A Small-Scale Study for the Treatment of Grey Wastewater Through Free Surface Constructed Wetlands Using Water Hyacinth Plant

Anudeep Nema, Dhaneesh K. H, Kunwar D. Yadav, and Robin A. Christian

Abstract This study was carried out to analyze the treatment efficiency of water hyacinth constructed wetland system with greywater. Greywater was collected from Boys' Hostel in SVNIT campus for constructed wetland reactor. Parameters such as pH, conductivity, BOD_3, COD, TS, TSS, TDS and TKN were analyzed. This study was observed in two phases. Water hyacinth wetland system operated in continuous mode with 3 retention time 1, 2 and 3 day. In continuous system, water hyacinth wetland system operated for 5 days with each different retention time. From the results of the continuous system, it can be concluded that the water hyacinth wetland system will work efficiently for a retention time of 2 days with high removal of BOD_3 and COD of 88.55% and 79.20%, respectively. TDS reduced by 56.76% in a continuous system, whereas, TS reduction occurred only by 14.03% in wetland operated with 2-day retention time. After the treatment conductivity, pH, TS, TSS, and TKN of greywater increased when operated in continuous modes as water hyacinth reintroduces nutrients to greywater. During the continuous operation of the water hyacinth wetland system, plant biomass also analysed and observed for its growth. Water hyacinth increased by 61.83% by mass after the treatment. This shows the high greywater-suitability of water hyacinth for its growth.

Keywords Greywater · Constructed wetlands · Water hyacinth · Surface flow · Continuous system · Small-scale study

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1 Introduction

Freshwater is a viable natural resource that has been depleting rapidly with time due to mismanagement of human activities and increasing in population. Water scarcity is a global problem and if not solved will imbalance the whole environment [1]. As the population and prosperity of the world are growing; water demand is increased and multiplying without the chance of increasing supply. The increasing demand for this finite and invaluable resource has motivated new freshwater management techniques, including innovative wastewater recycling techniques. Reducing the needs for freshwater can be achieved by reusing wastewater. An average person typically produces 150–250 L of domestic wastewater per day, and greywater accounts for up to 75% of wastewater. Greywater is very less polluted and easy to treat within decentralized system such as send filters, constructed wetland, trickling filters bio-reactor and coagulation.

Most constructed wetlands around the world are still primarily used to treat municipal and domestic wastewaters. However, the treatment of greywater, diffrent types of industrial, agricultural wastewaters, stormwater runoff and landfill leachate has recently come in trend. Despite the suspicion of many civil engineers and water authorities, constructed wetlands have been widely accepted around the world and have become a suitable solution for wastewater treatment. Constructed wetlands (CW) are engineered wastewater treatment systems that encompass a plurality of treatment modules including biological, chemical and physical processes, which are all to processes occurring in natural treatment wetlands. Bacterial metabolism, accumulation and plant uptake interaction with each other plays a crucial role in the removal of pollutants in constructed wetland [2]. Algae and bacteria remove impurities by natural processes in facultative ponds [3, 4]. Also, the most dominant feature of constructed wetland is its vegetation which also acts as an important biotic factor in the majority of treatment processes [5].

The aim of the study is to evaluate water hyacinth that can be used for the treatment of greywater with a constructed wetland system. In Surat, the Vapi river is covered with water hyacinth in the majority of areas and creates problems in pumping and irrigation. Hence, clearing water hyacinth required a huge amount of money that can be regained by using it beneficially. Using a low cost constructed wetland system with water hyacinth, that can implement a new system with beneficially use water hyacinth and greywater for non-potable applications.

2 Methodology

2.1 Water Hyacinth and Gravel

Water hyacinth collected from the pond near Bhagwan Mahavir College of Engineering, which is 2 km away from the SVNIT campus (Fig. 1). Collected water

Fig. 1 **a** Water hyacinth pond near VIP road, Surat **b** Location of pond

hyacinth had an average height of 15 cm. Collected water hyacinth was carefully washed with tap water without doing damage to roots. These plants were acclimatized for greywater by increasing the percentage of greywater (50, 60, 70, 80, 90 and 100%) into the water for 30 days.

