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SHORT RESEARCH COMMUNICATION

Preliminary study on greywater treatment using water hyacinth

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Abstract

Greywater constitutes a major portion of wastewater generated from domestic units. Greywater treatment through a natural treatment system provides a sustainable method of wastewater management. The objective of this study was to evaluate the potential of water hyacinth as phytoremediation aquatic microphytes for greywater treatment based on optimum growth and harvesting frequency. The treatment system was operated in continuous mode for 30 days. The physicochemical properties of treated greywater and physical characteristics of water hyacinth were determined. The physiochemical parameters of the influent greywater: water temperature (23.1–24.9 °C), pH (6.94–7.94), total dissolved solids (192–648 mg/L), turbidity (9.8–49.9 NTU), chemical oxygen demand (51.2–179.2 mg/L), ammonium–nitrogen (2.8–6.16 mg/L), and phosphate–phosphorous (0.45–1.168 mg/L). The results showed an average removal of ammonium–nitrogen, phosphate–phosphorous, and chemical oxygen demand of 63.26 ± 10.47%, 61.96 ± 12.11%, and 51.91 ± 5.32%, respectively. A 75% increase in the water hyacinth biomass was observed during the study which may be attributed to the dense roots, hyperaccumulative properties, and the rapid growth rate of water hyacinth. A harvesting interval of 15–20 days was recommended for phytoremediation of greywater for efficient treatment performance. However, feasible harvesting methods need to be developed for removing only matured mother plants, leaving baby water hyacinth in the treatment system. Water hyacinth found to be a potential phytoremediation plant for greywater treatment, providing consistent quality of treated water.

Keywords Eichhornia crassipes · Greywater · Phytoremediation · Harvesting

Introduction

In recent years, climate change and the limited availability of freshwater resources have caused worldwide water crises. Also, the increase in living standards and urbanization is causing an increase in water contamination (Ahamed et al. 2016; Barkoula et al. 2008; Inamuddin and Ismail 2010). Due to the limited availability of freshwater resources and to satisfy the ever-increasing water demand, the recycling and reuse of treated greywater for non-potable purposes becomes important. Therefore, low energy, low cost, easy to maintain, sustainable, and reliable greywater treatment technique is sought. The use of potable water for non-drinking purposes like gardening, toilet flushing, fire-fighting, and vehicle washing adds unnecessary strain on the already limited drinking water supply. The water requirements for non-drinking purposes can be met using treated greywater which accounts for two-thirds of the household wastewater generation (Friedler and Hadari 2006). The amount of greywater produced in domestic units varies from fifteen liters to several hundred liters per person depending upon the economics, geographical location, climate condition, and consumer behavior (Oteng-Peprah et al. 2018). Compared to blackwater, greywater has a low content of organic matter, nutrients, and pathogens. Greywater reuse can play a vital role in converting wastewater to usable water for its use in gardening, toilet flushing, and similar non-drinking purposes. Several treatment technologies have been investigated by researchers, which include physicochemical, biological, and natural treatments. Physical treatment is mainly a filtration-based process while biological treatment

