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Synergic Usage of *Pistia stratiotes sp., Eichhornia crassipes sp., Typha angustifolia sp.*, and *Lepironia Articulata sp.* Plants for Sewage Treatment *via* Phytoremediation Technology

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Abstract:

Introduction: Domestic wastewater management is challenging on a worldwide level. The discharge of a large amount of nitrogen and phosphate from sewage accelerates pollution can lead to reduced oxygen levels, excessive algal blooms, the expansion of aquatic weed plants, and the destruction of the aquatic environment. As a result, the right wastewater treatment is required prior to discharge into natural water bodies in order to prevent contamination and fulfill the wastewater acceptable limits established by the government and environmental protection agencies. For Previous studies, most of the research is carried out in a controlled environment within a small time frame. Phytoremediation offers a viable alternative by harnessing the natural capabilities of plants to enhance the degradation and removal of pollutants in sewage.

Aims: The objective of this study is to evaluate the phytoremediation performance using *Pistia stratiotes sp., Eichhornia Crassipes sp., Typha angustifolia sp., and Lepironia Articulata sp.* in treating real domestic wastewater.

Methods: The phytoremediation system conducted continuous treatment at the Sewage Treatment Plant (STP) effluent at Selangor, Malaysia. To the best of our knowledge there are no studies conducted on the phytoremediation plant in real STP using 4 types of aquatic plants in a row to achieve a high percentage removal of pollutants. This research observation was conducted by collecting data every 2 weeks for 4 consecutive months including the maintenance terms. In terms of pollutant removal, the phytoremediation system showed the highest removal efficiency in all tested parameters.

Results: The highest removal efficiency recorded for biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS) and ammoniacal nitrogen (AN) were 68.38%, 70.95%, 59.21% and 25.00%, respectively.

Conclusion: Following the guidelines of the Environmental Quality (Sewage Effluent) Regulation 2009 Malaysia, synergic usage of the aquatic plant had successfully achieved Standard A for sewage discharge after applying the phytoremediation technology while it has been proven that the environmentally friendly technologies can reduce the risk of water pollution by using the selected plant and may solve the water shortage with a cost-effective and efficient solution to wastewater treatment.

Keywords: Phytoremediation, Wastewater, Aquatic plant, Sewage, Integrated system, Pollutants.

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1. INTRODUCTION

As populations grow and natural environments deteriorate, it becomes increasingly challenging to ensure that everyone has access to sufficient and secure water. Reduced pollution and improved effluent management constitute a substantial portion of the solution. In a continuous, sustainable economy, environments are less likely to be polluted, and more waste is treated, recycled, and safely used again as a source of water, energy, and nutrition. About 42% of domestic effluent is improperly treated, endangering ecosystems and human health [1].

Wastewater treatment strategies are categorized into three subdivisions: Biological, Chemical and Physical. Wastewater treatment involves removing pollutants from household and wastewater sewage to create waste that is suitable for reuse or discharge. Southeast Asian countries use several methods to treat wastewater, including adsorption, advanced oxidation processes and membrane filtration.

The most common method for municipal wastewater treatment is filtration through fabric filters or sand. Typically, effluent is discharged directly into water bodies without purification, resulting in pollution and nutrient enrichment of surface waters [2]. In addition, untreated effluent can lead to waterborne diseases such as diarrhoea, typhoid, and cholera [3-5]. Therefore, it becomes necessary to identify wastewater treatment methods that can be used to reduce pollutants in wastewater prior to release into the environment [6]. Antibiotics continuing in effluents and residual sediment continue to accumulate and disperse in the environment, making sewage treatment plants the primary source of antibiotic contamination in the aquatic environment [7].

Indah Water Konsortium Sdn Bhd is Malaysia's national sewerage company tasked with creating and sustaining a modern and effective sewerage system for all Malaysians. Primary treatment systems like community septic tanks and Imhoff tanks have been used a lot in Malaysia. So have low-cost secondary systems like oxidation ponds, which aren't very reliable. Individual Septic Tanks (IST) are also used in big cities. It is thought that Malaysia has more than a million separate septic tanks. These tanks only partly clean water, releasing waste that is high in organic matter. Problems with public health and the environment could arise from this, especially in cities. Most likely, Malaysia's sewage system will work better over time as the types of plants used become more uniform. The handling of household waste in Malaysia has changed a lot because of these thorough programs. The whole system for treating water will probably need to be changed.

Most of the time, household wastewater is treated with traditional systems like active sludge systems, membrane bioreactors, and membrane separation. Running and maintaining these systems costs a lot of money, and they don't help many countries grow. In the past few years, there has been more interest in using man-made marshes to clean up wastewater [8]. Compared to conventional treatment systems, constructed wetland has the advantages of low maintenance costs and lower energy consumption, as well as a wide range of potential applications [9]. Constructed wetland performance may be enhanced by the presence of low hydraulic and pollutant loads. One possible approach to overcome this constraint is to successfully create wetland floating bed systems. Ecological floating platforms are highly recommended in light of their cost-effectiveness, superior efficiency, and ability to provide ideal conditions for plant development.

Previous research showed that the mechanisms of nutrient absorption from wastewater may be advanced based on the physiological, biological, and physiochemical behaviors of plants in aquatic environments. Several scientists have investigated the mechanics of aquatic plant nutrient absorption from wastewater systems [10]. The ability of aquatic plants to entrap nutrients is used to regulate eutrophication four types of aquatic plants in lakes, ponds, and built wetlands. Table **1** shows 4 aquatic plants that have been used in various research.

Table 1. Aquatic plant listing with contaminants percentage removal.

