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Assessing the efficiency and role of duckweed (Lemna Minor) in the removal of pollutants from wastewater treatment plant secondary clarifier tanks: a comprehensive review

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ABSTRACT

Aquatic plants, including duckweed (Lemna minor), are increasingly utilized in sewage and wastewater treat-ment to improve pollution parameters and organic matter removal. This study aimed to investigate the impacts and efficacy of duckweed in secondary clarifier tanks in a conventional biological treatment facility. The per-formance of four secondary clarifiers with and without duckweed was compared based on water quality efflu-ent and settling characteristics. As per the experiment results, the secondary clarifier tank with duckweed demonstrated higher removal efficiency for chemical oxygen demand (COD), biological oxygen demand (BOD5), ammonium, phosphate, total nitrogen (TN), and total phosphorus (TP) - of 70%, 75%, 72%, 82%, 67%, and 96%, respectively, compared to the tank without duckweed. The concentration of suspended solids in the effluent and sludge volume index (SVI) values were similar in both settings. The research findings suggest that duckweed can contribute to the treatment efficiency of conventional biological treatment plants, thus re-ducing the need for tertiary nutrient removal. Additionally, the cost-effectiveness of treatment with duckweed and its reuse as fertilizer and animal fodder make it a valuable resource. The optimal temperature for duck-weed growth is approx. +26°C, and it is influenced by sunlight and temperature more than nutrient concentra-tions.

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1. Introduction

Common duckweed (Lemna minor) represents an oval- or circle-shaped plant species with the “leaf” surface area not exceeding a few square millimetres (Timmerman and Hoving, 2016). It is often found floating on the surface of or immersed in water bodies (El et al., 2007). Due to its fast growth rate, common duckweed is well-suited for waste treatment purposes, as it is relatively easy to maintain and operate such systems (Juliet et al., 2015). Duckweed plants obtained by treating water are collected from the water surface itself; duckweed grown in sewage or livestock waste (wastewater) is not poisonous and can be used as fish and cattle feed, or as crop fertilizer (Gao & Liu, 2017). For more certainty, it can be kept in safe water for a certain term, or cleaned with UV-rays or O_3 gas after drying (Rafiee & Hosseini, 2020). Duckweed survives in 5 to 9 pH conditions, but grows best in the pH 6.5-7.5 range, with the growth generally controlled by temperature and sunlight exceeding nutrient concentrations in the water (Iqbal et al., 2019). The most suitable humidity (moisture) content of fresh duckweed is 95% (Kaur & Gupta, 2021). Duckweed has been used for tertiary treatment of municipal and industrial wastewater (Xu & Huang, 2010). Plant cultivation and growth does not require a significant initial population in a waterbody, because even a small amount will be enough for its quick reproduction and multiplication (Gürtekin & Şekerdağ, 2008).

The most common method for rapid duckweed growing is ensuring the water surface is calm with small to no current; in case the water moves too much, the plant growth will slow down (Yu et al., 2017). If desired, cultivation can be done separately in a rectangular container at least 5 inches deep, 18 inches long, and 12 inches wide (Xu et al., 2021). Duckweed possesses a great capacity to absorb nutrients, making it efficient in removing them from water and its application for treating sewage and untreated water a highly effective, commercially feasible, natural and simple method (Chen et al., 2018). In fact, the plant has been successfully used for domestic and industrial wastewater tertiary treatment for over a decade (Mohedano & Belli, 2012).

2. Materials and method

The main objective of the study was to assess the efficacy of duckweed in four secondary clarifier tanks at different wastewater treatment facilities. The method involved evaluating the impact of duckweed on the quality of effluent water and settling specifications. Thus, the performance of the secondary clarifiers with and without the presence of duckweed were the subject of comparison. The characteristics of wastewater treatment in the secondary settling tanks are provided in Table I.

To analyse water quality, daily raw water samples were collected from four points within the basin, each with four replicates. Certain wastewater parameters were determined using spectroscopy, i.e. laser-based pollution detection. The samples were digested using a thermos-reactor (TR) as per the ST method.

Table I. Wastewater characteristics.

