

## RESEARCH ARTICLE

## PRELIMINARY STUDY ON EFFECT OF DETENTION TIME ON NUTRIENT REMOVAL FROM GREYWATER USING WATER HYACINTH

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## ABSTRACT

Increasing water scarcity has resulted in the reuse of wastewater for non-potable purposes after treatment. In this laboratory-scale study, the effect of different hydraulic detention time (HDT) for remediation of nutrients from greywater was undertaken. Greywater was collected from the hostel building of educational institute in Surat, India. The experimental study was carried out in a circular plastic reactor all in triplicate and average removal were reported. The physicochemical properties of influent and effluent were monitored throughout the experiment duration. The average influent greywater characteristics were: water temperature ( $27.52 \pm 0.22^\circ\text{C}$ ), pH ( $6.95 \pm 0.07$ ), turbidity ( $57.80 \pm 11.14$  NTU), COD ( $273.60 \pm 11.53$  mg/L), ammonium-nitrogen ( $5.32 \pm 0.84$  mg/L), phosphate-phosphorous ( $1.30 \pm 0.07$  mg/L), and sodium ( $57.80 \pm 11.14$  mg/L). Water hyacinth was planted in all three sets, and one was kept as control (without adding water hyacinth). Significant nutrient reduction was observed in reactor planted with water hyacinth compared to control. The result showed that reactor with HDT of 3 days performed optimum for remediation of nutrients from greywater. The average removal under optimal HDT observed for turbidity, ammonia, phosphate-phosphorous, and sodium was  $97.77 \pm 0.33\%$ ,  $89.80 \pm 2.48\%$ ,  $84.64 \pm 0.84\%$ , and  $40.36 \pm 1.23\%$  respectively. This study shows the optimum HDT of 3 days are required for greywater treatment in batch mode. However, further study is needed to explore the optimum HDT for continuous operation mode for greywater treatment.

## KEYWORDS

Water hyacinth, Greywater, Constructed wetland, Batch study.

## 1. INTRODUCTION

Water scarcity around the world has made it mandatory to treat and reuse the household wastewater. Wastewater from the household are categorized into greywater and blackwater. Greywater is of two types, light greywater and dark greywater. Light greywater includes discharges from showers, hand basin, baths, and laundry whereas dark greywater includes discharges from kitchen sinks. Blackwater includes discharge from toilets. Light greywater (called as greywater) is less polluted compared to dark greywater and blackwater. Greywater accounts for 75-90% of the household wastewater (Hernández Leal et al., 2012). Greywater is considered a potential source of water due to its daily generation. It can be used for non-potable purposes like toilet flushing, irrigation, and floor cleaning depending upon treatment level.

Greywater treatment is emerging as a potential part of preserving and reducing freshwater demand and reducing the release of pollutant into the environment (Liu et al., 2010). Several treatment methods are available for greywater treatment like physicochemical (filtration-based process), chemical treatment (chemical coagulation, electrocoagulation) and

biological (aerated bioreactor, biological aerated filters). However, high operation and maintenance costs are the main constraints in the treatment process and are not feasible in developing countries. Hence, alternate potential and cost-effective treatment method have been searched in previous studies (Nayanathara et al., 2017; Mahunon et al., 2018). In recent years, green technology like plant treatment methods representing natural treatment systems is effective due to its cost of treatment and maintenance.

Green technology like phytoremediation has gained popularity due to its low operation and maintenance cost and environment-friendly treatment methods. The treatment success lies in adopting the suitable plant species that can adopt the variable influent concentration, remove the pollutants present in the wastewater, and generate high biomass. The aquatic plants have high nutrient reduction capacity, which has led to increased interest in wastewater treatment. The use of these plants for wastewater treatment generally includes use in a constructed wetland. Constructed wetland (CW) proves to be ideal due to its economic, ease in operation and maintenance.