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involves aerated bioreactor and biological aerated filters. Advanced technology like MBRs and cheap technology like red beds have been investigated. Chemical treatment process like chemical coagulation and electrocoagulation was also studied. Among the various natural treatment measures, phytoremediation gained popularity due to low operating and maintenance costs and being environment-friendly. Phytoremediation is a process in which plants are used to remove (transfer, mitigate, stabilize, or degrade) contaminants by the interaction between soil, water, plant, and microorganisms in wastewater treatment. The type of plants plays a key role in the efficacy of this treatment method. The plant must have rapid growth rate, high nutrient absorbing capacity, high biomass content, and easy to harvest. Different plant types like water lettuce, duckweed, and vetiver grass have been studied to treat wastewater from different sources (Barkoula et al. 2008; Gupta et al. 2012; Mohammad et al. 2015; Shah et al. 2014; Sooknah and Wilkie 2004). Aquatic plants like duckweed, water lettuce, canna lily, water hyacinth, and reed are preferred because they can directly absorb wastewater and do not require land for growth (Cheng and Stomp 2009). *Eichhornia crassipes* plant (ECP), commonly known as water hyacinth, belongs to the monocotyledonous family Pontederiaceae, a free-floating aquatic plant native to South America. The plant is considered invasive due to its rapid growth rate. It proliferates, having a biomass doubling time of 5–15 days (Agarry et al. 2018). ECP is often considered a problematic weed, uncontrollable if not appropriately managed, and possess a high risk to the water bodies and the aquatic ecosystem. It obstructs the natural flow of water, smooth navigation, fishing, and hydroelectric power generation. However, due to its physiological characteristics like a dense root system, hyperaccumulation capacity for nutrients, and survival in a wide range of environmental conditions, ECP has been used for phytoremediation of wastewater (Jayaweera and Kasturiarachchi 2004). It has a long and dense root system making it more efficient compared to rooted emergent plants. The successful use of ECP for wastewater treatment depends on the controlled growth, proper harvest, and disposal option. Qin et al. (2016) explored the in situ use of ECP as phytoremediation for nutrient removal from domestic sewage ponds. Upon removal of nutrients, ECP can be harvested. Then, the harvested biomass can then be used for soil enrichment, energy production in the form of bioethanol (Ganguly et al. 2012), briquette (Davies and Abolude 2013), biogas (Priya et al. 2018), and as a fertilizer (Gajalakshmi and Abbasi 2002). Also, ECP has been shown to be an excellent color removal (Prasad and Yadav 2020) and for eutrophic water treatment (Gao et al. 2014). However, studies of phytoremediation using ECP for greywater treatment for optimum nutrient removal and harvesting time for continuous operations are limited in the open literature. Therefore, the present study, for the first time in the open literature, aims to determine the potential of using ECP for greywater treatment and harvesting time required for optimum nutrient removal. The plant characteristics like biomass growth rate, root length, and shoot length were also determined and correlated to the ECP's nutrient removal performance.

Materials and methods

Location

This study was conducted in the laboratory scale system located in the old classroom complex building of the Civil Engineering Department, Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat, Gujarat, India (latitude 21.1643°N, longitude 72.784°E).

Experimental reactor

Figure 1 shows the elevation and plan view of the greywater treatment experimental setup used in this study. It consists of a rectangular reactor with one influent (inlet) pipe at the top and one effluent (outlet) pipe to the bottom of the reactor. Perforated pipes were fitted at the influent and effluent of the reactor. The surface area of the reactor was 0.3 m^2 (1 m length, 0.3 m width, and 0.3 m depth), and water volume of 80 L (0.27 m water depth). An overhead tank (1.1 m length, 0.73 m width, and 0.44 m depth) with a capacity of 250 L was provided, which provides a continuous feed of greywater to the influent of the reactor. A mixer was attached at the top of the overhead tank, which continuously mixes the greywater and prevents the settling of the suspended particles. The flow of greywater to the reactor was controlled using a control valve provided in the overhead tank. A similar reactor was used for ECP physical characterization with the same flow rate, water depth, and plant density parallel to the experimental reactor.

Greywater and experimental plant

The greywater was collected from the hostel building located on the campus of SVNIT, Surat, India. A greywater collection unit of 1000 L compacity was installed for collection from the shower, hand basin, and cloth washing area. The excess greywater is automatically discharged into the drainage pipe using the drain valve provided at the top of the greywater collection unit. Floating plant, ECP was collected from a pond at Hazira, Surat. Healthy baby plants with a length of 15 cm above root were collected. The average weight of the individual plant was 100 ± 20 g. Collected plants were stored in a separate tank, which acted as a plant bank for further studies.

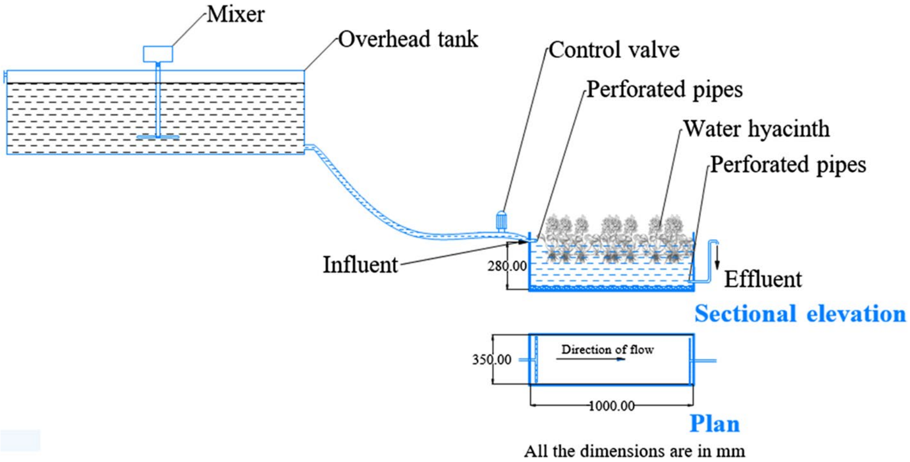

Fig. 1 Sectional elevation and plan view of the experimental setup for greywater treatment

