Phytoremediation Rates of Water Hyacinth in an Aquaculture Effluent Hydroponic System

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***Abstract*—**Conventional wastewater treatment plants of activated carbon, electrodialysis, ion exchange, reverse osmosis etc. are expensive to install, operate and maintain especially in developing countries; therefore, the use of aquatic macrophytes for wastewater purification is a viable alternative. On the first day of experimentation, approximately 100g of water hyacinth was introduced into the hydroponic units in four replicates. The water quality parameters measured were total suspended solids (TSS), pH and electrical conductivity (EC). Others were concentration of ammonium–nitrogen (NH_4^+-N), nitrite-nitrogen (NO_2^--N), nitrate-nitrogen (NO_3^--N), phosphate–phosphorus (PO_4^{3-}-P), and biomass value. At phytoremediation intervals of 7, 14, 21 and 28 days, the biomass recorded were 438.2 g, 600.7 g, 688.2 g and 725.7 g. Water hyacinth was able to reduce the pollutant concentration of all the selected parameter. The percentage reduction of pH ranged from 1.9% to 14.7%, EC from 49.8% to 97.0%, TDS from 50.4% to 97.6%, TSS from 34.0% to 78.3%, NH_4^+-N from 38.9% to 85.2%, NO_2^--N from 0% to 84.6%, NO_3^--N from 63.2% to 98.8% and PO_4^{3-}-P from 10% to 88.0%. Paired sample t-test shows that at 95% confidence level, it can be concluded statistically that the inequality between the pre-treatment and post-treatment values are significant. This suggests that the use of water hyacinth is valuable in the design and operation of aquaculture effluent treatment and should therefore be adopted by environmental and wastewater managers.

***Keywords*—**Aquaculture effluent, phytoremediation, pollutant, water hyacinth.

I. Introduction

NIGERIA is among the largest fish consumers in the world with over 1.5 million tons of fish consumed annually as the country imports over 900,000 metric tons of fish, while the domestic fish catch is estimated at 450,000 metric tons/year [1], [2]. This over dependence on imported fish has adversely affected the economy and mostly foreign reserves of the country [3]. In their work, [4] reported that since fish supplies from open water and lagoons continue to fall and human population rises, fish farming will offer an effective way of generating food and income from dwindling land spaces.

Aquaculture is the cultivation and harvest of aquatic plants and animals and fish culture is the most common type of aquaculture in Nigeria and other developing nations. As reported by [5], aquaculture produces large amount of pollutants as a result of uneaten fish feed and metabolic waste which adversely affects the water quality. The production of 1 tonne of channel catfish releases an average of 9.2 kg of nitrogen, 0.57 kg of phosphorus, 22.5 kg of biochemical oxygen demand (BOD) and 530 kg of settleable solids into the environment. Pollutants from aquacultural practices however constitute environmental problems and equipment using advanced treatment for fish tank effluent is expensive to import, install, operate and maintain, especially in developing countries. Phytoremediation could offer cheaper environmentally sustainable alternative. Some aquatic macrophytes have been successfully used for effluent treatment [6]-[9]. However, information is scarce on phytoremediation potentials of locally available aquatic macrophytes.

The complex nature of the nitrogen cycle to local fish farmers has caused the disposal of aquaculture wastewater indiscriminately, ignorantly and unprofessionally, thereby increasing the concentrations of ammonia, nitrites, nitrates and other contaminants in surface and groundwater above the permissible level. Also, the ineffectiveness of relevant regulatory agencies contributes to the non-compliance of the approved standards for wastewater disposal and so the attendant effect as a result of these could cause an epidemic [10]. Therefore, the objectives of this research were to measure the nutrient level of an aquaculture effluent at adult stage of production and evaluate the effects of retention times on phytoremediation rate of water hyacinth in aquaculture wastewater so as to ascertain the suitability of the treated effluent for re-use.

II. Materials and Methods

The experimental site was an open air space in front of the Agricultural and Environmental Engineering Laboratory, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria. Located in the mangrove swamp vegetative zone, the university has a tropical climate with two seasons: the wet season from March to October and the dry season between November and April.