Scientific Name	Common Name	Percentage Contaminants Removal	Sampling Period	Refs.
Typha angustifolia L.	Narrowleaf cattail	BOD5 (68%), Colour (62%), COD (65%), TDS (45%), TSS (35%), As (60%), Cd (28%), Cr (59%), Pb (45%);	42 days/ subsurface batch system constructed wetlands.	[11]
Lepironia Articulata sp.	Grey Sedge	Ammonium (75.8%), phosphate (58.3%), COD (90.8%)	24 hours treatment	[12]
Eichhornia crassipes	Water hyacinth	COD (49%), NH3 (81%), Nitrate (92%), Phosphorous (67%).	24 days/ reactor tanks	[10]
Pistia stratiotes	Water lettuce	BOD (17–8.3 mg/L), COD (126–52 mg/L), DO (7.54–5.33 mg/L), pH (7.81–7.37), Fe (137%), Nitrite (0.7 to —0.2 mg/L), oil & grease (0.91–1.54 mg/L).	2 months	[13]

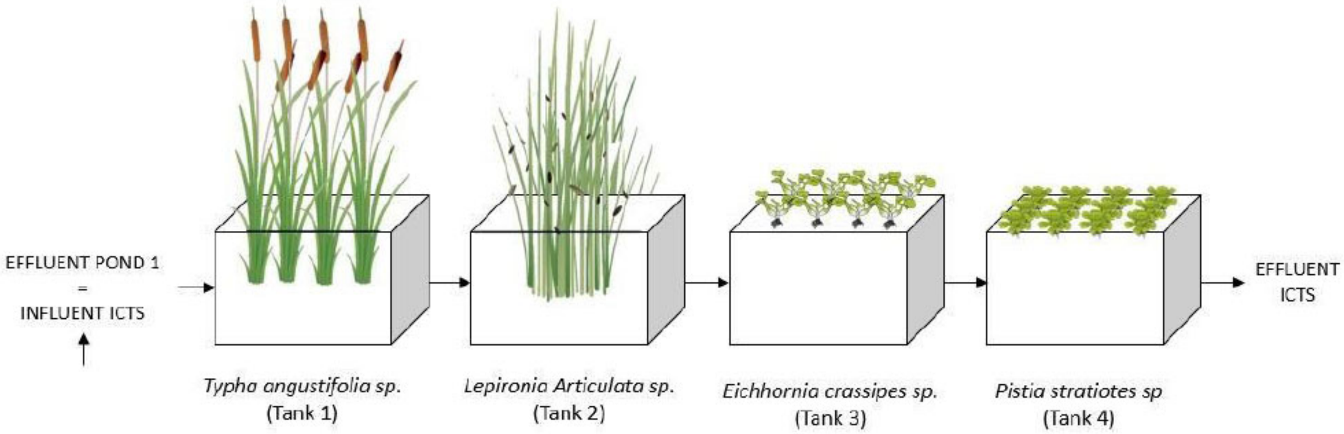

Fig. (1). Arrangement of phytoremediation system.

Hence, the development of cost-effective and environmentally friendly technology for the treatment of urban wastewater, particularly for the prompt management of monsoon discharge, has significant importance. Phytoremediation, a well-established and generally embraced green method, involves the use of plants to eliminate pollutants such as nutrients, organic compounds, radionuclides, and hazardous metals from wastewater [14]. Using *Pistia stratiotes sp* (water lettuce) as a phytoremediation agent, the water quality of the eutrophic ecosystem has been enhanced [15]. Nevertheless, it is important to acknowledge the inherent limits associated with the efficacy of plants used in phytoremediation. These constraints include the relatively low biomass shown by hyperaccumulators, as well as the inherent unsuitability of some plant species for effectively eliminating certain kinds of pollutants aims often seen in effluent [16]. In this study, the authors intend to evaluate the performance of multiple plants including *Pistia stratiotes sp., Eichhornia Crassipes sp., Typha angustifolia sp.,* and *Lepironia Articulata sp.* for treating sewage from real sites. A phytoremediation system was designed and employed on the site and assessed for 4 months continuously. Most researchers use lab-scale or simulated methods, while in these studies they use a combination of 4 types of aquatic plants in one system. To the best of our knowledge, no studies have been conducted on the phytoremediation plant in real, Sewage treatment plant (STP) using 4 types of aquatic plants in a row to achieve a high percentage removal of pollutants.

2. MATERIALS AND METHODS

2.1. Location and Arrangement

The study was conducted at the sewage treatment plant (STP) in Selangor. The raw sewage passes through the primary (Pond 1) and secondary stages (Pond 2) of water before being discharged into natural water bodies. The diagram of the phytoremediation system and the experimental setup is shown in Fig. (**1**). A treatment system consisting of a series of tanks (no. 1, 2, 3 & 4) was constructed for the cultivation of plants. The influent sample was the treated water that flows from the STP into the phytoremediation systems. Whereas, the effluent sample is the water sample collected from the phytoremediation systems after plant cultivation. For the treatment of municipal effluent, a phytoremediation system with horizontal flow and phytoremediation technology has been constructed. Each vessel was positioned at a distinct height and was connected to the next *via* gravity flow. The tank (1448mm x 1448mm x 1143mm) can hold more than 1,364 liters of effluent, but only 90% of it was utilized. Two extreme plants, *Typha angustifolia sp.* and *Lepironia Articulata sp.*, were introduced in the first two tanks. Meanwhile, two polishing polishing plants, *Eichhornia crassipes sp. and Pistia stratiotes sp.,* were simultaneously planted separately in tank 3 and 4. There are 4 tanks placed for all aquatic plants.

The domestic wastewater was directly collected from the STP in Selangor, Malaysia. This STP treats domestic wastewater from the community's laundries, restrooms, restaurants, offices, and homes. Before being discharged into natural water bodies, the wastewater is treated by an oxidation pond which consists of two ponds in series discharge from Pond 1 of the oxidation pond is being used as an influent to the phytoremediation system. To eradicate contamination, water samples were collected in polyethylene vessels washed with double-distilled water [17].