Operation and sampling

A similar-sized plant was used (100 ± 20 g) with a total weight of 2 kg (wet). The reactor was fed with greywater continuously from the inlet (Fig. 1), and effluent was collected using siphon action synchronous with the flow from the outlet. The hydraulic loading rate during the experiment was 0.26 m/day, with a retention time of 24 h. The experiment lasted for 30 days. Water samples were collected (daily between 9:30 and 10:00 am), stored in an ice container, and immediately transported to the laboratory for analysis. The characteristics of ECP were determined at a 5-day interval and expressed in fresh weight (kg). The plant was harvested and weighed using a portable electronic balance. The shoot and root lengths were measured using a scale ruler. After measuring, the plant was placed back into the reactor.

Sample analysis

Greywater samples of the influent and effluent were analyzed for water temperature, pH, TDS, turbidity, chemical oxygen demand (COD), ammonium-nitrogen (NH_4-N), and phosphate-phosphorous $(PO_4)^{3-}$ -P. The pH, TDS, and temperature were measured using a pH and EC meter (Hanna Instruments, HI98129, Romania). Turbidity was measured using a turbidity meter (turbidity meter -135, Systronics). COD, NH_4-N, and $(PO_4)^{3-}$ -P were analyzed using standard methods (APHA 2012). For analysis, water samples (approximately 1L) were collected from the influent (inlet) and effluent (outlet) of the treatment system. Biomass wet weight (kg) of ECP was analyzed at the beginning and the end of the study. Treatment efficiency was calculated using Eq. (1):

$$\text{Removal efficiency (\%)} = \frac{C_i - C_e}{C_i} \text{ X } 100 \tag{1}$$

where C_i and C_e are influent and effluent concentration in mg/L. Statistical analysis of the obtained result was performed using IBM SPSS 17.0. The data tested with one-way analysis of variance (ANOVA) to find the statistical difference between influent and effluent parameters.

Results and discussion

The minimum–maximum and average values of the influent greywater characteristics are shown in Table 1. Variations in process parameters (temperature, pH, TDS, turbidity, COD, and nutrients) in the influent and effluent during the

Table 1 Untreated greywater characteristics

Parameter	Unit	N*	Min–max	Average ± SD
Temperature	°C	30	23.4–24.7	23.91 ± 0.42
pH	–	30	7.26–7.45	7.35 ± 0.05
Total dissolved solids	mg/L	30	249–329	285.47 ± 19.12
Turbidity	NTU	30	28–42.8	29.75 ± 9.895
Chemical oxygen demand	mg/L	30	88.8–141.6	113.86 ± 15.61
Ammonium–nitrogen (NH_4-N)	mg/L	30	3.36–5.32	4.52 ± 0.55
Phosphate–phosphorous $(PO_4)^{3-}$ -P	mg/L	30	0.77–1.17	0.96 ± 0.12

