glory has poorer performance in treatment of ammonium due to the less extensive root zone as compared to water hyacinth. The ammonium concentration was lowest of 14.36 mg/L in E2; however this value was still higher than the Vietnamese national regulation QCVN14:2008/BTNMT for ammonium concentration (10 mg/L).

3.3.4. Phosphate

The changes in phosphate concentrations in all samples during 21 days of sampling were shown in Table 7.

Table 4. The mean TSS concentrations in I1, I2 and E1, E2 (mg/L)

Sample / *Sampling time*	*Day 1*	*Day 5*	*Day 9*	*Day 13*	*Day 17*	*Day 21*
I1	133.3±2.86	126.3±6.43	119.4±3.76	112.7±12.34	106±3.61	99.3±1.97
I2	122±2.65	114.9±3.72	108.1±7.47	101.1±2.88	94.5±3.89	87.7±2.59
E1	124.1±2.98	117±2.65	106.5±7.52	97.1±1.08	88.2±3.57	78±4.36
E2	113.2±2.65	89.8±8.88	80±8.50	79.7±6.55	62.6±2.19	52.5±3.63

Table 5. The mean COD concentrations in I1, I2, E1 and E2 (mg/L)

Sample / *Sampling time*	*Day 1*	*Day 5*	*Day 9*	*Day 13*	*Day 17*	*Day 21*
I1	156.4±7.07	133.5±4.33	116.7±3.05	110.2±9.34	107.8±2.60	105.9±12.19
I2	137.4±5.99	115.1±4.16	98.3±8.92	92.6±2.91	90.3±5.50	87.5±3.05
E1	144.8±5.20	120±4.42	105.2±5.57	98.5±2.40	95.3±10.22	93.4±4.06
E2	126.5±6.60	101.3±9.48	89.2±5.01	83.5±7.45	80.4±3.78	78.3±5.27

Table 6. The mean ammonium concentrations in I1, I2, E1 and E2 (mg/L)

Sample / *Sampling time*	*Day 1*	*Day 5*	*Day 9*	*Day 13*	*Day 17*	*Day 21*
I1	20.53±3.80	18.96±2.27	18.19±4.27	17.56±2.68	17.85±5.30	16.52±3.80
I2	18.93±2.96	17.37±2.05	16.5±4.00	16.16±4.01	15.89±5.32	15.6±2.69
E1	20.44±5.14	18.65±4.87	17.74±3.60	17.08±1.32	16.5±2.34	16.16±3.25
E2	17.74±2.96	16.18±2.31	15.3±1.75	14.97±4.11	14.57±4.24	14.36±3.45

Table 7. The mean phosphate concentrations in I1, I2, E1 and E2 (mg/L)

Sample / *Sampling time*	*Day 1*	*Day 5*	*Day 9*	*Day 13*	*Day 17*	*Day 21*
I1	1.6±0.46	1.43±0.36	1.29±0.58	1.17±0.17	1.08±0.64	1.05±0.39
E1	1.45±0.12	1.29±0.44	1.12±0.24	1±0.19	0.93±0.46	0.89±0.19
I2	1.42±0.17	1.23±0.60	1.07±0.45	0.99±0.28	0.94±0.39	0.91±0.30
E2	1.39±0.52	1.18±0.35	1.02±0.45	0.9±0.29	0.84±0.38	0.81±0.17

Together with ammonium, phosphorus also causes environmental problems and detrimental effects on aquatic ecosystems. In wetlands, phosphorus occurred as the two main forms: phosphate in organic and inorganic compounds (Vymazal and Kröpfelová, 2008). The use of wetland plants for phosphorus removal in different types of wastewater, especially for domestic wastewater has been reported (Torit et al., 2012; Vymazal and Kröpfelová, 2008). In the present study, phosphate concentrations in Nhue Giang pond were lower than the Vietnamese national regulation QCVN14:2008/BTNMT, type B for phosphate concentration in domestic wastewater (10 mg/L). After 21 days, phosphate concentrations in I1, E1 and I2 were decreased about 1.5 - 1.6 time and the speed of decline in phosphate concentration in E2 was highest of 1.71 (0.81mg/L). Phosphate concentrations in E1 and E2 were both lower than that in I1 and I2 but not significantly. Major processes involved in the removal of phosphate may include microbial and plant uptake, adsorption and precipitation.