Parameter	Concentrations			
COD, mg/L	260	300	195	---
BOD5, mg/L	175	---	137	---
Ammonium, mg/L	11.5	---	31	34.9
Nitrate, mg/L	---	---	0.12	1.6
Phosphate, mg/L	9	6.5	7.8	3.7
pH	7.3	7.5	7.4	7.0
SS, mg/L	140	---	86	---
Temperature, °C	21	---	26	25.4
Total phosphorus, mg/L	---	35	6.2	44
Total nitrogen, mg/L	---	45	38.2	28
References	Gürtekin & Şekerdağ, 2008	Ozengin & Elmaci, 2007	Nassar et al., 2015	Iwano et al., 2020

The experimental study lasted for 7 days without harvesting. During the experiment, no cases of Lemna Minor death were observed. Data collection was done twice, and mean values were reported (Abdel et al., 2016). The analyses of COD, phosphate, suspended solids, and ammonium were performed based on the Standard Methods (SM) (APHA, 1998). In addition, the suspended solid concentrations were determined using WG-GF/C filters. Ammonium and nitrate concentrations were measured using a standard kit, and BOD5 analysis was performed using a Lovebird apparatus, a liquid colorimetric testing device (Mohedano et al., 2012). All tests were conducted over varying time periods ranging 7-20 days, and results were averaged in this study (Katole & Patil, 2015).

3. Results and discussion

The study findings show that secondary settling tanks facilitate the settling of microorganisms and waste solids after biological treatment, resulting in minimal treatment of chemical oxygen demand and nutrients. Table II. presents the range of effluent concentrations registered during the experimental period. The efficiency of COD removal in secondary settling tanks with and without duckweed was found to be 20% and 5%, respectively, indicating 15% higher COD removal efficiency in the presence of duckweed. The research likewise points to duckweed enhancing the degradation of organic material through the additional supply of oxygen and surface area for bacterial growth. Table II shows the parameters of effluents in the secondary settling tanks. The measurements demonstrate that duckweed contributes to the efficiency of conventional biological treatment methods and can reduce the need for tertiary nutrient removal. There were no significant differences in effluent concentrations between the two clarifiers. Therefore, the formation of duckweed in the secondary clarifier tanks did not have an adverse effect on sludge settling characteristics in the first phase. However, further assessment and investigation are required to improve the conditions for duckweed formation.

Table II. Wastewater characteristics in secondary clarifier effluents.

Parameter	Concentrations			
COD, mg/l	208	120	58	---
BOD5, mg/l	79	---	33.6	---
Ammonium, mg/l	7.5	---	8.6	18.6
Nitrate, mg/l	---	---	0.12	0.6
Phosphate, mg/l	5	1.2	2.5	1.8
pH	7.8	7.5	8.6	7.0
SS, mg/l	50	---	36.9	---
Temperature, °C	21	22.4	23.2	24.3
Total phosphorus, mg/l	---	1.5	2.5	2.8
Total nitrogen, mg/l	---	15	11	13.6
References	Gürtekin & Şekerdağ, 2008	Ozengin & Elmaci, 2007	Nassar et al., 2015	Iwano et al., 2020

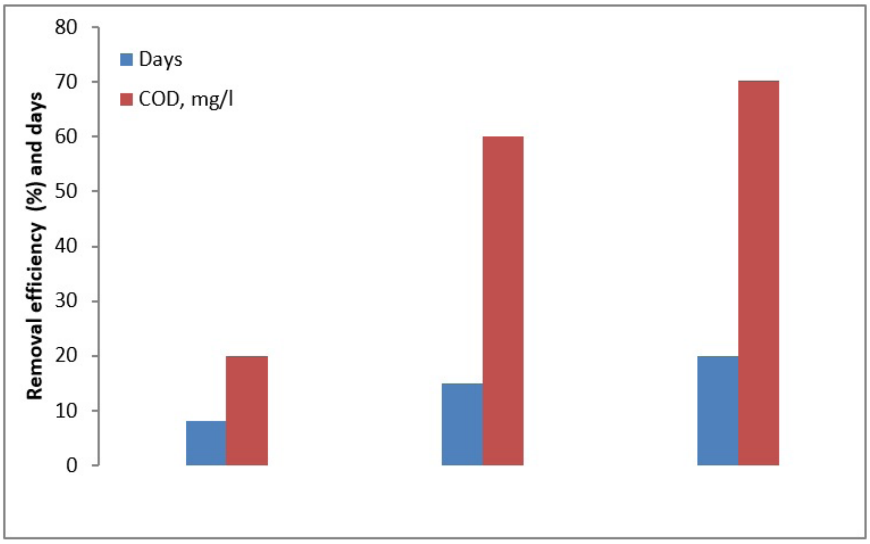

Figure 1. COD removal efficiency considered at different times.