The samples need to be cooled down after being collected in order to preserve all pollutants in the sample bottle. The wastewater sample was collected at the sewage treatment plant Rawang area and the sample with an amount of 1 litre influent and 1 litre effluent was stored for pre-treatment analysis at 4°C.

Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), and Ammoniacal Nitrogen (AN). Various tests were conducted for this investigation including. All testing methods are in accordance with the Standard Code of the American Public Health Association (APHA 2017). Table **2** shows the list of testing used in this treatment.

Table 2. Testing method for water quality.

Parameter	Unit	Testing Method
BOD5	mg/L	APHA 5210B
COD	mg/L	APHA 5220 D
TSS	mg/L	APHA 2540 D
NH3-N	mg/L	APHA 4500

Table 3. Efficiency percentage removal in 5 weeks observation.

Aquatic Plant	Efficiency %			
	BOD	COD	TSS	AN
Eichhornia crassipes sp.	84.74	96.79	99.24	99.66
Pistia stratiotes sp.	87.67	98.77	97.73	99.66
Typha angustifolia sp.	78.43	99.26	93.94	99.31
Lepironia Articulata sp.	76.89	99.75	87.88	98.28

2.2. Plant Sampling

Four aquatic plants, *Typha angustifolia sp., Lepironia articulata sp., Eichhornia crassipes sp.*, and *Pistia stratiotes sp.*, Fig. (**1**) were selected. The collection location of the aquatic plant is at Gebeng, Pahang for *Typha angustifolia sp.*, Runchang, Pahang for *Lepironia articulata sp.*, Sungai Isap, Pahang for *Eichhornia crassipes sp.* and Segamat, Johor for *Pistia stratiotes sp.* Before being used in sewage treatment plants, the plants acclimated for a week in a tank of tap water. The aquatic plants were tested in a lab scale for 5 weeks for a preliminary study of performance averaged removal. The percentage removal of each plant was average in 5 weeks of observation. During the phytoremediation process, the growth of plants plays a role in the successful removal of contaminants from the environment. As the process unfolds, a noticeable transformation in plant growth will be observed. The increases in height, root, the width of leaves and canopy of the plant will be observed. Table **3** shows the efficiency percentage removal for 5 weeks of observation in lab-scale data before real treatment in STP.

2.3. Phytoremediation Monitoring

This research observation was conducted by collecting data for 4 consecutive months and samples of influent and effluent wastewater were taken every two weeks. While phytoremediation can be effective in reducing pollution, there are situations where it is necessary to harvest the plants used in the process. As phytoremediation plants grow and accumulate contaminants, their biomass increases. Harvesting helps manage the growth of these plants and prevents them from becoming overgrown and unmanageable. Harvesting phytoremediation plants allows for the assessment of the effectiveness of the remediation process. Analysing the plant tissues can provide valuable information on the extent of contaminant removal and the overall success of the phytoremediation process.

Within wastewater treatment systems, phytoremediation utilizing aquatic plants can serve a vital function in eliminating pollutants. The phytoremediation technique of rhizofiltration specifically entails the absorption of contaminants by plant root structures from polluted aqueous sources. These aquatic plants can bioconcentrate the pollutants within their tissue biomass or metabolize them into less toxic chemical forms. The fate of phyto-remediating plants in wastewater involves complex interactions between the uptake kinetics, sequestration, transformation mechanisms, and disposal of accumulated toxicants. Successful implementation of phytoremediation for wastewater treatment relies on the selection of appropriate aquatic plant species, comprehending their pollutant assimilation pathways, and effective management of harvested plant biomass to prevent secondary pollution. Further research into ideal plant selection, uptake capacities, translocation factors, and harvest logistics is imperative to optimize phytoremediation using aquatic plants as an ecotechnological approach for effluent remediation and sustainable wastewater treatment.

The effectiveness of a phytoremediation system is a critical aspect to consider when addressing wastewater treatment. This effectiveness was evaluated and it is essential to estimate the removal of contaminants from the phytoremediation system. This assessment involves a comprehensive monitoring program that focuses on the physicochemical characteristics of the wastewater treatment process. This includes the analysis of various parameters in both the influent and the effluent of the phytoremediation system.

2.4. Phytoremediation System

The phytoremediation system treatment makes extensive use of the sample by employing standard water and effluent techniques. This innovative system offers a cost-effective and efficient solution for effluent treatment, enabling the successful removal of contaminants from water. Fig. (**2**) shows plants like *Pistia stratiotes* (water lettuce), *Eichhornia crassipes* (water hyacinth), *Typha angustifolia* (cattail), and *Lepironia articulata* (swamp sawgrass) will be selected for their potential to remove various contaminants from the wastewater. The selected plants will be planted in separate tanks within the phytoremediation system. The configuration may include different types of plants in different tanks to assess their individual and combined treatment capabilities. The arrangement may also consider factors like plant density, spacing, and growth conditions. The tanks are set up at varying heights, allowing for gravity flow from one tank to another. This design facilitates the movement of wastewater from the initial treatment tank through subsequent ones, allowing the plants to interact with the water as it progresses. Phytoremediation, as a natural treatment process, relies on the ability of aquatic plants to absorb, adsorb, or transform contaminants. These plants play a crucial role in removing pollutants through mechanisms such as rhizofiltration (root absorption), phytoaccumulation (bioaccumulation in plant tissues), and rhizodegradation (microbial activity in the root zone). Throughout the experiment, various parameters need to be monitored and measured regularly. These include water quality indicators such as pH, turbidity, COD, BOD, nutrient concentrations, heavy metal levels, and plant growth parameters. A phytoremediation system utilizing phytoremediation technology offers a sustainableand environmentally friendly approach to municipal wastewater treatment. Through careful planning, plant selection, and systematic monitoring, researchers can demonstrate the potential of this method to enhance water quality and reduce the environmental impact of wastewater discharge from the domestic wastewater.