* No. of samples

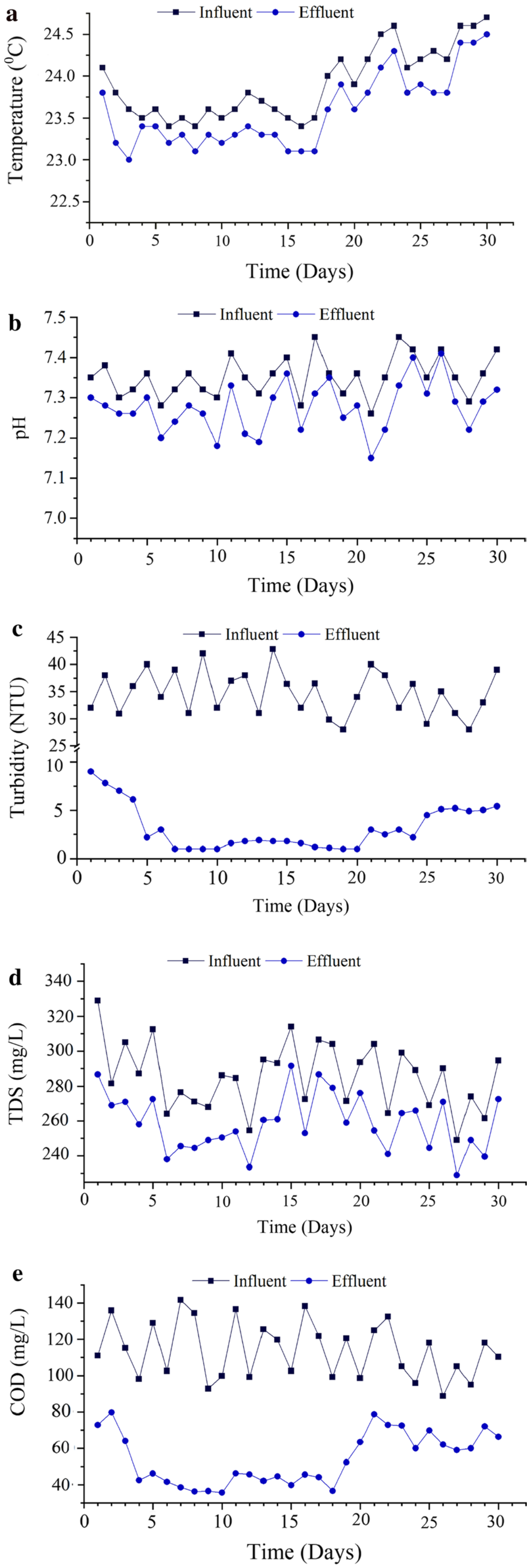

Fig. 2 Temporal variations in the physicochemical properties of **a** ▸ water temperature; **b** pH; **c** turbidity; **d** TDS; and **e** COD of influent and effluent greywater samples

sampling period were observed in discussed in the following sections.

Physicochemical properties of the water sample

The physicochemical properties of greywater from the reactor influent and effluent are shown in Fig. 2. Variations in all parameters when comparing inlet and outlet greywater properties were of significance ($p < 0.05$). As shown from Fig. 2a) the greywater temperature for the influent and the effluent streams were in the range of 23.4–24.7 °C and 23–24.5°C, respectively. Also, the average influent and effluent water temperatures were 23.91 ± 0.42 °C and 23.58 ± 0.44 °C, respectively. The temperature of untreated and treated greywater did not change substantially during the duration of the experimental run. The slightly lower temperature in the effluent stream can be attributed to the presence of ECP (Hill and Payton 2000). The minimum and maximum atmospheric temperatures of 19.6 °C and 34.1 °C are considered as most favorable for ECP growth and reproduction (Dersseh et al. 2019; El-Gendy et al. 2004). Higher growth rate and reproduction will consequently result in the absorption of more nutrients from greywater. Changes in pH values are shown in Fig. 2b. The average pH of the influent and effluent greywater was 7.33 ± 0.05 and 7.28 ± 0.06, respectively. Overall, the pH values of effluent water were slightly lower than the influent. Kadlec and Wallace (2009) reported pH of 6.5–8.5 is required for the denitrification process in the treatment system, whereas for ECP growth pH of 4–8 is necessary for optimum growth (El-Gendy et al. 2004). The average turbidity of the influent greywater was 34.73 ± 4.13 NTU which was reduced to 3.16 ± 2.28 NTU at the effluent, Fig. 2c. The TDS of the influent was 285.47 ± 19.12 mg/L and for the effluent, it was 259.0 ± 16.35 mg/L as shown from Fig. 2d. The COD value of the influent was 113.82 ± 15.61 mg/L reduced to 54.25 ± 14.36 mg/L by the effluent as shown in Fig. 2e Compared to the influent greywater stream, a reduction in ammonium–nitrogen was observed from 4.52 ± 0.55 mg/L to 1.72 ± 0.49 mg/L as shown by Fig. 3a. A similar trend was observed for phosphate–phosphorous, where the average influent phosphate concentration was 0.96 ± 0.12 mg/L and reduced to 0.39 ± 0.13 mg/L at the effluent, Fig. 3b.