Gravels were sieved, analyzed as per ASTM and were thoroughly washed with tap water to remove the deposited impurities peel off from the surface. The grain size distribution ranges from 20–40 mm. Gravels were provided in the outlet area of the reactor for avoiding the entry of dead plants, leaves and roots and also to minimize the disturbance during sample collection.

2.2 Feeding Tank and Constructed Wetland Reactor

Feeding tank and the reactor were made by cutting half of a rectangular tank of 300 L capacity. One part of the plastic/PVC rectangular tank was used as a feeding tank. Feeding tank had the capacity of 130 L with dimensions of 120 cm × 40 cm × 35 cm (L × W × H) and an effective height of 25 cm. Feeding tank has one outlet pipe at the bottom of the tank to feed greywater to the reactor. The reactor was made of the remaining half part of the plastic/PVC rectangular tank. The reactor had a capacity of 130 L and had the same dimensions as the feeding tank. It had a void volume of 115 L in the presence of vegetation and other internals were used to form a shallow pond system. It had 2 outlets; one located at bottom of the tank for taking sample and another located at height of 18 cm from the bottom for maintaining the water level to a fixed height.

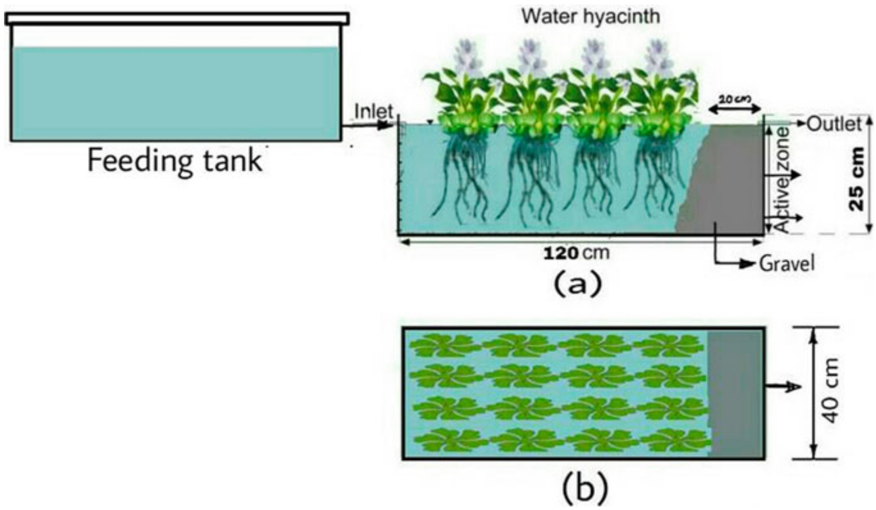

Fig. 2 Schematic diagram of the constructed wetland setup: **a** Cross-section view; **b** Plan view

2.3 Operational Procedure

The laboratory-scale setup was divided into two parts. Feeding tank and constructed wetland reactor schematic diagram are shown in Fig. 2. The water hyacinth (*Eichhornia crassipes*) plants were placed in the reactor at the initial stage of the plantation to give full coverage of 171–172 plants/m^2 [6–9]. The surface area of the reactor comes around 0.35 m^2. For this area, 60 plants are used in a constructed wetland system in continue run. The input and output management was performed according to standard practices. In the outlet of the reactor provides the gravel layer of 20 cm depth with size ranging from 20 to 40 mm provided, as shown in Fig. 2. Raw greywater was fed manually into a feeding tank and after by gravitational flow greywater transferred to the wetland.