The removal percentage for each pollutant parameter from wastewater using Eq. (**1**) [18]:

$$\frac{\boldsymbol{C_0 - C_e}}{\boldsymbol{C_0}} \times \mathbf{100\%} = \%\,\boldsymbol{removal} \tag{1}$$

Where,

C_o = initial concentration of pollutants parameters in domestic wastewater

C_e = final concentration of pollutants parameter in domestic wastewater.

Fig. (2). Four types of aquatic plants (**a**) *Typha angustifolia sp.* (**b**) *Lepironia Articulata sp.* (**c**) *Eichhornia crassipes sp.* and (**d**) *Pistia stratiotes sp.*

3. RESULTS AND DISCUSSION

3.1. Performance of Phytoremediation System in Treating Wastewater

The efficiency of the phytoremediation system may be evaluated by determining the quantity of pollutants that were removed by the phytoremediation system. The analysis of physicochemical traits was done to evaluate how well the phytoremediation system treated actual municipal wastewater overall. In order to examine the overall removal during the course of the study period, a data comparison between the influent and effluent of wastewater was done.

3.1.1. Biochemical Oxygen Demand (BOD) Removal

The results of the BOD analysis of the phytoremediation system throughout the 107 days of the research period are shown in Fig (**3**). The BOD data indicated that most of the BOD removal occurred due to the microorganism activity in the medium. Wastewater from sewage treatment plants often contains organic materials that are decomposed by microorganisms, which use oxygen in the process. The amount of oxygen consumed by these organisms in breaking down the waste is known as the biochemical oxygen demand or BOD.

The pattern for BOD was fluctuating due to the irregular entry of sewage treatment water every day. In the first 5 days, the removal percentage was 31.94%, which increased to 41.37% on the 19th day. It dropped to 15.95% and 14.23% on days 33th and 47th, respectively. It started to rise on day 61st with the third highest reading over 178 days with a reading of 68.38%. The highest removal percentage was on the 96th day with a reading of 90.87%. On the 107th day, the removal percentage decreased to 57.94%. The lowest and greatest BOD values are clearly visible in the data. During Week 8, the lowest BOD reading was obtained, with a surprisingly low number of 14.23%. In contrast, the greatest BOD measurement came on day 96, when the BOD value increased to a significant 90.87%. This substantial reduction in BOD reflects the efficiency of the treatment system in significantly improving the water quality. At the end of January (day 33), the average weather is 31° and rises to 33° in early February on average. Temperature stress affects the geographical distribution of plants and reduces plant productivity, thus deteriorating the effectiveness of the plants. If plants are stressed or die due to the contaminants, their metabolic activity, including respiration, can decrease, resulting in less oxygen consumption and has given effect on aquatic plants as depicted (Fig. **4**).