Discussion

The natural treatment method involving green and environment-friendly techniques that use plants to remove contaminants from the environment and have attracted the attention

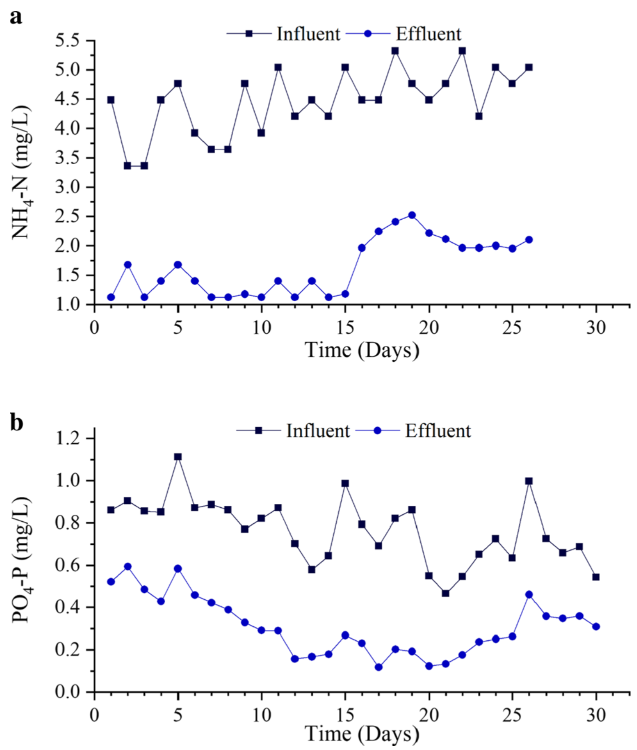

Fig. 3 Temporal variations in the influent and effluent greywater streams for **a** ammoniacal–nitrogen and **b** phosphate–phosphorous