2.4 Greywater Sampling and Analysis

The treated greywater was collected from a constructed wetland daily for performance evaluation to observe the variation in the treatment efficiency wetland in each day operation. All samples were analyzed for water quality parameters like pH, electrical conductivity (EC), BOD_3, COD, Total suspended solids (TSS), Total dissolved solids (TDS) and Total Kjeldahl Nitrogen (TKN) according to the standard method (APHA 2012).

3 Results and Discussion

3.1 Variation in One Day Retention Time

Initial pH value was 8.06 ± 0.43, and after treatment, pH value decreased to 7.87 ± 0.28. Conductivity was 0.89 ± 0.05 mS/cm in the initial stage of treatment, and it increased to 1.00 ± 0.02 mS/cm after treatment. Initial BOD_3 was 90.27 ± 0.55 mg/L and was reduced to 23.38 ± 5.90 mg/L and also initial COD of greywater was 137.33 ± 7.02 mg/L and was reduced to 49.20 ± 14.39 mg/L after treatment with 1-day RT. Valipour et al. (2015) show that after treatment TS reduced from 457.00 ± 67.58 mg/L to 451.40 ± 51.20 mg/L and TSS increased from 151.00 ± 32.60 mg/L to 174.60 ± 26.20 mg/L. TDS value decreased from 306.00 ± 39.95 mg/L to 276.80 ± 28.80 mg/L after treatment, but TKN value increased from 3.39 ± 1.47 mg/L to 6.62 ± 1.39 mg/L). Figure 3 shows the variation of greywater characteristics in initial and treated greywater.

During this study, the pH of the sample does not change significantly from the initial value, and conductivity also has only a slight increase from the initial value. Initial conductivity was 0.89 mS/cm, and it varies close to 1 mS/cm during the 1-day RT operation of continuous system. The temperature of the sample varies with respect to the ambient temperature variation. Initial BOD_3 of the sample was 90.27 mg/L and treated greywater reduced BOD_3 values ranging between 20.30 and 30.30 mg/L. During 5 days of operation, on 3rd-day maximum removal of BOD_3 of 81.16% was observed. Initial COD of the sample was 137.33 mg/L. The observed COD of the treated sample was shown in Fig. 3. During the operation of a continuous system with 1-day RT, COD removal efficiency was observed in the range of 53.39–76.69%. Maximum removal obtained in the 2nd day of operation of the reactor was 76.69%.

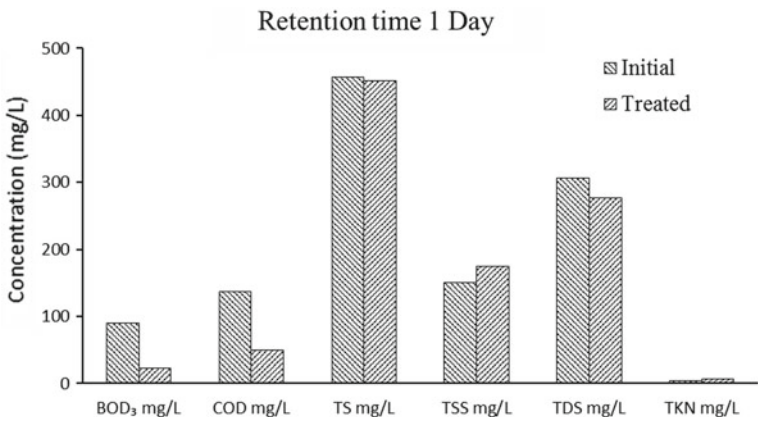

Fig. 3 Characteristics of initial and treated greywater (BOD_3, COD, TS, TSS, TDS) in 1-day retention time

TS removal was very low in the 5 days of the operation period; maximum removal obtained was 8.31% on the 5th day of operation period. Initially first day of operation, TS removal was not obtained in the treated greywater. TSS removal was not observed during 5 days of operation. TDS and TS removal were very less up to 18.95% and 8.31%, respectively. On the 1st day of operation, TDS removal was not obtained and from 2nd day onwards removal was obtained in the treated greywater ranging from 6.53 to 18.95%. The maximum removal of TDS was observed on the 5th day of operation of the reactor with a removal efficiency of 18.95%. Mean variation of influent greywater and effluent after treatment for various parameters are shown in Fig. 3.