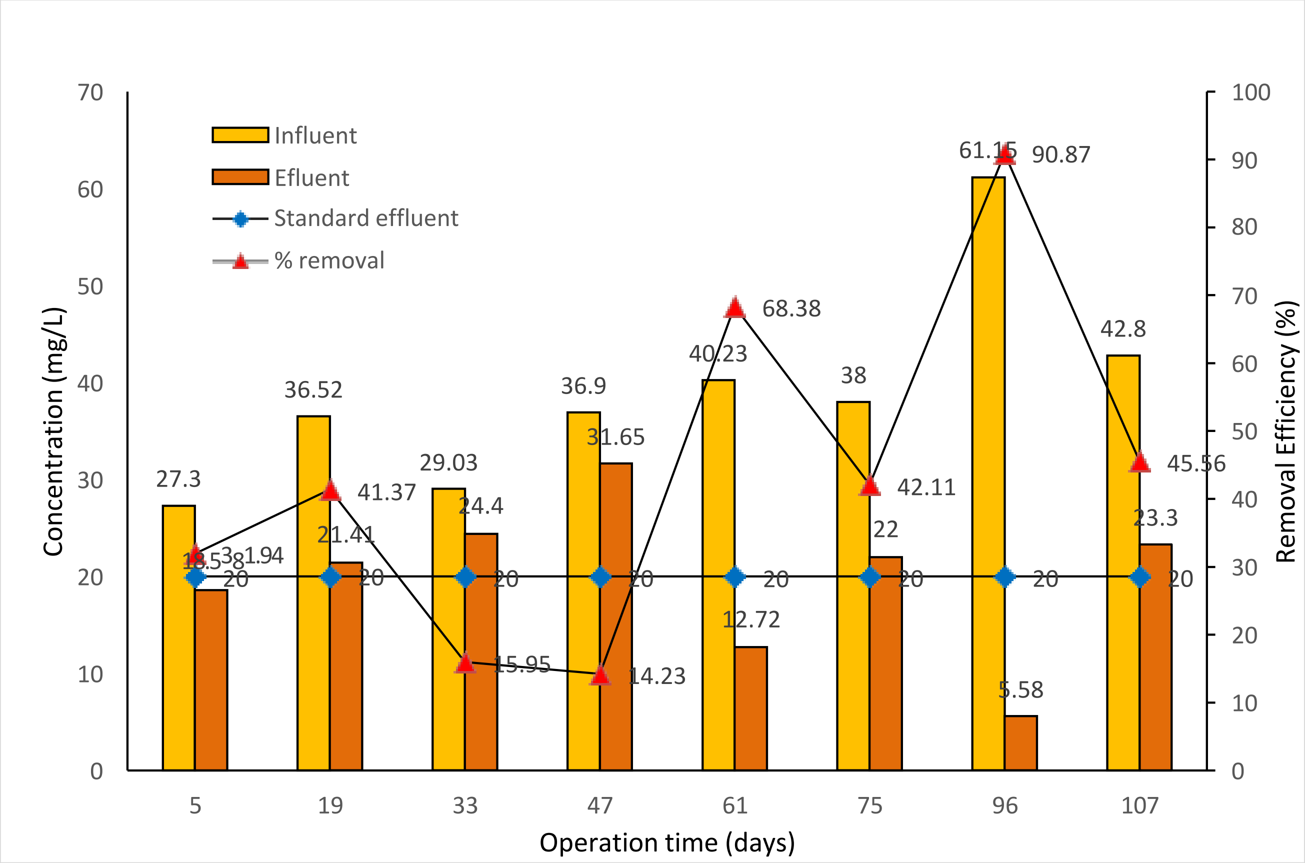

Fig. (3). Removal performance of BOD by phytoremediation system.

Fig. (4). Condition of *lepironia articulata sp.* in February.

It was observed in February that some trees in tank 2 had died as shown in Fig (**4**). The dead plants might increase in pollutants inside the tank and affect the actual pollutants value in tanks. The trunk becomes yellowish and the roots of the tree become damaged. Some plants can take up contaminants through their roots and translocate them to above-ground parts. This process may reduce the availability of contaminants in the water or soil, potentially leading to reduced microbial activity and oxygen consumption. In some cases, contaminants may have phytotoxic was effects, harming the plants' health. Lepironia Articulata sp. is an aquatic plant that can absorb a lot of BOD. It is supported by a previous study that stated 99.94% removal of BOD5 can be removed by *Lepironia articulata and Scirpus grossus* [19].

The result proved that the synergic utilization of plants selected has led to significant improvements in BOD removal of the sewage. The data showcases both an initial reduction and a remarkable reduction over a longer period, highlighting the positive impact of plants on the treatment process. The enhanced bacterial growth and accelerated treatment process attributed to the plants have collectively resulted in higher removal rates and improved water quality in a shorter timeframe. This reduction of BOD as organic compounds by plants is generally achieved through phytodegradation, which involves the release of enzymes from roots to the media and metabolic activity from the plant [20].

3.1.2. Chemical Oxygen Demand (COD) Removal

Based on Fig (**5**), the trend for COD started at 23.57% on the 5th day and increased to 27.08% on the 19th day. The increase in removal percentage continued to the 33rd and 70th day with readings of 41.10% and 70.95% each. It decreased to 49.08% and 31.90% on the 75th and 96th day. Increased removal reduction on the 107th day with a value of 70.93%. the lowest and maximum COD values are clearly visible. The lowest COD reading was recorded in Week 2, with a comparatively low value of 23.57%, while the greatest COD reading was found in Week 10, with a significant 70.95%. This very high COD level indicates that the water sample contained a substantial quantity of organic and inorganic contaminants during Week 10. In the context of this experiment, the focus is on the removal efficiencyof the phytoremediation system concerning COD. COD was a measure of the amount of oxygen required to chemically oxidize organic substances in water. Following the guidelines of the Environmental Quality (Sewage Effluent) Regulation 2009 stated that standard A of COD concentration was 120 mg/L.

All the effluent in the phytoremediation system showed a concentration COD lower than standard A. Most researchers proved that all four aquatic plants had successfully obtained high COD removal. In a recent article [21] *Thypha angustifolia* was used and managed to remove 77.3% of COD, from real wastewater. Another study [19] also showed the results that *Lepironia articulata* in Constructed Wetland showed high removal of COD with values up to 96.94%. A study [22] used *Pistia stratiotes* and *Eichhornia crassipes* and successfully reduced COD up to 99% after five weeks. Higher COD values indicate higher levels of organic pollutants in the water, which can be harmful to the environment if not treated. It was found that the sulfamethoxazole enriched the co-metabolizing bacteria resulting in higher removal rates of organics and antibiotics. It was not clear whether plants increased sulfamethoxazole removal through either uptake or microbial enrichment in the study by Qu *et al*. Similarly, COD found that in constructed wetlands, aerobic microbial degradation was responsible for the majority of sulfonamide removal. Biodegradation was found to be highest and closest to the plant roots [23].