On the day of the experiment, adequate quantities of water hyacinth (*Eichornia crassippes*) in their natural habitats were randomly and carefully collected from nearby streams, lakes and ponds within and around Yenagoa metropolis in Bayelsa State. The water hyacinths were then placed in four replicates of non-flow hydroponic units containing the aquaculture effluent and a control. The chemical constituents of the aquaculture effluent are presented in Table I. The plants were first washed thoroughly with clean water to avoid pre-contamination carry-over effects [9] and allowed to dry in the open air for 1 hour. The plants were then weighed using a 0.1 g precision digital weighing balance (Model HL 122, Avery

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Berkel) and the hydroponic units labeled, before the commencement of the experiment. Each hydroponic unit was then stocked with plants of approximately 100 g. In order to maintain dissolved oxygen (DO) in the hydroponic units, mechanical aeration using air pump and air stone was applied every three days for 10 minutes, throughout the experimental period. On the first day of the experiment, the effluent level of each hydroponic unit after the introduction of the aquatic plant was marked on the inside of the trough, and was topped with clean water to the same level on each day of aeration and observation, in other to compensate for evaporation loses. The mass of each hydroponic unit containing a plant was also recorded. In each hydroponic unit, the plants were allowed to grow for 30 days and water samples were collected on days 3, 7, 11, 14, 18, 21, 24 and 28 from each unit and refrigerated in plastic bottles until needed for chemical analyses. The plants biomass yield was also recorded on each day of observation by weighing the hydroponic unit. All samples collected were refrigerated and later sent to the Chemical Sciences Laboratory of the Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria, to determine the pH, EC, TDS, TSS, $NH_4{}^+$-N, NO_2^--N, NO_3^--N, and PO_4^{3-}-P.

TABLE I
CHEMICAL CONSTITUENTS OF THE AQUACULTURE WASTEWATER

Parameter (mg L^{-1})	Value
pH	6.40
EC (µs cm^{-1})	4020
Total Dissolved Solids (TDS)	2010
Total Suspended Solids (TSS)	12.60
Ammonium-Nitrogen (NH_4^+-N)	0.054
Nitrite-Nitrogen (NO_2^--N)	0.338
Nitrate-Nitrogen (NO_3^--N)	0.56
Ortophosphate (PO_4^{3-}-P)	0.40

Note: Concentrations are in mg/l except pH and EC

III. RESULTS AND DISCUSSION

The water hyacinths in all the hydroponic units initially appeared stressed but grew rapidly and look healthy with lush green colours as the phytoremediation day increases. The control shows algal bloom as it turns greenish in colour with decomposing insects floating. Table II shows that the water hyacinth was able to reduce the pollutant concentration of all the selected parameter from the starting of the experiment to day 14 thereafter the pollutant reduction was negligible.

TABLE II
MEAN EFFECTS OF THE WATER HYACINTH ON SOME PHYSICOCHEMICAL CHARACTERISTICS OF THE AQUACULTURE EFFLUENT AND ITS WEIGHT FOR THE 7 DAYS TIME INTERVALS

Effluent Parameter (mg L^{-1})	Phytoremediation Period (Days)				
	0	7	14	21	28
pH	6.40	5.82	5.66	5.50	5.46
EC (µs cm^{-1})	4020.0	1276.5	397.4	189.1	122.5
TDS	2010.0	499.8	102.5	49.1	54.4
TSS	12.60	5.80	5.75	2.73	4.58
$NH_4{}^+$-N	0.054	0.023	0.010	0.008	0.008
NO_2^--N	0.338	0.120	0.079	0.075	0.052
NO_3^--N	0.560	0.079	0.029	0.007	0.008
PO_4^{3-}-P	0.400	0.180	0.125	0.078	0.048
COD	108.00	161.95	143.25	114.00	104.13
Weight (g)	103	438.2	600.7	688.2	725.7

Pollutant reductions by water hyacinth on the aquaculture effluent for the time interval are shown in Tables III and IV. The effluent pH was 6.4 and the percentage reduction ranged from 1.9 to 14.7%, making the effluent slightly acidic. The implication of the results is that the using the treated effluent for recirculatory aquaculture system with respect to pH may adversely affect the growth of the aquatic animal. The favourable range of pH for fish production is 6.5-8.0 [11]. The decay of matter and oxidation of compounds in bottom sediments also alter the pH of in water bodies. Slow or poor growth will result in waters with pH of 4.0-6.0 or 9.0-10.0 and that management of waters, too acidic for fish production is by liming [11].