TKN of the initial sample was 3.39 mg/L, and after treatment, TKN value increased from the initial value. Treated greywater had TKN in the range of 5–7.70 mg/L. Increased TSS and TKN were observed from the initial values, and 1-day RT did not show any removal in operation period. TKN increment was due to the organic nitrogen component that was reintroduced into the water from ecosystem decomposition processes [8]. In a previous study, raw sewage treating with water hyacinth showed 31% removal of TKN after treatment [6]. However, this study showed that water hyacinth not suitable for TKN removal from the greywater.

3.2 Variation in Two-Day Retention Time

In this study, Initial pH value was 7.91 ± 0.42 and it increased to 8.67 ± 0.11 after treatment. Conductivity was 0.91 ± 0.02 mS/cm in the beginning and it was increased to 0.94 ± 0.03 mS/cm after treatment. Initial BOD_3 was 83.45 ± 10.54 mg/L reduced after treatment with 2-day RT to 9.32 ± 1.21 mg/L. Initial COD was 134.00 ± 5.66 mg/L reduced to 28.80 ± 12.13 mg/L after treatment with 2-day RT. After treatment TS reduced from 383.50 ± 16.26 mg/L to 380.00 ± 51.87 mg/L and TSS increased from 170.50 ± 20.51 mg/L to 253.60 ± 42.46 mg/L [6]. TDS value was decreased from 213.00 ± 4.24 mg/L to 126.40 ± 10.24 mg/L after treatment but TKN value was increased from 3.82 ± 1.80 mg/L to 7.64 ± 2.55 mg/L [7].

Initial BOD_3 of the sample was 83.45 mg/L and the treated sample showed reduced BOD_3 in the range of 8–10.30 mg/L. During 5 days of operation maximum BOD_3 removal was 90.41% that was observed on the 2nd day of operation. On each day, the operation of the system had a small variation in the treated quality of water. Initial COD of the sample was 134 mg/L. During the operation of continuous system with 2-day, RT COD removal efficiency was observed in the range of 64.18–88.06% in the 5 days of operation period. The maximum removal of COD, observed on the 4th day of operation of the reactor, was 88.06%.

Initial TS of the sample was 383.50 mg/L and after treatment, it increased to 392 mg/L within 24 h TDS of treated greywater was gradually decreasing during the 5-day operation period. During wetland working with 2-day retention time, TDS removal attained considerably throughout 5 days of operation period. On the 1st day of operation TDS removal was observed to be 40.85%. The removal efficiency

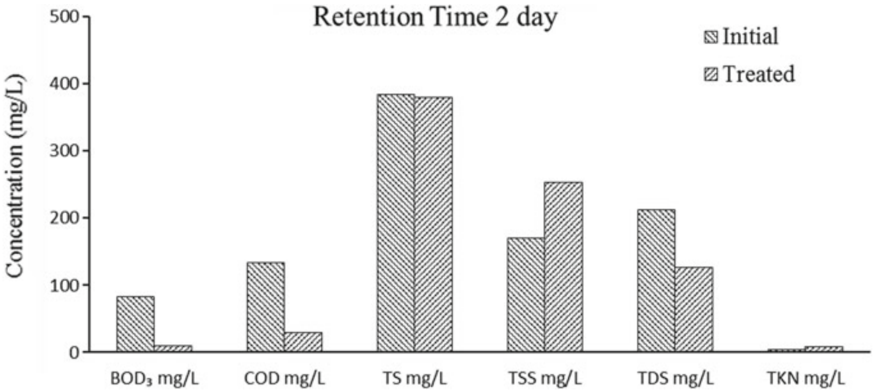

Fig. 4 Characteristics of initial and treated greywater (BOD_3, COD, TS, TSS, TDS) in 2-day retention time

of TDS obtained in the treated greywater ranged between 35.21 and 48.36%. The maximum removal of TDS was obtained on the 3rd day of operation of the reactor with a removal efficiency of 48.36%.