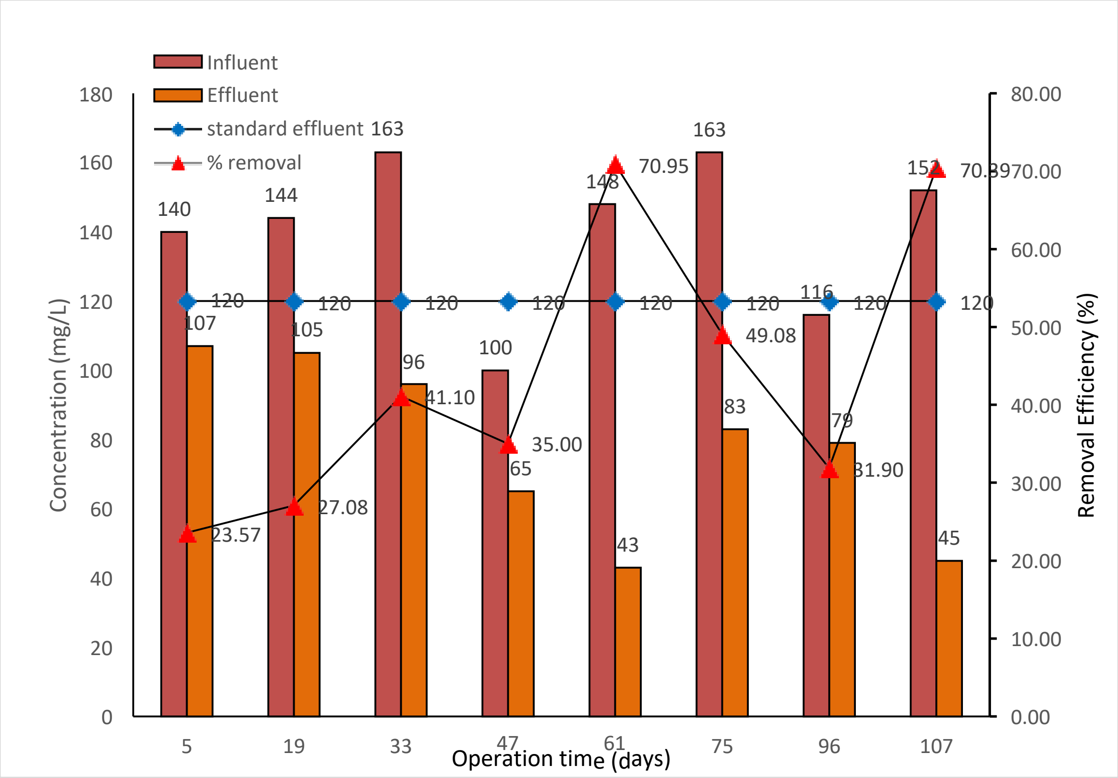

Fig. (5). Removal performance of COD by phytoremediation system.

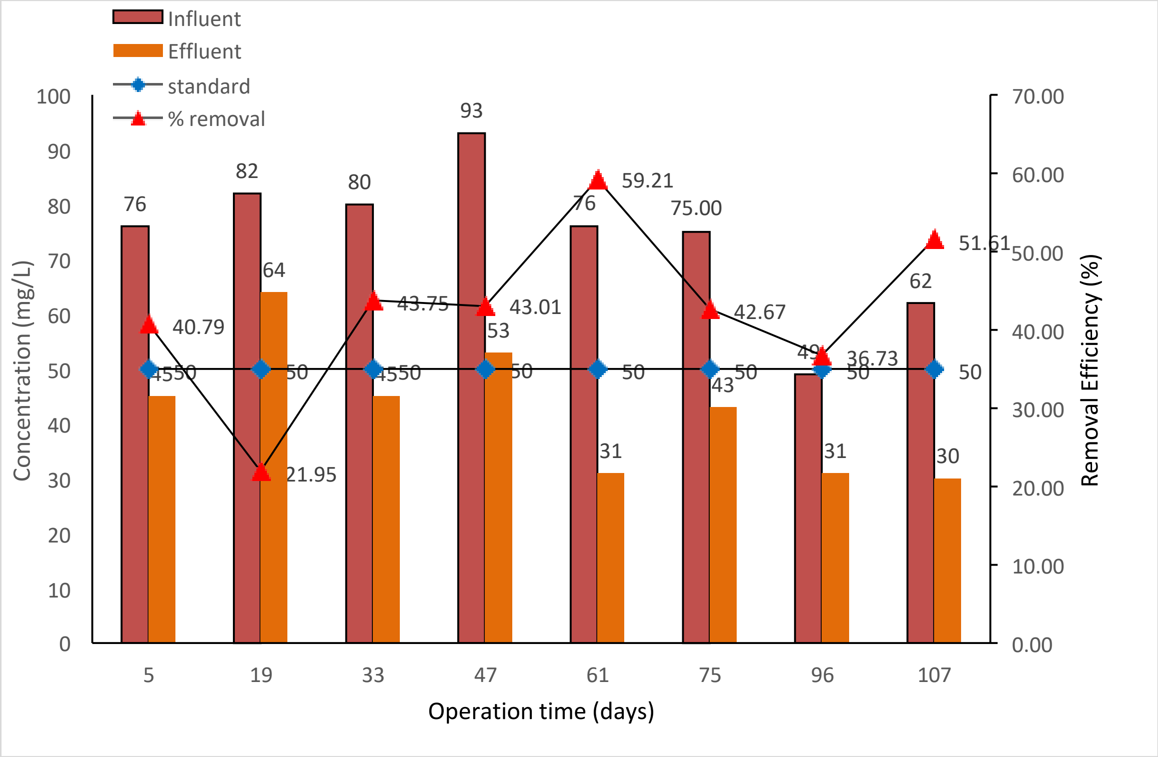

Fig. (6). Removal performance of TSS by phytoremediation system.

3.1.3. Total Suspended Solids (TSS) Removal

Fig. (**6**) provides data on the removal of TSS over the course of the experiment. The data shows that the concentrations of these suspended solids were reduced from their initial values as the wastewater flowed through the phytoremediation system. According to the figure, the percentage removal of TSS over a series of days reveals fluctuations in the efficiency of the remediation process. The results demonstrate a dynamic pattern in the reduction of TSS levels. On Day 5, there was a notable removal rate of 40.79%, which experienced a decline to 21.95% on Day 19. However, the efficiency rebounded on Day 33, achieving a removal rate of 43.75%, and remained relatively steady at around 43% on Day 47.

A substantial improvement was observed on Day 61, with a removal rate of 59.21%, yet this progress was followed by a decline on Day 75 to 42.67%. Over time, fluctuations persisted, with a decrease to 36.73% on Day 96, followed by an increase to 51.61% on Day 107. Overall, these results highlight the dynamic nature of TSS removal during the remediation period, emphasizing the need for careful monitoring and analysis to understand the underlying factors driving these fluctuations.

The combination of the 4 types of aquatic plants used in this phytoremediation system produced a high impact on the removal performance of TSS because almost all effluent samples were standard A. In the 4th week alone, the concentration of 64 mg/L remained constant but approached standard A. This is because microorganisms within the root zones of plants in phytoremediation systems can form biofilms.