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CW are an engineered ecosystem designed and constructed to mimic the natural treatment system in combinations with aquatic plants, soil, and microbial populations to degrade wastewater pollutants. It is one of the methods of phytoremediation, where plants and microorganisms help in the treatment of wastewater. CW are classified as surface flow or subsurface flow depending upon the water hydrology. Subsurface is again of two types depending upon the direction of water flow as horizontal or vertical flow. Surface flow, also known as free water surface (FWS) CW, is considered as an efficient natural system for wastewater remediation (Sabokrouhiyeh et al., 2020). The treatment in a CW is interceded by collaboration media, plant and microorganisms, primarily through the plants roots. The other parameter for proper treatment and removal of nutrients from wastewater includes a surface area for bacteria growth, release of oxygen through the roots, and hydraulic flow maintenance (Vymazal, 2013).

To ensure the CW performance, plant species selection is a critical component in the design process (Zheng et al., 2016). Water hyacinth (WH) is a floating aquatic plant with broad, waxy and ovate leaves with up to 1m height above the water surface. It is considered as one of the worst prolific plants with a doubling capacity of 7-15 days. It interferes with waterbodies' normal function like for navigation, irrigation, recreational work, hydropower generation, and fishing. WH multiplies through sexual and asexual growth. The asexual development is dominant due to nutrient presence, which can be adsorbed by its dense root present inside the water. WH fulfils all the criteria necessary for a good phytoremediation aquatic plant. Hence, WH was used as a phytoremediation plant in this study.

Several literatures were available for contaminant removal from wastewater (Ayyasamy et al., 2009; Rezania et al., 2016; Mishra et al., 2017; Prasad et al., 2020) using WH. For example, Wang et al. (2012) reported improvement in the water quality near the WH water bodies. The pollutant removal takes place using degradation by microorganisms and absorption by the plant as a nutrient. Previous studies show a significant impact of HDT on pollutant removal (Dierberg et al., 2005). The detention time is considered as critical in pollutant degradation. It indicates the length of time for which wastewater remains in contact with the plant in the CW. A previous study of hydraulic efficiency showed different HDT required for different wastewater. For example, Rangel-Peraza et al. (2019) observed HDT of 4 days for maximum nutrient removal of pollutants from institute wastewater using WH and gravel as support media. Agarry et al. (2018) observed 10 days HDT for maximum reduction of nutrients from petroleum refinery wastewater. Qin et al. (2016) observed 24 hr HDT as optimum for pond contaminated with domestic wastewater. Rezania et al. (2014) observed 12 days HDT as most suitable for nutrient removal from domestic wastewater. Shah et al. (2014) observed 10 days HDT as optimum for maximum COD and ammonia-nitrogen reduction from municipal wastewater. Victor et al. (2016) observed 20 day HDT for effective phytoremediation of industrial wastewater. Sooknah et al. (2004) observed 20 days HDT as optimum for optimum removal for TKN,  $\text{NH}_4\text{-H}$ , TP for dairy manure wastewater. From the literature, it is evident that different wastewater sources require different detention time depending upon level of contamination. The pollutant removal in phytoremediation is affected by the plant density and residence time between the plant and the contaminates (Harvey et al., 2005).

In, this preliminary study, the effect of hydraulic residence time was assessed. When the residence time increases, there is a reduction in the flow velocity. Thus, longer contact time is available for the microorganisms present on the roots of WH for biological, chemical reactions (Kadlec et al., 2009). It is clear that for different wastewater, different HDT is required. The optimum HDT plays a significant role in optimum nutrient reduction and the duration needed for biomass harvesting. However, no data available for greywater treatment using WH and hence the study was carried out to know the suitable HDT required for greywater treatment using WH. The batch experiment was carried out

to understand the optimum HDT required for greywater treatment. This study may serve as a practical reference for further studies on the nutrient removal from greywater under different loading conditions.

Therefore, present work aims to assess the optimum HDT required for greywater treatment using WH in a batch study using a laboratory-scale treatment system. The result of this study may be used for further analysis of the continuous system. The experiment was carried out three times all in triplicate, and the average result were reported. One reactor was used as a control in all study.

