

Phytoremediation of Aquaculture Wastewater: Duckweed (*Lemna minor* L.) as a Phytoremediator

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Abstract

*Aquaculture systems discharge huge quantities of waste into the aquatic ecosystem, in the form of excretory products and excess feed. These have grave implications on physicochemical and biological quality of the receiving environment. The study aimed to determine potential of duckweed (*Lemna minor* L.) for phytoremediation of aquaculture effluent. Hundred grams (100 g) of duckweed was grown in 10 L aquaculture effluent for 7-, 14-, 21-, and 28-day retention period in 15-L plastic containers. Effluent samples were analyzed for some physicochemical parameters (phosphate, nitrate, ammonia, chemical oxygen demand, electrical conductivity, total dissolved solids, and pH). The evaluations were conducted using established and recognized methodologies. The characterization of aquaculture effluent revealed high pollution level. It was found that duckweed reduced aquaculture effluent pollution concentration load to a great extent. Nitrate, ammonia-nitrogen, chemical oxygen demand, and pH were within permissible limits. Discharging aquaculture effluent without prior treatment will be detrimental to the environment and water bodies. This study evaluates the phytoremediation potential of duckweed (*Lemna minor* L.) for treating aquaculture wastewater. Duckweed was cultivated in aquaculture effluent for varying retention periods (7–28 days) in controlled conditions. Physicochemical analyses of the effluent showed significant reductions in pollutants such as phosphate (68.92%), nitrate (66%), ammonia-nitrogen (79.11%), and chemical oxygen demand. While pH levels were stabilized within permissible limits, electrical conductivity and total dissolved solids exceeded acceptable thresholds for drinking and domestic use. The findings highlight duckweed's cost-effective and sustainable utility for mitigating aquaculture effluent pollution, supporting environmental conservation and resource management.*

Keywords: Aquaculture, bioremediation, effluent, physicochemical parameters, macrophytes

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INTRODUCTION

Aquaculture has been ranked as the fastest growing animal food industry worldwide. Aquaculture provides approximately 49% of the total fish consumed by humans globally and is projected rise to over 50% of world fish consumption by 2030. Fish accounted for 16.7% of the animal protein intake of the global population and 6.5% of the total protein consumed. Aquaculture has an annual growth rate of 3.2% and plays a crucial role in global food production. According to reports, consumption of cultured fish exceeded that of wild fish, emphasizing the significance of aquaculture in the seafood industry [1, 2].

Water resources are subjected to grave dangers from contamination produced by human activities and indiscriminating discharge of untreated municipal and industrial effluents into the environment. Some human activities, including the release of contaminated industrial wastewater, indiscriminating disposal of domestic waste, and agricultural and aquaculture effluents, surface water contamination and degradation of water quality. Some researchers recommended regular evaluation of physicochemical water quality parameters as a means of investigating the water and soil environment, ecosystem, hydrochemistry, and ecology, thereby improving the overall water quality [3, 4].

The use of aquatic plants and microalgae for phytoremediation of aquaculture wastewater have great potential because of their efficient nutrient removal capabilities and cost-effectiveness. Many researchers have worked on have conducted studies on various aquatic plants including water lettuce, water hyacinth, giant salvinia and water lily for the purpose of phytoremediation of wastewater from diverse sources, for instance sewage effluents, cassava processing mills, sewage, livestock, aquaculture wastewater.

The access to clean and portable water resources, safeguarding existing water sources, and ensuring hygienic safety are essential prerequisites for sustainable development in rural and urban areas. Developing countries face significant bottlenecks in implementing sustainable water treatment systems, including economic hardship, technological gaps, and a lack of energy resources to support cost-effective solutions [5, 6].

Aquaculture has a major impact on the rise of dissolved and particulate nutrients. The excessive introduction of nutrients, specifically nitrogen and phosphorus, into the aquatic environment can lead to eutrophication, depletion of oxygen, and siltation in aquatic ecosystems. Thus, this study examined the characterization of aquaculture wastewater and investigates the efficiency of water lettuce and duckweed used in phytoremediation of aquaculture wastewater treatment [7–10].

MATERIALS AND METHODS

Study Area

The research site is located in Yenizue-gene, Yenagoa, Bayelsa State, within the Niger Delta region of Nigeria. The geographical coordinates are as follows: N 4° 52' 3.9972", E 5° 53' 55.3704".

