Assessment of Sewage Treatment Plant Treated Effluent Remediation using Phytoremediation Technique

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Abstract. The increasing global demand for clean water has intensified the need for efficient and sustainable wastewater treatment methods. More studies are focusing on overcoming the limitations of conventional wastewater treatment technologies by exploring sustainable, low-cost, and low-maintenance alternatives. With rapid population growth and industrialization contributing to higher pollution loads in receiving water bodies, there is a growing emphasis on environmentally friendly treatment solutions. Among these, phytoremediation has emerged as a promising approach due to its effectiveness, affordability, and ecological compatibility. This study investigates the application of phytoremediation for sewage treated effluent using two aquatic plant species cultivated in separate treatment tanks installed at the effluent discharge point of a local wastewater treatment facility. Two operational parameters, namely pH and hydraulic retention time were varied to evaluate treatment performance. Water samples were collected and analyzed during each treatment cycle to assess pollutant removal efficiency. The results demonstrate the potential of phytoremediation systems to enhance effluent quality under con-trolled conditions, offering a sustainable complement to conventional sewage treatment processes.

1 Introduction

Traditional bioprocesses are not always able to fully treat wastewater as the current wastewater treatment processes have limitations, environmental and health impacts [1-2]. Hence, researchers are looking for alternative treatment methods which should have been less in cost, maintenance, and contamination as well as being environmentally friendly. The phytoremediation technique can treat wastewater with high performance in absorbing the organic and nutrient substrates in the wastewater with low cost and contamination besides its ecosystem [3-5]. A potential and competitive technology that can get around some of the drawbacks of individual treatment options is represented by some creative approaches [6].
The characteristics of untreated domestic wastewater are varies from weak to medium and strong in relation to the contents of organic and nutrient substrates represented in chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), and total dissolved solids (TDS) as organic substrates and total ammonia (TA), total nitrogen (TN), and total phosphorus (TP) as nutrients. According to previous studies, the COD, BOD_5, TDS, TA, TN, and TP in the domestic wastewater can be ranged from 250-1000, 110-400, 250-850, 12-50,

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20-85, and 4-15 mg L-1 respectively [7]. This number of substrates required advanced treatment methods which are usually physiochemical and biological-based methods that also varies depending on the technology and type of contaminants found in the raw wastewater. However, most of these processes have limitations or need to be coupled with each other for better performance [8].

The typical contents of organic and nutrient substrates in the domestic wastewater are varying, and on the other hand, the common wastewater treatment technologies with regards to chemical and biological-based methods are also varied depending on the technology and type of contaminants found in the raw wastewater. The performance of wastewater treatment technologies varies, and each technology has its own advantages and disadvantages. These processes remove pollutants either biologically, using microorganisms, or through physicochemical methods [9]. However, most of these processes have limitations or needs to be coupled with each other for better performance compounds [10].

The current study focuses on the biological phytoremediation treatment system which could contribute to the development of many future studies. This process is a step to ensure the safe disposal of the pre-treated wastewater into the environment with minimum contamination.

2 Methods

The phytoremediation system using the *Salvinia molesta* and *Water hyacinth* plants was placed at the discharge of residential wastewater treatment plant to treat the treated effluent, and the wastewater quality was monitored daily for 5 days. Samples were collected before and after the phytoremediation system and the parameter optimization were analyzed using the response surface methodology (RSM) method. The design of the experimental runs were according to two independent factors, hydraulic retention time (HRT) and referred to it as (X_1), and pH level and referred to it as (X_2) (Table 1). Also, there were four responses variables considered as dependent factors, which are COD (Y_1), TDS (Y_2), TN (Y_3) and turbidity (Y_4). A total of ten experimental runs were designed and the obtained results from each run were added to the central composite design (CCD) in Design-Expert 11.1.2.0 software (Stat-Ease, Inc., Minneapolis, United State) through the option of “Historical Data Design” which allows the users to add an external data to be analyzed using the software.