TKN of the initial sample was 3.82 mg/L and after treatment, its value started increasing. Treated greywater had TKN values in the range of 5.09–10.18 mg/L. TS, TSS and TKN removal was not achieved in the 5 days of operation period with 2-day RT. The TKN increment was due to the organic nitrogen component that was reintroduced into the water from ecosystem decomposition processes [8]. The reactor operating with 2-day RT shows good removal efficiency in BOD_3, COD and TDS. Figure 4 shows the variation of greywater characteristics along with different operation periods keeping RT as 2 days.

3.3 Variation in 3-Day Retention Time

Initial pH value was 8.01 ± 0.06 and increased to 8.68 ± 0.82 after treatment. Conductivity was 0.93 ± 0.04 mS/cm in the beginning and increased to 1.18 ± 0.15 mS/cm after treatment. Initial BOD_3 of 70.50 ± 7.78 mg/L reduced to 18.32 ± 8.40 mg/L. Initial COD, which was 144.00 ± 5.66 mg/L came down to 41.60 ± 6.69 mg/L after treatment with 3-day RT.

On the 2nd day of operation, maximum removal of BOD_3 of 85.39% was observed. On each day, the operation of the system had small variations in the treated quality of water. Initial COD of the sample was 144 mg/L. During the operation of the continuous system with 3-day RT in the 5 days of operation, the removal efficiency of COD was in the range of 66.67–77.78%. The maximum removal of COD, observed on the 2nd day of operation of the reactor, was 77.78%. Initial TS of the sample was 485.50 mg/L and after treatment, it decreased to 408 mg/L within 24 h. The maximum

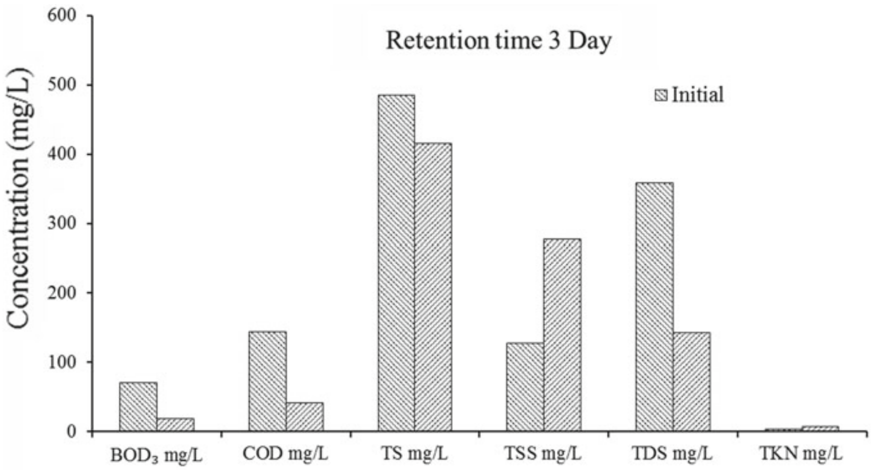

Fig. 5 Characteristics of initial and treated greywater (BOD_3, COD, TS, TSS, TDS) in 3-day retention time

removal obtained was 19.46% on the 5th day of operation of the reactor. On the first day of operation, TS removal efficiency was 15.76%. TS removal efficiency ranged between 10.20 and 19.46%. TDS of treated greywater was found to be decreasing during the 5-day operation period. TDS removal efficiency was 52.56%, and from the 2nd day onwards the removal efficiency gradually increased from 45.51 to 61.54%. The maximum removal of TDS was observed on the 5th day of operation of the reactor with a removal efficiency of 61.54%.