Collection of Aquaculture Effluent

The collection of effluent and aquatic plants was carried out between 15th of August and 26th of October, 2022. The aquaculture effluent was collected at 6.30 am from a semi-earthen fish pond with dimension of 4 m × 4 m × 6 m. Precaution were taken to ensure sample's preservation and prevent contamination, the aquaculture effluent samples were specifically collected on non-rainy days. The grab technique was utilized to collect the aquaculture effluent sample. The two aquatic plants were put in plastic containers filled distilled water for 7 days for the process of acclimatization, prior to introducing the aquatic plants into the aquaculture effluent. For the experiment, 10-L wastewater samples were filled into each of the 15 cleaned and sterilized plastic containers of 15-L capacity. The careful selection of 10 L of aquaculture effluent per cleaned and sterilized plastic container accounted for the volume of the samples needed to conduct the laboratory's physicochemical analyses [11–15].

Laboratory Analysis

Physicochemical parameters were analyzed by employing standard methods. In the lab, seven physicochemical characteristics were examined, including phosphate, nitrite, ammonium-nitrogen, chemical oxygen demand, conductivity, total dissolved solid and power of hydrogen [16, 17].

Statistical Analysis

The data was subjected to statistical analysis using analysis of variance (ANOVA) and descriptive statistics. Statistical significance was confirmed at $p < 0.01$, $p < 0.05$, and $p < 0.001$.

RESULTS

The concentration of phosphate in the aquaculture effluent decreased as the retention time of duckweed increased to 28 days. The recorded values varied from 1.4575 ± 0.0475 mg/L (Day 28) to 4.69 ± 0.03 mg/L (Day 1) (Table 1). The removal efficiency of phosphate in the effluent by duckweed was 68.92%. The acceptable range for phosphate concentration, according to the National Environmental Standards and Regulations Enforcement Agency (NESREA) ranged between 0.1 and 1.0 mg/L. The concentration of nitrate reduced over 28 days retention periods. The average nitrate concentration ranged from 0.2105 ± 0.0075 mg/L on Day 28 to 0.62 ± 0.01 mg/L on Day 1, as indicated in Table 1. The nitrate concentration reduction from aquaculture effluent using duckweed for phytoremediation was 66%. Water hyacinth demonstrated efficacy in reducing nitrate levels in aquaculture wastewater. Throughout 28 days cultivation time, there was reduction in the concentration of ammonia-nitrogen. On day 28, the mean ammonia-nitrogen concentration duckweed was 0.5725 ± 0.0475 mg/L, while on Day 1 it was 2.74 ± 0.01 mg/L. Percentage reduction of ammonia-nitrogen concentration was 79.11%. The concentration of chemical oxygen demand in fish wastewater decreased on average over the 28-day retention period [18–22].

The average total dissolved solids reduced all across the 28 days. Total dissolved solids (TDS) ranged from 509.5 ± 6.5 mg/L on Day 28 and 1865 ± 43.41 mg/L on Day 1. The pH level indicates the acidity or alkalinity of the water and provides an estimation of the proportion of free hydrogen and hydroxyl ions. Throughout the experiment the pH of the aquaculture wastewater increased. On Day 1, the average pH value was 6.2 ± 0.00 , while on 28th day it was 7.025 ± 0.075 as shown in Table 1. The pH of the effluent varied slightly from acidic to alkaline. Power of hydrogen (pH) is a significant factor when assessing the quality of water [23–29].

DISCUSSION

The result obtained at 28-day showed a slightly higher value than the recommended limit. Plants and microbes use dissolved inorganic phosphorus for photosynthesis, chemosynthesis, and decomposition. The permissible limit recommended for phosphate according to World Health Organization (WHO) for drinking water and aquatic life is 5 mg/L.

Excessive levels of phosphate can have detrimental effects on the ecosystem, including the formation of algae blooms, the proliferation of invasive plants, decreased oxygen levels, fish mortality, and the creation of dead zones. The nitrate levels recorded at 28-day treatment fell within the acceptable range of 50 mg/L. The decline in nitrate concentration observed could be traced to nitrogen uptake by plants aided by microorganisms, a process known as denitrification or ammonia volatilization. High levels of nitrates can be extremely detrimental when they exceed the acceptable limits set by the WHO. Aires et al. have highlighted the potential link between high nitrate levels and an increased risk of stomach cancer. Duckweed effectively reduced the $\text{NH}_3\text{-N}$ concentration to the permissible level of 0.01 to 2.0 mg/L. The decrease in ammonium-nitrogen levels over time can be attributed to ammonia volatilization. The reduction $\text{NH}_3\text{-N}$ could be linked to biological processes in nutrient uptake and ammonia absorption and significant proliferation of denitrifying bacteria [30–36].

Table 1. Physicochemical parameters of catfish wastewater treated with water duckweed.