Table 1: The levels of coded and un-coded independent variables.

Factor	Symbol	Low (-1)	Middle (0)	High (+1)
Hydraulic retention time (HRT), (Day)	X_1	1	3	5
pH	X_2	5	6	7

3 Results and Discussion

The monitoring results of COD, TDS, TN, and turbidity were analyzed using the RSM through the Design-Expert software by applying two independent factors using HRT and pH. Table 2 displays the observed (Obs.) and predicted (Pred.) removal results. Here, "observed" results refer to those measured in the laboratory, whereas "predicted" results were generated by the software.

Table 2: CCD arrangement and responses for the system removal efficiency.

Type	Run	HRT (d) (X_1)	pH (X_2)	COD % (Y_1)		TDS % (Y_2)		TN % (Y_3)		Turbidity % (Y_4)	
				Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
[illegible]	1	1	5	9.14	8.28	11.00	8.81	10.91	7.83	21.14	21.58

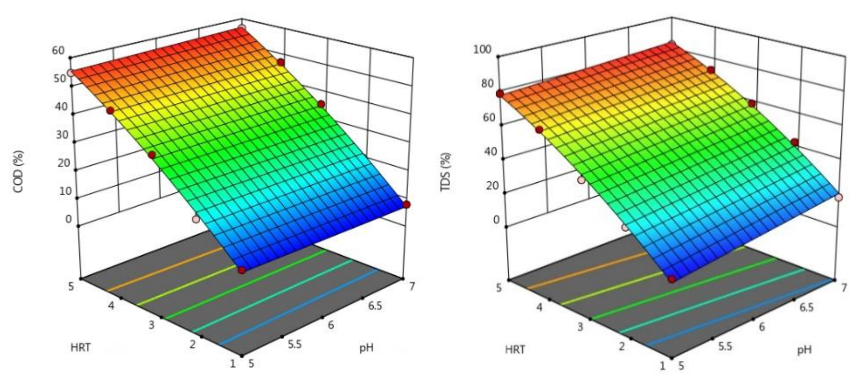
	2	2	5	19.84	22.13	29.00	30.29	12.51	17.53	33.12	29.84
	3	3	5	36.04	34.59	46.00	48.99	29.10	28.05	39.15	41.49
	4	4	5	46.21	45.68	66.00	64.89	40.01	39.40	53.15	56.55
	5	5	5	54.84	55.39	79.00	78.01	51.84	51.57	77.91	75.01
	6	1	7	8.01	7.27	18.00	20.41	9.84	10.91	29.15	28.64
	7	2	7	20.13	21.73	43.00	40.59	21.45	20.53	34.12	37.20
	8	3	7	35.43	34.80	59.00	57.99	30.15	30.97	50.51	49.16
	9	4	7	47.08	46.50	73.00	72.59	45.41	42.23	69.05	64.52
	10	5	7	56.47	56.82	83.00	84.41	52.12	54.32	79.98	83.28
Water hyacinth	1	1	5	12.42	11.32	8.00	7.36	3.10	1.91	1.09	0.8479
	2	2	5	17.03	19.03	16.00	18.42	2.60	5.06	5.66	8.48
	3	3	5	29.34	27.70	28.00	24.84	8.94	8.15	17.45	14.53
	4	4	5	35.66	37.32	25.00	26.62	12.21	11.17	20.66	19.00
	5	5	5	48.81	47.89	24.00	23.76	13.56	14.12	19.89	21.89
	6	1	7	10.37	10.21	10.00	8.56	0.51	0.27	1.58	-0.0781
	7	2	7	14.98	17.49	14.00	18.32	1.91	2.46	1.28	3.34
	8	3	7	30.06	25.72	28.00	23.44	4.25	4.59	5.51	5.18
	9	4	7	33.11	34.91	22.00	23.92	8.03	6.65	4.33	5.44
	10	5	7	44.87	45.06	20.00	19.76	7.92	8.64	5.29	4.11

3.1 Treated wastewater quality in Salvinia molesta tank

The TDS removal efficiency was 11% on first day while COD removal was 70% after 5 days in both setups (pH 5 and 7) as shown in Table 2 and Figure 1. The results obtained were close to the predicted values, which increased the confidence of the study results.