Table II. presents the results of analysing the effluent samples harvested from secondary clarifier tanks. Thus, when duckweed was not present, the COD levels ranged from 195-300 mg/L, but after adding duckweed, they dropped to 58-208 mg/L. Similarly, BOD5 values decreased from 135-175 mg/L to 79-33.6 mg/L after duckweed treatment. Without duckweed, initial ammonium concentrations ranged from 11.5-34.9 mg/L, but with duckweed they declined to 7.5-18.6 mg/L. In the experiment, initial nitrate and phosphate concentrations in raw wastewater amounted to 0.12-9 mg/L and 1.6-7.8 mg/L, respectively. In the effluent, nitrate fell to 0.6 mg/L, and phosphate – to 5-1.2 mg/L. Additionally, total phosphorus, suspended solids, and total nitrogen in raw wastewater ranged between 44 and 6.2 mg/L. In the effluent, TN concentrations decreased to 45-28 mg/L, and SS – to 140-86 mg/L. The diagrams below illustrate the efficiency of removal for each target parameter.

Table III. Duckweed (Lemna minor) removal efficiency for treating different pollutants in wastewater.

Pollutant in wastewater	Removal efficiency by duckweed	References
Total nitrogen	60-90%	Aziz and Yusoff, 2015
Ammonia-nitrogen	80-90%	
Nitrate-nitrogen	30-80%	
Total phosphorus	70-95%	Chen et al., 2016
Orthophosphate	70-80%	
Total suspended solids	80-90%	
Biochemical oxygen demand (BOD)	80-90%	Islam et al., 2017
Chemical oxygen demand (COD)	60-80%	
Heavy metals	30-80%	

The pollutants listed in Table III. above include nutrients such as total nitrogen, ammonia-nitrogen, nitrate-nitrogen, and total phosphorus. Nutrients in wastewater can promote the growth of algae and other microorganisms, which may cause environmental issues like eutrophication when discharged into natural water bodies. The table also includes other types of pollutants – total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and heavy metals – with TSS referring to solid particles suspended in wastewater; and, BOD and COD indicating the amount of organic matter in it. Heavy metals are toxic pollutants capable of harming aquatic organisms as well as human health (Zhang et al., 2017).

The removal efficiency may vary depending on factors, including initial pollutant concentration in wastewater, temperature, light intensity, and nutrient availability. Thus, regular monitoring and testing to ensure optimal performance of duckweed-based wastewater treatment systems is important (Wang & Liu, 2021).