The effluent EC was 4020 and reduction by the water hyacinth ranged from 49.8 to 97.0%. EC can be used to obtain reliable estimates of salinity or total dissolved solids [11]. The average concentration of TDS and TSS were 2010 and 12.6 mg/l respectively. This high concentration of TDS can be attributed to uneaten fish feed and fish faeces. The reductions of both TDS and TSS from the control and hydroponic units containing water hyacinth ranged from 50.4 to 97.6% for TDS and 34.0 to 78.3 % for TSS. There was a gradual reduction of both TDS and TSS.

The aquaculture effluent contained 0.054 mg/l of ammonia-nitrogen ($NH_4{}^+$-N). Ammonia is produced as a by-product of fish protein catabolism is excreted as un-ionized ammonia (NH_3) through their gills and is quickly absorbed by phytoplankton and aquatic plants. Ammonia is also produced through the decomposition of urea, fish faeces, and uneaten food [11]. This ammonia is highly toxic to aquatic animal. The reduction of $NH_4{}^+$-N from the control to the hydroponic units containing the water hyacinth ranged from 38.9 to 85.2 %.

The aquaculture effluent had 0.338 mg/l of nitrite-nitrogen (NO_2^--N) and 0.56 mg/l of nitrate-nitrogen. Nitrification is the oxidation of ammonia to nitrate with nitrite formed as an intermediate product.

Nitrification is a two-stage aerobic process. The first stage is the conversion of ammonia to nitrite by *Nitrosomonas* bacteria. Since nitrification is an aerobic process; it was facilitated by the mechanical aeration of all the hydroponic units.

The chemical reaction is shown in (1):

$$NH_4^+ + 1.5O_2 \rightarrow 2H^+ + H_2O + NO_2 \quad (1)$$

The oxidation of nitrite is a single-step process that uses oxygen from water to form nitrate and only molecular oxygen as an electron acceptor.

The chemical reaction is shown in (2):

$$NO_2 + 0.5O_2 \rightarrow NO_3 \quad (2)$$

TABLE III
POLLUTANT REDUCTION BY WATER HYACINTH ON THE PH, EC, TDS AND TSS OF THE AQUACULTURE EFFLUENT FOR 7 DAYS TIME INTERVAL

Parameter	Phytoremediation Interval (days)	Treatment	Influent (mg L^{-1})	Effluent (mg L^{-1})	Reduction	
					Difference	(%)
pH	7	Control	6.40	6.52	-0.12	-1.9
		Water hyacinth	6.40	5.52	0.88	13.8
	14	Control	6.40	6.68	-0.28	-4.4
		Water hyacinth	6.40	5.66	0.74	11.6
	21	Control	6.40	7.08	-0.68	-10.6
		Water hyacinth	6.40	5.50	0.90	14.1
	28	Control	6.40	6.28	0.12	1.9
		Water hyacinth	6.40	5.46	0.94	14.7
EC (μs cm^{-1})	7	Control	4020.0	2016.8	2003.2	49.8
		Water hyacinth	4020.0	1276.5	2743.5	68.2
	14	Control	4020.0	1273.8	2746.2	68.3
		Water hyacinth	4020.0	397.4	3622.6	90.1
	21	Control	4020.0	1222.3	2797.7	69.6
		Water hyacinth	4020.0	189.1	3830.9	95.3
	28	Control	4020.0	1383.5	2636.5	65.6
		Water hyacinth	4020.0	122.5	3897.5	97.0
TDS	7	Control	2010.0	1008.5	1012.5	50.4
		Water hyacinth	2010.0	499.8	1510.2	75.1
	14	Control	2010.0	636.8	1373.2	68.3
		Water hyacinth	2010.0	102.5	1907.5	94.9
	21	Control	2010.0	611.3	1398.7	69.6
		Water hyacinth	2010.0	49.1	1960.9	97.6
	28	Control	2010.0	691.8	1318.2	65.6
		Water hyacinth	2010.0	54.4	1955.6	97.3
TSS	7	Control	12.60	6.50	6.10	48.4
			12.60	5.80	6.80	54.0
	14	Control	12.60	8.32	4.28	34.0
		Water hyacinth	12.60	5.75	6.85	54.4
	21	Control	12.60	6.66	5.94	47.1
		Water hyacinth	12.60	2.73	9.87	78.3
	28	Control	12.60	3.64	8.96	71.1
		Water hyacinth	12.60	4.58	8.02	63.7

The reduction of NO_2^--N ranged from 0 to 84.6%, while that of NO_3^--N ranged from 63.2 to 98.8 %.