The TN samples before treatment were low (10.46 mg L^{-1}), and that affected the growth of the experimental plants because of their needs for nitrogen. The *Salvinia molesta* tank recorded TN removal percentage of 51.84 % (pH 5) and 52.12% (pH 7) in the fifth day.

The turbidity level was 17.70 mg L^{-1} and the removal was 77.91% on the fifth day (pH 5) and slightly better at pH 7 with 79.98%.



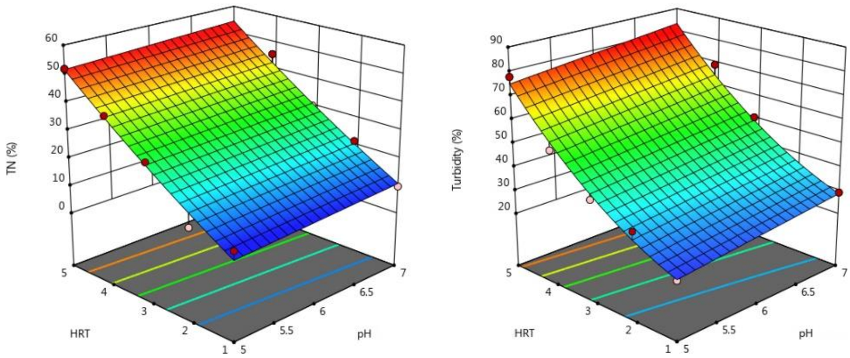


Fig. 01. COD, TDS, TN, and Turbidity removal vs independent factors in *Salvinia molesta* tank.

3.2 Treated wastewater quality in Water hyacinth tank

The COD removal efficiency was initially 12.42% and increased to 48.81% on the fifth day (pH 5) and 44.87% (pH 7) as shown in Table 2 and Figure 2. The TDS removal increased continuously until the third day then decreased towards the fifth day recording 24% (pH 5) and 20% (pH 7). TN concentration recorded a slight drop from 10.46 to 9.04 mg L^{-1} (pH 5) and from 10.46 to 9.63 mg L^{-1} (pH 7). Turbidity removal was unstable in both setups, consistent with several previous reports; for example, one study observed 25.98% removal after 28 days [7].