## 2. MATERIALS AND METHODS

### 2.1 Material Collection

Greywater was collected from the girls hostel located in the SV National Institute of Technology (SVNIT), Surat, with a seating capacity of 700 girls. A collection system was provided to collect greywater consisting of wastewater from the washbasin, bathroom, laundry area, and floor cleaning. The greywater was collected in a 250 L capacity collection tank, and provision was made to discharge excess greywater into the drain using the overflow valve shown in Figure 1. It was transported to the experimental location 500 m away from the greywater collection system. Young WH was collected from a pond located in Hazira of Surat city, India and stored in the propagation area. All the foreign matter were removed by thoroughly washing with tap water before cultivating into the propagation area. Propagation area is water hyacinth cultivation area, where water hyacinth is grown for further studies. Similar sized young WH (70-100 mg) having a plant height of 12-15 cm were used. Young WH was selected as it requires more nutrients compared to matured WH. Moreover, Valipour et al. (2015) reported that young WH plants release more oxygen into the water than mature.

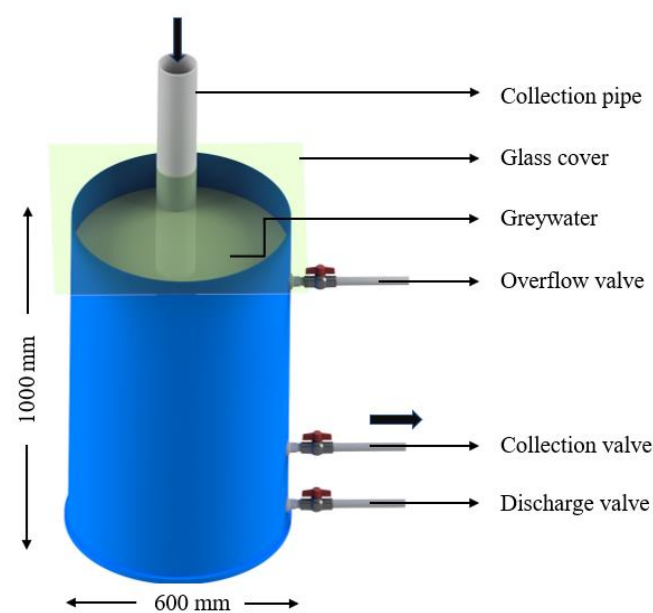


Figure 1: Greywater collection system

### 2.2 Experimental Reactor

The experimental reactor was located in an open area of the Civil Engineering Department, old classroom complex, SVNIT (21.1643° N, 72.7841° E), Surat, India. The reactor consisted of a circular bucket made up of plastic material with a dimension of 320 mm diameter and height of 400 mm with a capacity of 25 L. Each study consisted of three sets of seven circular buckets (reactors) with a working depth of 320 mm, and one set was used as a control (without WH) for different HDT. WH was planted in the three-set, and one set as control was used for treatment. The young WH used was 7 days matured after procuring, was in the growth phase.

The average plant height of 15 cm with an average number of leaf 8 and average weight of 570 gm. The total of 5 number of WH plant were planted into each reactor with greywater having HDT of 1-7 days. The operation consisted of fill and react and draw. In fill phase, the greywater was filled into the reactor and retained into the reactor for absorption by the plant through growth, settling and physicochemical reaction in react phase under different detention time. The pollutant removal mechanism takes place in react phase where WH absorb nutrients from greywater for its growth. The react phase was variable between 1 to 7 days. In the final draw phase, effluent samples were taken for analysis after different HDTs and treatment performance was reported.

### 2.3 Sampling and Method of Analysis

Initially, the system was operated using a combination of greywater and tap water for 7 days as a booting period and for plant growth and acclimatization. Kutty et al. (2009) reported WH grows well after 6 days of the plantation until the 24th day. Hence, each replica of the study was carried out for 14 days (7 days of the experiment), followed by a cleaning period of 4 days, making 18 days for each batch study. Once the plant showed survivability and growth, greywater was poured into the reactors. The effluent samples were collected in the morning (8:00 am to 9:00 am) in 500 mL plastic bottle and analyzed immediately for physicochemical parameters. The influent sampling and analysis were done on the fill phase, followed by effluent sampling under different HDT in the draw phase. Thus, for each HDT, three different effluent samples for three reactors and one from the control reactor were collected. Greywater samples were analyzed for water temperature, pH, turbidity, chemical oxygen demand (COD), ammonium-nitrogen ( $\text{NH}_4\text{-N}$ ), phosphate-phosphorous ( $\text{PO}_4^{3-}\text{-P}$ ), and sodium. Water temperature and pH were measured using a pH meter (Hanna Instruments, HI98129, Romania). Turbidity was measured using a turbidity meter (turbidity meter -135, Systronics). COD was determined using COD digester (DBK Instruments, India) at 150°C for 2h and titration of excess hot potassium dichromate with ferrous ammonium sulphate.  $\text{NH}_4\text{-N}$  and  $\text{PO}_4^{3-}\text{-P}$  were measured following standard methods (APHA 2012).