The aquaculture effluent had 0.4 mg/l of orthophosphate PO_4^{3-}-P. The reduction of PO_4^{3-}-P ranged from 10.0 to 88.0 %. The effect of the water hyacinth treatment was tested by paired sample t-Test using Microsoft Excel Stat software. At 95% confidence level, the analysis show that t (critical) is less than t (cal) and $p < 0.05$ therefore it can be concluded statistically that the inequality between the pre-treatment and post-treatment values are significant (Tables V-XII). This suggests the potency of water hyacinth for remediation of aquaculture effluent

IV. CONCLUSIONS AND RECOMMENDATIONS

The conclusion on this research will therefore be that:

1. Water hyacinth was able to phytoremediate the aquaculture effluent to permissible levels.
2. The pollutant reduction increased with increase in phytoremediation period.
3. The treated effluent can be re-use for aquaculture since the quality is within the permissible level.

The advantage of using aquatic plants for purification is that the water resources are conserved as the environment is naturally controlled by the plants creating a mutually beneficial, symbiotic relationship with the aquatic animals. This research is multidisciplinary and its findings will help aquaculturists, wastewater managers, environmentalists etc. in the design, construction and management of water systems for commercial aquaculture, farms, domestic and municipal supplies.

The major findings from this work are that it is valuable in the design and operation of aquaculture effluent treatment and should therefore be adopted by environmental engineers, wastewater managers. The effects of the various aquatic macrophytes on sewage effluent and hydrocarbon polluted surface water should also be investigated.

TABLE IV
POLLUTANT REDUCTION BY WATER HYACINTH ON THE NH_4^+-N, NO_2^-N, NO_3^-N AND PO_4^{3-}P OF THE AQUACULTURE EFFLUENT FOR 7 DAYS TIME INTERVAL

Parameter	Phytoremediation Interval (days)	Treatment	Influent (mg L^{-1})	Effluent (mg L^{-1})	Reduction	
					Difference	(%)
NH_4^+-N	7	Control	0.054	0.033	0.021	38.9
		Water hyacinth	0.054	0.023	0.031	57.4
	14	Control	0.054	0.018	0.036	66.7
		Water hyacinth	0.054	0.010	0.044	81.5
	21	Control	0.054	0.020	0.034	63.0
		Water hyacinth	0.054	0.008	0.046	85.2
	28	Control	0.054	0.028	0.026	48.1
		Water hyacinth	0.054	0.008	0.046	85.2
NO_2^-N	7	Control	0.338	0.338	0	0
		Water hyacinth	0.338	0.120	0.218	64.5
	14	Control	0.338	0.223	0.115	34.0
		Water hyacinth	0.338	0.079	0.259	76.6
	21	Control	0.338	0.143	0.195	57.7
		Water hyacinth	0.338	0.075	0.263	77.8
	28	Control	0.338	0.175	0.163	48.2
		Water hyacinth	0.338	0.052	0.286	84.6
NO_3^-N	7	Control	0.56	0.206	0.354	63.2
		Water hyacinth	0.56	0.079	0.481	85.9
	14	Control	0.56	0.138	0.422	75.4
		Water hyacinth	0.56	0.029	0.531	94.8
	21	Control	0.56	0.132	0.428	76.4
		Water hyacinth	0.56	0.007	0.553	98.8
	28	Control	0.56	0.154	0.406	72.5
		Water hyacinth	0.56	0.008	0.552	98.6
PO_4^{3-}P	7	Control	0.400	0.360	0.040	10.0
		Water hyacinth	0.400	0.180	0.220	55.0
	14	Control	0.400	0.230	0.17	42.5
		Water hyacinth	0.400	0.125	0.275	68.8
	21	Control	0.400	0.190	0.210	52.5
		Water hyacinth	0.400	0.078	0.322	80.5
	28	Control	0.400	0.220	0.180	45.0
		Water hyacinth	0.400	0.048	0.352	88.0