These biofilms can help in the breakdown and entrapment of suspended solids. The microorganisms produce extracellular substances that can bind particles and improve their settling. Phytoremediation systems, such as constructed wetlands, incorporate plants with extensive root systems that create a matrix within the treatment system. This matrix helps slow down the flow of wastewater, allowing suspended solids to settle out of the water column and be trapped within the wetland sediment.

The plants themselves can also act as monitors by catching solid particles on their roots. Most of the species tried in this trial had a concentration of TSS that started to slowly go down or stayed the same.

This could be because it had already reached the highest concentration at which it could be removed [24]. Umar *et al*. stated that the charges on the roots of watery plants or macrophytes help them trap and attract particles like TSS in a medium. So, plants' ability to reduce TSS relies mostly on their root systems, and plants with woody roots can store more TSS than plants with taproots. In this study, the woody and long-rooted *Pistia stratiotes sp* lowered 98% of the TSS. Previous studies showed that *Pistia stratiotes sp* was able to make water clearer by catching floating solids in its roots [25].

3.1.4. Ammoniacal Nitrogen (AN) Removal

Fig (**7**) shows the results of AN of phytoremediation system. The data reveals varying degrees of effectiveness in AN removal, showcasing both positive and negative trends. On Day 5, a modest initial removal rate of 3.75% was recorded. However, by Day 19, the system experienced an unexpected downturn, with a negative removal rate of -9.05%, indicating an increase rather than a decrease in AN level.

The system's efficiency slightly improved on Day 33, achieving a 1.17% removal rate, which remained consistent on Day 47. A notable upturn in AN removal was observed on Day 61, indicating a removal rate of 16.31%, suggesting improved performance. This positive momentum continued with a removal rate of 25% on Day 75, demonstrating a substantial improvement in AN removal. Nonetheless, the system encountered another setback on Day 96, with a negative removal rate of -3.77%. Rebounding from this decline, the system exhibited effective AN removal on Day 107, recording an 18.75% removal rate.

Pistia stratiotes is one that helps the removal of ammonia. During April observation, it was found that the *Pistia stratiotes* had been damaged by dragonfly larvae. Organic materials such as dead plant leaves increase ammonia and that decomposition produces high levels of ammonia. According to Gusti Wibowo *et al.* (2023), *Pistia stratiotes* and *Eichhornia crassipes* were used in this study and successfull reduced heavy metals *i.e*. Fe up to 89% and Mn up to 74%. Both plants also successfully reduce other pollutants such as BOD up to 98%, COD up to 99%, ammonia up to 70% after five weeks in a wetland system, plants play a significant role in removing AN content in wastewater through both direct (*i.e.* plant uptake) and indirect (microbial activity at rhizosphere) ways. For plant uptake, AN present in wastewater can be directly absorbed by roots, either accumulated in plants' parts or assimilated by plants into transported amino acids (*e.g.* glutamine, glutamate, aspartate and arginine) to support biomass growth and development (Fig. **8**) [26].

Hydraulic retention time (HRT) is the average amount of time that a compound or substance spends in a reactor or a system within a wastewater treatment plant. In the context of nitrification, which is the biological conversion of ammonia to nitrate *via* nitrite, HRT plays a crucial role in providing sufficient time for the nitrifying bacteria to carry out these conversions. The HRT for this study was regulated to 9 hours per cycle. In many wastewater treatment systems, biological processes are used to break down organic and nitrogenous compounds. HRT impacts the efficiency of these processes. A longer HRT typically allows more time for microorganisms to convert ammonium (NH_4^+) to nitrate (NO_3^-) through nitrification and then to nitrogen gas (N2) through denitrification. This can lead to better removal of Ammoniacal Nitrogen. HRT indicates the mean residence time of the wastewater within a biological reactor, thus determining the contact time between the pollutant and the microorganisms. The HRT usually applied for conventional processes ranges from 5 to 24 hours [27].