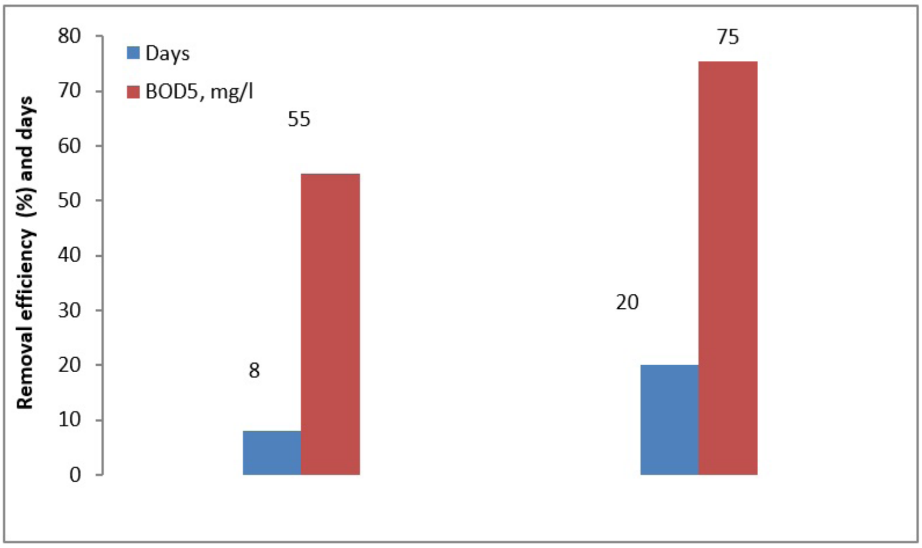

Figure 2. BOD removal efficiency.

The statistical analyses of the data from each sampling point represent the experiment outputs. The removal efficiency for each target parameter at different times was calculated as per the following formula:

$$\text{Removal efficiency (\%)} = \frac{C^0 - C}{C^0 \times 100} \quad ,$$

with C^0 representing the initial pollutant concentration in mg/L, and C representing pollutant concentration in the effluent at the time of subsequent measurement.

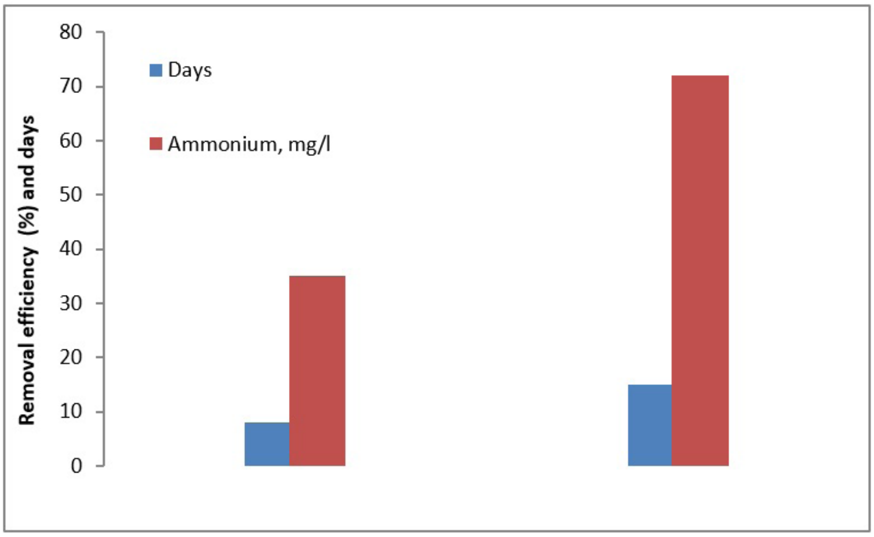

Figure 3. Ammonium removal efficiency.

Thus, the study examined the growth of Lemna minor and its effectiveness in removing COD, BOD, and ammonium. Figures 1., 2., and 3. demonstrate that the amount of ammonium absorbed by the duckweed body mass increased from approx. 35% after 8 days to over 70% after 15 days. Duckweed's high growth rate also contributed to BOD and COD reduction. However, it's important to note that in addition to absorption by duckweed nitrogen and phosphorous removal can also occur through microbial activities, algal growth, and natural decomposition in a natural duckweed system.