TABLE V
PAIRED SAMPLE T-TEST BETWEEN PRE-TREATMENT AND POST-TREATMENT LEVELS FOR PH REDUCTIONS IN AQUACULTURE EFFLUENT USING WATER HYACINTH

	Pre-treatment	Post-treatment
Mean	6.4	5.67125
Variance	9.01555E-31	0.053669643
Observations	8	8
df	7	
t Stat	8.897319959	
P(T<=t) one-tail	2.29798E-05	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	4.59596E-05	
t Critical two-tail	2.364624251	

TABLE VI
PAIRED SAMPLE T-TEST BETWEEN PRE-TREATMENT AND POST-TREATMENT LEVELS FOR EC REDUCTIONS IN AQUACULTURE EFFLUENT USING WATER HYACINTH

	Pre-treatment	Post-treatment
Mean	4020	755.34125
Variance	0	866557.92
Observations	8	8
df	7	
t Stat	9.919367628	
P(T<=t) one-tail	1.12832E-05	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	2.25665E-05	
t Critical two-tail	2.364624251	

TABLE VII
PAIRED SAMPLE T-TEST BETWEEN PRE-TREATMENT AND POST-TREATMENT LEVELS FOR TDS REDUCTIONS IN AQUACULTURE EFFLUENT USING WATER HYACINTH

	Pre-treatment	Post-treatment
Mean	2010	308.0875
Variance	0	206528.5974
Observations	8	8
df	7	
t Stat	10.59234515	
P(T<=t) one-tail	7.31102E-06	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	1.4622E-05	
t Critical two-tail	2.364624251	

TABLE VIII
PAIRED SAMPLE T-TEST BETWEEN PRE-TREATMENT AND POST-TREATMENT LEVELS FOR TSS REDUCTIONS IN AQUACULTURE EFFLUENT USING WATER HYACINTH

	Pre-treatment	Post-treatment
Mean	12.6	5.2325
Variance	3.60622E-30	4.54845
Observations	8	8
df	7	
t Stat	9.770874284	
P(T<=t) one-tail	1.24606E-05	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	2.49212E-05	
t Critical two-tail	2.364624251	

TABLE IX
PAIRED SAMPLE T-TEST BETWEEN PRE-TREATMENT AND POST-TREATMENT LEVELS FOR NH_4^+-N REDUCTIONS IN AQUACULTURE EFFLUENT USING WATER HYACINTH

	Pre-treatment	Post-treatment
Mean	0.054	0.016125
Variance	0	0.000125268
Observations	8	8
df	7	
t Stat	9.571451671	
P(T<=t) one-tail	1.42673E-05	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	2.85346E-05	
t Critical two-tail	2.364624251	

TABLE IX
PAIRED SAMPLE T-TEST BETWEEN PRE-TREATMENT AND POST-TREATMENT LEVELS FOR NO_2^--N REDUCTIONS IN AQUACULTURE EFFLUENT USING WATER HYACINTH

	Pre-treatment	Post-treatment
Mean	0.338	0.10125
Variance	0	0.003792214
Observations	8	8
df	7	
t Stat	10.87398041	
P(T<=t) one-tail	6.14145E-06	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	1.22829E-05	
t Critical two-tail	2.364624251	

TABLE XI
PAIRED SAMPLE T-TEST BETWEEN PRE-TREATMENT AND POST-TREATMENT LEVELS FOR NO_3^--N REDUCTIONS IN AQUACULTURE EFFLUENT USING WATER HYACINTH

	Pre-treatment	Post-treatment
Mean	0.56	0.06875
Variance	0	0.013929071
Observations	8	8
df	7	
t Stat	11.77298184	
P(T<=t) one-tail	3.61357E-06	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	7.22713E-06	
t Critical two-tail	2.364624251	

TABLE XII
PAIRED SAMPLE T-TEST BETWEEN PRE-TREATMENT AND POST-TREATMENT LEVELS FOR PO_4^{3-}-P REDUCTIONS IN AQUACULTURE EFFLUENT USING WATER HYACINTH

	Pre-treatment	Post-treatment
Mean	0.4	0.131125
Variance	3.5217E-33	0.006932696
Observations	8	8
df	7	
t Stat	9.133649151	
P(T<=t) one-tail	1.93767E-05	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	3.87533E-05	
t Critical two-tail	2.364624251	

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