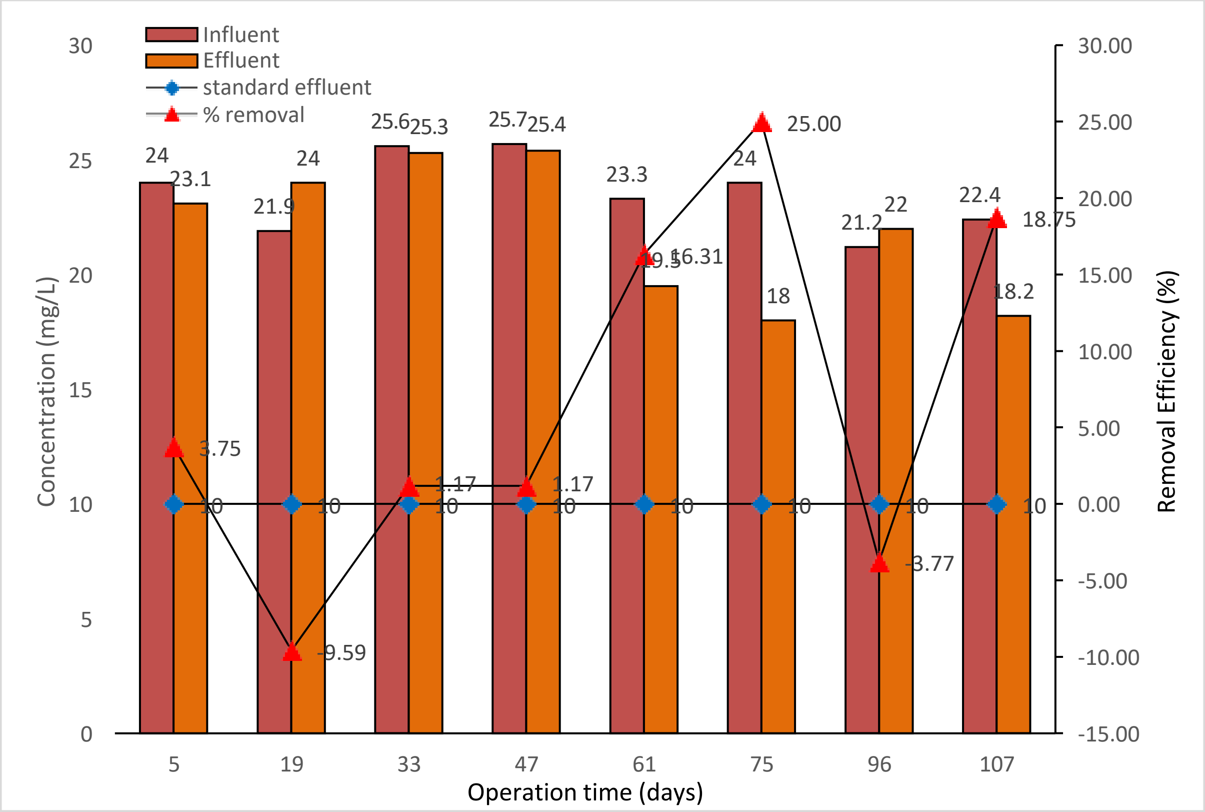

Fig. (7). Removal performance of AN by phytoremediation system.

Fig. (8). A few *thypha angustifolia* condition on March dan *pistia stratiotes* on April.

Table 4. Shows the achievement removal by parameter.

-	Parameter	i. Description
1	BOD	Consistently meet Standard A (Para 1) about 50% of data and 50% meet Standard B (Para 1).
2	COD	All data meets Standard A (Para 1).
3	TSS	Consistently meet Standard A (Para 1) in about 87.5% of data and 12.5% meet Standard B (Para 1)
4	AN	Consistently meets Standard B (Para 1) about 37.5%.

CONCLUSION

The development of phytoremediation performance was observed through chemical and biological parameters and the performance of the phytoremediation system was monitored for 4 months.

Phytoremediation system treatment showed the highest removal efficiency in all tested parameters. The percentage removal efficiency at all pollutants BOD, COD, TSS and AN was was recorded as 68.38%, 70.95%, 59.21% and 25.00%, respectively. The lowest removal was that of AN because the wastewater becomes more acidic due to the decomposition plant process. The broken roots release ammonia, which is then converted into nitrite. The concentration of nitrite increased as a result, impacting the system since day 61. An interesting observation from the present study is that broken roots must be removed before they affect the entire system. The aquatic plant needs to be monitored monthly. The ineffectiveness in percentage removal can be attributed to the fact that phytoremediation takes a longer time compared to standard bioremediation. This prolonged duration is necessary as the plants require time to grow and absorb hazardous pollutants from the water. Aquatic plants, in particular, need time to adapt to the phytoremediation system system. In terms of regulations, the phytoremediation system was able to reach Standard A following Environmental Quality (Sewage Effluent) Regulations for sewage discharge after applying phytoremediation technology for BOD, COD and TSS parameters.

Phytoremediation employs the potential of the plant roots to uptake pollutants from wastewater and translocation to the upper part of the plant. A combination of 4 types of aquatic plants *Pistia stratiotes sp., Eichhornia crassipes sp, Typha angustifolia sp., and Lepironia Articulata sp.* was used in removing pollutants in phytoremediation system and sewage treatment by accumulating BOD, COD, TSS and AN. For further study, this phytoremediation system needs to help the phytoremediation process requiring good aeration for microbes to function effectively. An aerator is needed because the tank is partially covered by trees, and there is a significant amount of sludge. It is very important for removing pollutants, especially ammoniacal nitrogen.

This study serves as an important basis for the wastewater treatment industry to implement phytoremediation systems as a low-cost treatment technology based on a real-world application. By demonstrating this approach in an actual case study, the research provides evidence that phytoremediation using aquatic plants can be an effective, ecologically sustainable wastewater treatment solution. The system's ability to remove contaminants at a reasonable cost compared to conventional methods supports broader adoption of phytoremediation by utilities and engineers. With many communities facing challenges while providing affordable wastewater treatment, especially in developing regions, a phytoremediation system utilizing locally available plant species could offer a viable alternative. The success in the real-world conditions examined in this study suggests such systems could be designed and operated successfully at larger scales. The evidence provided by this applied research project removes a key barrier to the wider use of phytoremediation by validating its feasibility and performance in practice. Utilities can utilize these findings to justify implementing similar systems in their communities to provide low-cost, natural wastewater treatment leveraging the phytoremediation abilities of aquatic plants.

HIGHLIGHTS

- A novel study of phytoremediation technology using sewage treatment was first reported here.
- Native aquatic plant species *i.e. Pistia stratiotes sp., Eichhornia crassipes sp., Typha angustifolia sp.,* and *Lepironia Articulata sp.* were used to treat the sewage treatment.
- The aquatic plant performed removals of BOD, COD, TSS and AN.
- The highest removals in phytoremediation system were 68.38%, 70.95%, 59.21% and 25% for BOD, COD, TSS and AN, respectively.

LIST OF ABBREVIATIONS

BOD = Biochemical Oxygen Demand
COD = Chemical Oxygen Demand
TSS = Total Suspended Solid
AN = Ammoniacal Nitrogen
IST = Individual Septic Tanks
STP = Sewage Treatment Plant
PGR = Plant Growth-Promoting Rhizobacteria

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The author's original raw data is not derived from any other journal or article. The data that supports the findings of this study is available from the corresponding author [S.S] on special request.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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