of the environmentalist because of its high efficiency, low cost, and ease of harvest. In particular, aquatic plant-like ECP has a significant advantage over other plants due to its prolific growth and ease of harvest. Macrophytes with long and dense roots are essential for nutrients absorption and act as a media for intercepting and absorbing suspended particulate matter (Kim and Kim 2000). Characteristics of wastewater play a vital role in achieving higher removal in the phytoremediation process. Aquatic plants (ECP) are highly sensitive to the pH of the water and atmospheric temperature which controls the overall growth and removal of the nutrients. The pH and water temperatures were in the range of 6–9 and 15–38 °C, respectively, considered appropriate for WH growth (Shah et al. 2014). Hence, water temperature throughout this study was varied between 23.1 and 24.7 °C. Vymazal (2007) reported a minimum temperature of 20 °C for optimum performance, below which the rate of nitrification reduces until it reaches zero at 6 °C. Hence, this study was carried out under appropriate temperature and pH. Overall the experiment was carried out under optimal pH (7–8) suitable for nutrient absorption and biochemical reactions of the living organisms (Qin et al. 2016). The maximum increase in biomass production occurred at a pH of 5.8–7.5, leading to an increase in ECP nutrient uptake (Gupta et al. 2012; Ting et al. 2020). A decrease in the pH level of water is a limiting factor for biomass growth. The overall water temperature and pH were kept within the range for higher growth of ECP to result in high nutrients removal. Turbidity is the measure of suspended materials in water. In this study, the average removal of 90.68 ± 7.01% and maximum removal of 97.62% were observed. The turbidity removal efficiency increased till the 20th day beyond which a reduction in removal efficiency was observed. Three mechanisms for turbidity reduction are possible interception, sedimentation, and filtration (Trang et al. 2010). In this study, the turbidity removal was mainly through physical mechanisms, the sedimentation process removed organic and inorganic particles resulting in the reduction of turbidity (Vymazal 2005). Similar results were obtained by (Rameshkumar et al. 2019). The TDS removal of 9.21 ± 2.65% was observed in this study. It can be seen that a significant reduction was not observed ($p > 0.005$). It can be said that ECP does not participate in the removal of TDS (Munavalli and Saler 2009). A similar result was observed by Rezania et al. (2016) where only an 11% reduction in domestic wastewater treatment. Nitrogen removal takes place through combinations of uptake by the plant as a nutrient, consumption by microbes, adsorption, volatilization, nitrification, and denitrification. Among the various forms of nitrogen, ammonia removal was found to be the highest (Chen et al. 2010). The factors that had the most influence on the nitrification process were the dissolved oxygen level, temperature, and retention time. ECP exhibits the highest nitrification due to its dense fibrous root system. Ammonia removal depends on the pH and the temperature (Wallace and Knight 2006) but plant decay decreases the amount of dissolved oxygen level and thereby also affects the treatment performance. The removal performance observed in this study can be attributed to nitrification and the plant uptake through a well-developed rhizosphere. Aquatic plant species that increase DO concentrations most efficiently also show the highest nitrification rates. An average reduction of 62.15 ± 09.08% was observed during the study period for this investigation. On the contrary, Fox et al. (2008) and Nahlik and Mitsch (2006) achieved 60%–85% and 40.34% respective reduction of ammonia nitrogen. The plant influences the denitrification rate by providing a large surface area for biofilms, thus providing a favorable environment needed for denitrifies (Sooknah 2000). From Fig. 3a, it can be seen that the continuous removal of ammonia was observed till the 15th day of treatment after which a reduction in the removal efficiency was observed. This period can be referenced to the start of decomposition of ECP litter which essentially released its absorbed nutrients back into the water. The decomposition process occurred when ECP stem and leaf were saturated due to maturity and not able to uptake nutrients for its survival resulting in its fall in the water stream leading to its litter and subsequent decomposition. To prevent the decomposition, the mature ECP should be removed. It is important to note that while the mother plant matures at the same time baby plant (asexual growth) is in full growth phase requiring nutrients for its growth, survival, and development, hence, only the matured mother plant has to be removed. Phosphorous is an important nutrient for vegetative reproduction in plants and its growth. The phosphorous removal takes place through three main mechanisms: sorption, utilization by the plant for its growth, and refectory residual (burial). The major resource for phosphorous removal is through ECP vegetative and stolon growth with the latter being the dominant ECP growth pathway. The reduction in the phosphorous was through consumption by the plant and microorganisms as nutrients (Rangel-Peraza et al. 2019) filtration of particulate matter via roots and settling mechanism (Shah et al. 2014). The nutrition needs through stolon growth are met by the nutrients present in the greywater. Kadlec (2005) found that out of the total reported uptake by plant only 10%–20% is stored permanently in the residual and remaining returned into the water through the decomposition process. Thus, to prevent decomposition, the timely removal of ECP from the treatment system is critical. From this study, and in the present nutrient concentration the cycle of growth and decomposition of biomass occurred within 20 days of plantation and hence it is necessary to harvest the matured biomass by that time. Hence, the harvesting of biomass is important for the removal process to continue and become sustainable. In phytoremediation, plant productivity is directly related to the nutrient removal efficiency during the greywater treatment process. Also, nutrient removal efficiency depends on the operating conditions of contacting system, i.e., reactor. The productivity of macrophytes (floating) is higher than that of terrestrial and crops as they have adequate water supply (Shah et al. 2014). The roots of water hyacinth play an important role in the assimilation of nutrients for its growth and multiplication. The ECP has long and dense roots that are responsible for absorbing nutrients thereby act as media for intercepting and absorbing the suspended particulate matter (Qin et al. 2016). Rhizofiltration, a form phytoremediation, is the mechanism involved in the degradation and filtration of contaminants in greywater. Nutrients present in the greywater act as nutrition for plants essential for their growth. The growth rate is directly related to the nutrient removal capacity of the plant. ECP is an aquatic macrophyte having the potential to double its biomass within 7–15 days (Coetzee et al. 2014). Its higher productivity is directly related to the nutrient removal capacity. At first, when the plant is fresh, the nutrient uptake would be rapid, leading to higher nutrient removal rates relative to the mature plants. Hence, there is a need to harvest biomass regularly to obtain efficient removal continuously. An increase in biomass was measured at the beginning and the end of the experimental run. Initially, the biomass weight was 2 kg, which increased to 3.5 kg resulting in a 75% increase in biomass during the study period. Qin et al. (2016), in their study of phytoremediation of domestic sewage, achieved a 52.52% increase in WH biomass in 30 days. In this study, the maximum nutrient uptake by ECP was observed by day 20 after which a reduction in the removal efficiency was observed, which can be attributed to the plant maturation. During the initial days of plant growth, the rate of nutrient uptake is generally higher to meet its growth demands, and after that, as the plant matures, the nutrient uptake reduces, and hence the nutrient removal efficiency also reduces as observed in this study. The optimal removal was obtained during the first 15–20 days in contrast to the result obtained by Shah et al. (2014) where the optimal period of harvesting was 8–10 days, whereas Rezania et al. (2016) reported optimal removal efficiency in 13–17 days for phytoremediation in municipal wastewater. The difference in the duration in these studies can be due to the variation in the nutrient concentration. Greywater generally has a lower level of a nutrient compared to municipal wastewater due to the separation of black water. This difference in nutrient level changes the growth rate and hence the duration of harvesting. The root and shoot length in 5 days intervals is presented in Fig. 4. Harvesting frequency is a key factor in effective phytoremediation using ECP (Ting et al. 2018). It preserves the balance between the biomass available and the nutrients to be removed. The harvested biomass can be used as mulch for transferring nutrients to the kitchen garden. The decay in the plant tissue after its useful life is a natural process that results in decomposition and consumption of a large amount of oxygen (Mishra and Maiti 2017) and hence hinders the phytoremediation process. Nahlik and Mitsch (2006) recommended 30% harvesting of biomass at a given time resulting in improved optimum nutrients removal throughout the treatment process. The challenge in this process is the nondiscriminatory harvesting of the baby plant along with mature mother plants putting the process at a disadvantage. The baby plant is typically attached to the mother plant through stolon, which initially supplies essential nutrients for growth and development. So, while removing the mother plant, the