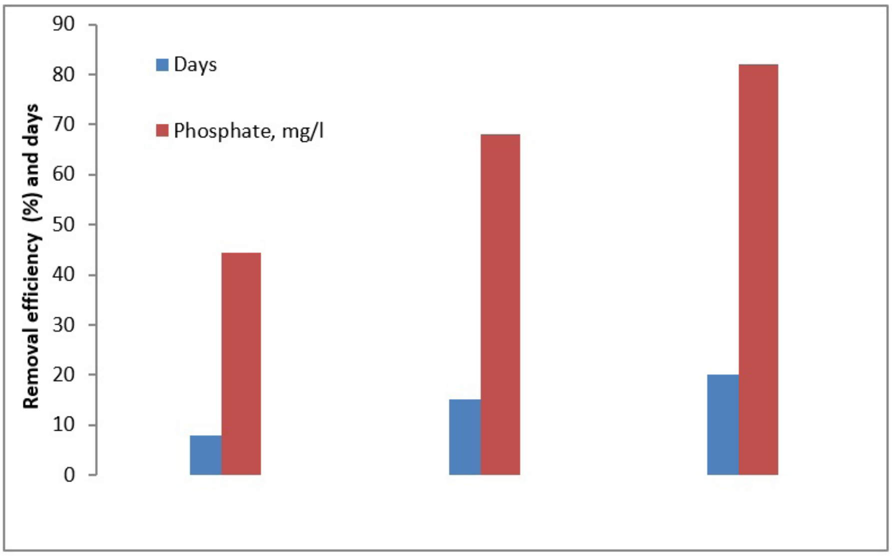

Figure 4. Phosphate removal efficiency.

Furthermore, the effluent suspended solid concentrations in clarifiers did not differ significantly ranging between 36.6-50 ml/g, respectively (Adeleke & Cloete, 2012). Other research papers report higher suspended solid removal efficiency in duckweed-based wastewater treatment facilities compared to waste clarifiers and algae-based ponds (Alam et al., 2023).

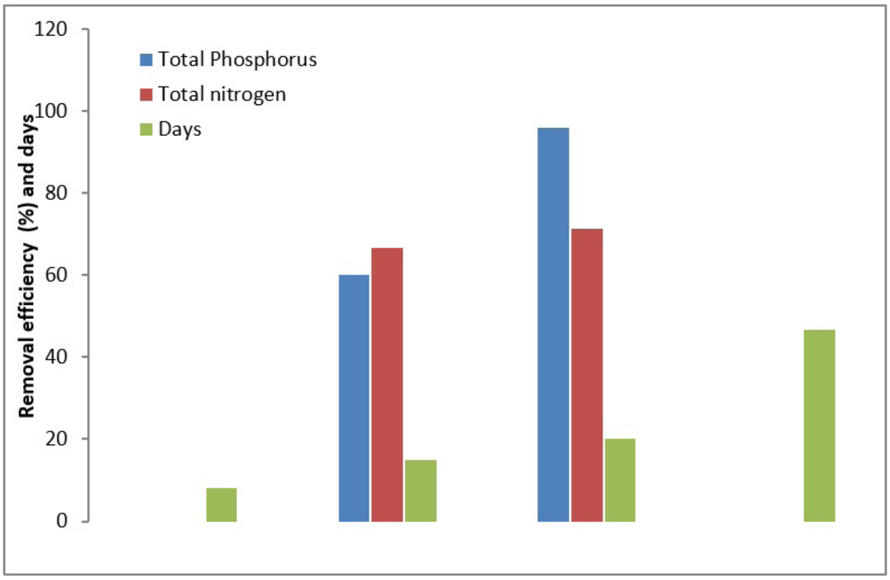

Figure 5. TP and TN removal efficiency.

The results of this study - inconsistent with other researchers - potentially suggest that the removal of suspended solids was primarily the outcome of sedimentation further enhanced by duckweed.

Conclusion

The study examined the effectiveness of duckweed (Lemna minor) in the secondary clarifier tanks of the target treatment plant. The findings indicate that the presence of duckweed in the tanks resulted in a significant reduction of chemical oxygen demand (COD), biological oxygen demand (BOD5), ammonium, nitrate, phosphate, suspended solids (SS), total phosphorus (TP), and total nitrogen (TN) in the effluent. The removal efficiencies for these parameters were higher in the tanks with duckweed than in those without it. The investigation likewise proved that the addition of duckweed improved the breakdown of organic matter by providing extra oxygen and surface area for bacterial growth. Overall, the research results suggest that the use of duckweed in secondary clarifier tanks can enhance the efficiency of conventional biological treatment methods, as well as reduce the need for tertiary nutrient removal. Further research is necessary to optimize the conditions for duckweed growth in tanks. As a natural filter, duckweed is characterized by high nutrient absorption capacity, and its high nutrient removal capability can be utilized to purify wastewater effectively, inexpensively, and easily. The results of this study indicate that duckweed-based wastewater treatment can achieve up to 73-84% COD removal, 83-87% TN removal, 70-85% TP removal, and 83-95% OP removal, reflecting optimal results.

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