TKN of the initial sample was 3.82 mg/L. In 3-day RT, treated sample TKN concentration was higher than the initial concentration; which was due to organic nitrogen as explain privious sections. TKN increased by 30-50 % in all observed RT. TS removal was very low (up to 19.46%) and TSS and TKN were found to be increasing from the initial value and not showing any removal on operation period of 5 days with 3-day RT. The reactor operating with 3-day RT showed good removal efficiency in BOD_3, COD and TDS. TS removal was observed but with low efficiency. Figure 5 shows the variation of characteristics of greywater treated with 3-day retention time with an operation period of 5 days.

3.4 Mass Variation of Water Hyacinth

In this study change in biomass was carried out by selecting 5 plants and further total biomass was calculated for 60 plants. Plants were selected randomly, and separation analysis was done for root, stem and leaves. Change in biomass was carried out by weighing the different parts of plants. After weighing calculated total mass growth of plants in the reactor during this continuous system operation considering total plants

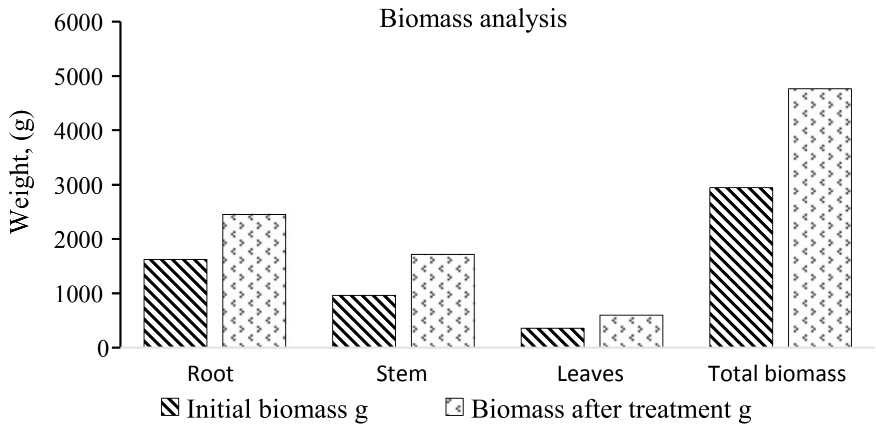

Fig. 6 Biomass production in a continuous process of treatment

used in the reactor. The change in the mass of plants is obtained by weighing each part of the plants separately after treatment. A continuous run of wetland system took 3 weeks for completing constructed wetland operation in three different retention times.

This analysis gave an idea about plant mass growth during the treatment and suitability of greywater with water hyacinth growth. Figure 6 shows the mass variation plant after the treatment process. It was observed that the weight of plant increased to 61.83%, 51.459% and 77.85% in plant root and stem, respectively, leaves weight increased to 65.67%. Maximum growth of biomass was observed in the stem than roots and leaves. Initial biomass of 2944.08 g of 60 plants was increased to 4764.48 g after treatment process.

4 Conclusions

Greywater has a great potential to be reused due to its availability and the low concentration of pollutants in it when compared to combined household wastewater. Greywater reuse is a useful measure for saving water at the domestic level. In this study, water hyacinth was used for the treatment of greywater with a constructed wetland system. Constructed wetland performs well in removing BOD_3 and COD. From the results of a continuous system, it can be concluded that the water hyacinth wetland system will work efficiently for a retention time of 2 days with high removal of BOD_3 and COD (88.55% and 79.20%, respectively). TDS reduced by 56.76% in a continuous system, whereas, TS reduction occurred only by 14.03% in wetland operated with 2-day retention time. Conductivity, pH, TS, TSS, and TKN of greywater were observed to increase from the initial values after treatment because of the presence of plant parts and their decomposition. In continuous system wetland works effectively with a retention time of 1 day, 2 day and 3 day in the removal of BOD_3, COD and TDS, but the maximum removal was observed when wetland works with 2-day retention time. Water hyacinth increased by 61.83% by mass after the treatment. This shows the high greywater-suitability of water hyacinth for its growth.

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