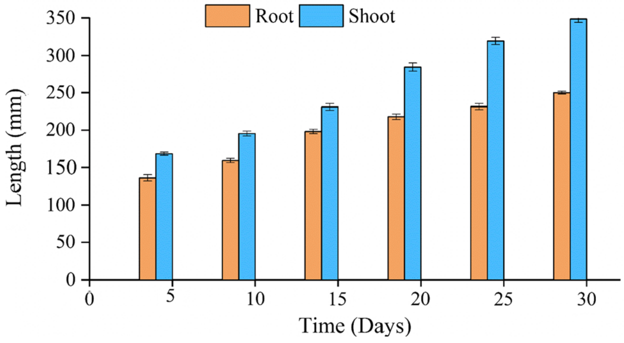

Fig. 4 Change in root and shoot length of ECP grown in greywater

baby plant also gets accidentally removed. To avoid complete removal of mother and baby ECP, a method of harvesting needs to be studied and developed.

Disposal options for ECP

The use of *Eichhornia crassipes* plant (ECP) for greywater treatment provides the added value of the rapid production of ECP biomass. The proper disposal of nutrient-rich ECP is important to prevent further loss of nutrients in the environment. One of the economical and environmentally friendly disposal options of harvested ECP biomass is its conversion into nutrient-rich organic fertilizer. Other disposals or utilization options that are cost-intensive include its use as an adsorbent for dye removal (Prasad and Yadav 2020), biogas (Adanikin et al. 2017), bioethanol (Adanikin et al. 2017), composite (Flores Ramirez et al. 2015), a substrate for mushroom (Andrew et al. 2013), and briquette (Munjeri et al. 2016) production.

Conclusions

The current preliminary study on greywater treatment systems showed the treatment potential that can transform greywater to water that has reduced concentration of organic matter reusable for multiple purposes. The current study showed the efficacy of ECP as a greywater treatment agent with a significant reduction in COD (51.61 ± 13.56%), ammonium–nitrogen (62.15 ± 9.08%), and phosphate–phosphorous (58.13 ± 15.23%), turbidity (90.68 ± 7.01%), and other parameters like pH were 7.15–7.41, and TDS reduction was 9.21 ± 2.65%. The biomass content of ECP increased by 75% during the study duration. ECP was also capable to effectively reduce the nitrogen and phosphorous nutrient components for the treated greywater. The results show the proposed treatment system requires the harvesting of ECP after 15–20 days one stream for consistent and optimum treatment performance. After 20 days, the ECP plant starts to decay which leads to a reduction in the ECP treatment abilities and capacity for contaminants removal. The proposed treatment system is simple to operate, low energy, and requires minimal maintenance. Also, the process gives the additional benefit in terms of regular ECP biomass production, which can be used as a raw material to make fertilizer and other chemicals and biofuels. It is recommended that this preliminary study be furthered for a more comprehensive evaluation of other technical aspects such as optimum ECP density, hydraulic retention time, reactor design, TDS removal, long-term performance stability, and the process economics before it can be implemented at a larger scale.

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Declaration

Conflict of interest All authors have no conflict of interest to report.

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