Parameter	Day				
	1	7	14	21	28
Phosphate (mg/L)	4.69±0.03	4.0325±0.058	3.305±0.115	2.56±0.04	1.4575±0.0475
Nitrate (mg/L)	0.62±0.01	0.509±0.004	0.43675±0.0053	0.2895±0.0045	0.2105±0.0075
Ammonia-nitrogen (mg/L)	2.74±0.09	2.26±0.03	1.6775±0.0225	1.19±0.04	0.5725±0.0475
COD (mg/L)	40.3±1.13	35.425±0.525	32.125±0.375	30.925±0.375	30.225±1.475
EC (µS/cm)	3734±17.58	2729.75±9.75	2014.25±10.25	1391.25±9.75	942.75±41.25

TDS (mg/L)	1865±16.42	1610.75±6.75	1094.25±10.25	811.5±9.5	509.5±6.5
pH	6.2±0.15	6.325±0.075	6.575±0.75	6.85±0.05	7.025±0.075

COD, chemical oxygen demand; *EC*, electrical conductivity; *TDS*, total dissolved solids.

The treatment of catfish wastewater using duckweed was effective in meeting the acceptable limit of 30.0 mg/L. The acceptable limit of chemical oxygen demand (COD) for drinking purposes is 4 mg/L. On the other hand, the United States has an irrigation standard of 200 mg/L. Based on the analysis of the effluent samples, it can be concluded that they are not suitable for drinking, domestic, or agricultural use. The COD percentage reduction for duckweed was 25%. The electrical conductivity reduced over the 28-day period of the experiment. The electrical conductivity (EC) of aquaculture effluent varied from 942.75 ± 41.25 $\mu\text{S}/\text{cm}$ on Day 28 to 3734 ± 8.53 $\mu\text{S}/\text{cm}$ on Day 1. The permissible limits of 700 mS/cm for drinking water and 1000 mS/cm for irrigation were recommended. Thus, water samples with less than 28 days of retention time are not suitable for drinking, domestic use, recreational activities, or agricultural purposes. Duckweed failed to meet the acceptable limit recommended by the WHO in 2017, which ranged from 340 to 700 $\mu\text{S}/\text{cm}$ [37–42]. The percentage reduction in electrical conductivity was 72.68%. The mean values of electrical conductivity of aquaculture effluent ranged from 448 ± 6.19 at 28-day retention time 3582 ± 15.38 $\mu\text{S}/\text{cm}$ (control). The result analysis of variance indicated that the mean values of electrical conductivity at different retention time showed significant difference at $p < 0.05$. The maximum allowable limit for electrical conductivity as recommended by WHO is 400 $\mu\text{S}/\text{cm}$ for drinking water. However, the recommended limit assigned for drinking water was exceeded. All the TDS values exceeded the allowable range as recommended for domestic and recreational purpose. Recorded maximum allowable limits of 500 and 600 mg/L, respectively. DoE (1997) reported an acceptable TDS limit of 2000 mg/L for irrigation, indicating that the aquaculture effluent samples were suitable for irrigation but not for domestic use such as bathing and drinking. Duckweed was able to remediate the aquaculture effluent to meet the recommended pH limits of 6.5 to 8.5. The pH range of 6.5 to 8.5 is considered normal for surface water systems, while the optimum limit for irrigation and fish culture is from 6.5 to 8.0 [43–49]. The allowable limit of pH for drinking water based on WHO varied from 6.5 to 8.0. The photosynthetic activity of these microorganisms absorbs dissolved CO_2 in the form of H_2CO_3 , leading to an increase in pH. This pH range aligns with the optimal pH values of 6.6 to 8.0 for microbial activities and the nitrification process. Therefore, it can be inferred that maintaining a stable pH throughout the phytoremediation process creates a favorable environment for microorganisms and selected plants to efficiently break down and absorb pollutants. This study showed that pH range of 6 to 9 is more suitable for the effective performance of aquatic plants in the phytoremediation of aquaculture effluent. Power of hydrogen (pH) is a significant factor when assessing the quality of water [50, 51].

CONCLUSION

In this study, the physicochemical characteristics of aquaculture effluent were studied such as electrical conductivity, phosphate, pH, total dissolved oxygen, nitrate, ammonium-nitrogen, and chemical oxygen demand. Additionally, the effectiveness of duckweed in remediating aquaculture effluent was also evaluated. The results indicated that the effluent was contaminated and posed a threat to various aspects, including its suitability for drinking, washing, and irrigation purposes, as well as its impact on human health, aquatic life, ecological diversity, and the overall ecosystem.

Thus, if this effluent is discharged without proper treatment, it could have negative effect on the environment. However, duckweed reduced the contamination levels. Furthermore, the duration of cultivating these plants in the aquaculture effluent was found to have a significant effect on the efficacy of contaminant removal. Some of the physicochemical parameters, such as total dissolved oxygen, nitrate, and pH, ammonium-nitrogen, and chemical oxygen demand were within the acceptable ranges after 28 days. It could be inferred that the utilization of phytoremediation techniques for treating organic and inorganic effluent offers a cost-effective, sustainable, and environmentally friendly method of water treatment.

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