3.4. Wastewater treatment efficiency by aquatic plants and microorganisms in Nhue Giang pond

After the changes in concentrations of typical parameters in wastewaters were determined, wastewater treatment efficiencies by aquatic plants and microorganisms in Nhue Giang pond were preliminarily evaluated and the results were shown in Fig. 4.

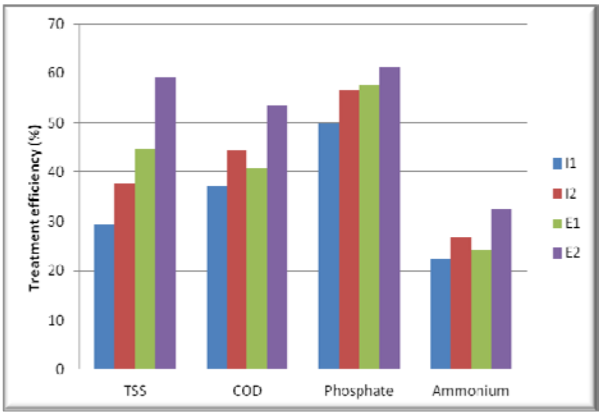


Fig. 4. Treatment efficiencies of wastewaters by aquatic plants and microorganisms in Nhue Giang pond

The treatment efficiencies of TSS, COD, ammonium and phosphate in all samples with water hyacinth (E1, E2) were higher than that in samples with water morning glory (I1, I2). These results are consistent with the results of microbial populations attached on the roots of aquatic plants (in section 3.2.2) which showed that microbial populations were highest on the roots of water hyacinth. Water hyacinth is one of the most widely studied aquatic plants due to its potential on nutrient removal from wastewaters (Kivaisi, 2001; Gupta et al., 2012). With the rapid growth (biomass can be doubled in 6 days) and extensive root zone, water hyacinth provide large area for microorganisms attached and therefore stimulate biodegradation of organic matters and other nutrients in wastewater (Reddy and Sutton, 1984; Kivaisi, 2001). Among all tested parameters, phosphate was removed most effectively (over 50% in all samples) and the treatment efficiency reached highest in E2 (61.4%).

Almost the same level in treatment performance of phosphate by water hyacinth to treat textile wastewater was reported (52.9%) (Gamage and Yapa, 2001). The treatment efficiencies of COD and TSS were also highest in E2 (53.4% and 59.3%, respectively). A better treatment performance of COD (78%) and TSS (90%) in treating domestic wastewater for reuse by water hyacinth was reported in Morocco (Mandi, 1998). Effective ammonium removal probably mainly depends on nitrification-denitrification processes by microorganisms (Stottmeister et al., 2003).

Ammonium removal was again highest in E2 perhaps mostly due to microbial degradation, however in general treatment efficiencies of ammonium in all samples were not significant (in range of only 20 – 30%), while other studies reported that wastewater treatment systems with water hyacinth provided high treatment efficiencies of ammonium (87 - 99%) (Elias et al., 2001; Moorhead et al., 1988). Positive effects of plants and microorganisms in wetlands for wastewater treatment has been well-documented and the results obtained in this study confirms previous findings and contributes to existing knowledge on the important role of aquatic plants and microorganisms in domestic wastewater treatment.

4. Conclusions

Two types of aquatic plants in this study (water morning glory and water hyacinth) are both capable of treating domestic wastewater thanks to, among others, the groups of microorganisms including bacteria, Actinomycetes, mold and yeast attached in their root, where the bacteria accounted for $2.1x10^6$ and $8.7x10^5$ CFU/mL.

The treatment efficiencies of water hyacinth samples (E1, E2) were all higher than that of water morning glory samples (I1, I2) for TSS, COD, PO_4^{3-} and NH_4^+ after 21 days. Particularly, it was in range of 37.8% - 53.3% for TSS; 44.4% - 53.4% for COD; 56.7% - 61.4% for PO_4^{3-} and 26.8% - 32.6% for NH_4^+, respectively.

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