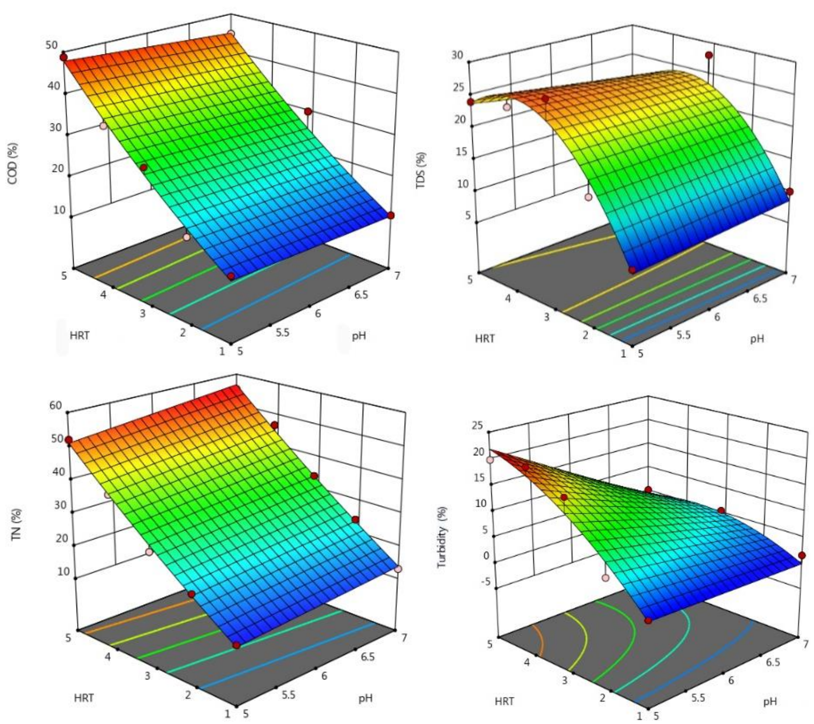


Fig. 02. COD, TDS, TN, and Turbidity removal vs independent factors in *Water hyacinth* tank.

4 Conclusions

Systems for a phytoremediation system were designed and installed at a nearby plant to collect the plant's wastewater. *Water hyacinth* and *Salvinia molesta* were planted in separate tanks. During many runs, the pH level and HRT were changed while the four responses - COD, TDS, TN, and turbidity - were evaluated. The RSM prediction assisted in predicting the parameters, and the system operated effectively. Further studies could be conducted by monitoring additional parameters over a longer operating period.

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References

1. J. S. Sravan, L. Matsakas, O. Sarkar, Advances in biological wastewater treatment processes: focus on low-carbon energy and resource recovery in biorefinery context. Bioengineering 11, 281 (2024). https://doi.org/10.3390/bioengineering11030281

2. K. S. R. Yadav, V. B. Mandaliya, Phytoremediation for water pollution: A patent landscaping review. Environ. Eng. Sci. 43, 199–217 (2026). https://doi.org/10.1177/15579018261442662

3. R. Sharma, R. Rana, R. Kumar, Phytoremediation and smart wetlands: A sustainable framework for wastewater and resource management. Urban Water J. 23, 1–24 (2026). https://doi.org/10.1080/1573062X.2026.2648237

4. J. D. Aliyu, I. Abubakar, S. Maliki, S. G. Umar, Application of some selected plants biomasses in treatment of wastewater. Biol. Med. Nat. Prod. Chem. 15, 1203–1212 (2026). https://doi.org/10.14421/biomedich.2026.151.1203-1212

5. P. Schröder, J. Navarro-Aviñó, H. Azaizeh, A. G. Goldhirsh, S. DiGregorio, T. Komives, A. Ranalli, Using phytoremediation technologies to upgrade waste water treatment in Europe. Environ. Sci. Pollut. Res. Int. 14, 490-497 (2007). https://doi.org/10.1065/espr2006.12.366

6. W. Zeng, B. Yao, Y. Zhou, J. Yang, D. Zhi, Combination of electrochemical advanced oxidation and biotreatment for wastewater treatment and soil remediation. J. Environ. Sci. 150, 36–53 (2025). https://doi.org/10.1016/j.jes.2024.02.036

7. I. Rawat, R. R. Kumar, T. Mutanda, F. Bux, Dual role of microalgae: phytoremediation of domestic wastewater and biomass production for sustainable biofuels production. Appl. Energy 88, 3411-3424 (2011). https://doi.org/10.1016/j.apenergy.2010.12.029

8. M. Rahimnejad, A. Adhami, S. Darvari, A. Zirepour, S. E. Oh, Microbial fuel cell as new technology for bioelectricity generation: A review. Alexandria Eng. J. 54, 745-756 (2015). https://doi.org/10.1016/j.aej.2015.03.031

9. G. Crini, E. Lichtfouse, Advantages and disadvantages of techniques used for wastewater treatment. Environ. Chem. Lett. 17, 145-155 (2019). https://doi.org/10.1007/s10311-018-0785-9

10. G. A. Alade, S. O. Ojoawo, Purification of domestic sewage by water-hyacinth (Eichhornia crassipes). Int. J. Environ. Technol. Manag. 10, 286-294 (2009). https://doi.org/10.1504/IJETM.2009.025313