## 3. RESULTS AND DISCUSSIONS

The characteristics of greywater vary from place to place, as well as the time of the day. It also depends on the lifestyle of the people in general. As per Ghaitidak et al. (2014), the greywater contains 30% of organics, of which 10 - 20% of nutrients are easily degradable. The average influent characteristics of the greywater in the present study was  $6.95 \pm 0.07$ ,  $27.52 \pm 0.22^\circ\text{C}$ ,  $57.80 \pm 11.14$  NTU,  $273.6 \pm 11.53$  mg/L,  $5.32 \pm 0.84$  mg/L,  $1.29 \pm 0.07$  mg/L, and  $57.80 \pm 11.14$  mg/L for pH, water temperature, turbidity, COD, ammonium-nitrogen, phosphate-phosphorous, and sodium respectively.

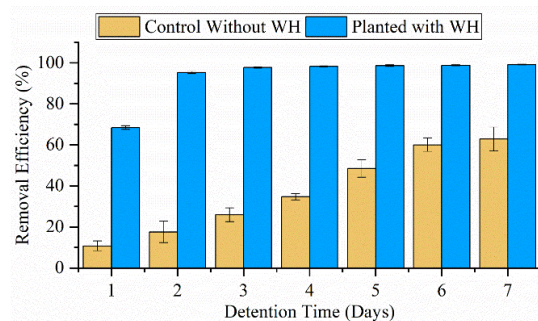
### 3.1 Experimental conditions

All reactors were kept in the open atmosphere to replicate the natural treatment system. The average influent greywater temperature was  $27.52 \pm 0.22^\circ\text{C}$ . The average effluent temperature during the sample collection was  $27.02 \pm 0.10^\circ\text{C}$  in the treatment reactor and  $28.45 \pm 0.25^\circ\text{C}$  in the control reactors. A lower average temperature in the treatment reactor was observed compared to control was due to plant presence (Hill et al., 2000). During the study period, the atmospheric temperature recorded was a minimum of  $22^\circ\text{C}$  and a maximum of  $36^\circ\text{C}$ , favourable for WH growth (El-Gendy et al., 2004; Dersseh et al., 2019). At this temperature range, the growth of WH is high, resulting in the maximum nutrient uptake. The water temperature in the planted reactor provides the suitable condition for the microorganisms to grow and degrade the nutrients present in the greywater. The floating plant provides an appropriate temperature, which may boost increased pollutant removal (Hill et al., 2000). Variation in the temperature affects the physical and biological activity of the treatment system (El-Refaie, 2010).

### 3.2 pH, turbidity and loss of water

The average pH of the influent samples was  $6.95 \pm 0.07$ , and average pH of effluent (reactor) and control were  $7.08 \pm 0.12$  and  $7.04 \pm 0.05$ , respectively, which are in the optimum range (6.5 - 7.5) for the biological denitrification process (Kadlec et al., 2009). El-Gendy et al. (2004) reported pH in the range of 4 - 8 as most suitable for WH growth. A significant difference ( $p < 0.05$ ) was not observed in pH between the planted and control reactor's effluent. However, in the planted reactor, the roots of the plant provide diffused oxygen into the reactor. This provides proper conditions necessary for the development of nitrifying and denitrifying microorganisms, thus increasing the nitrification and denitrification process (Peng et al., 2014). The increase in pH in the wetland favours the growth of a plant and microbial action to remove nutrients from the greywater (Gupta et al., 2012).

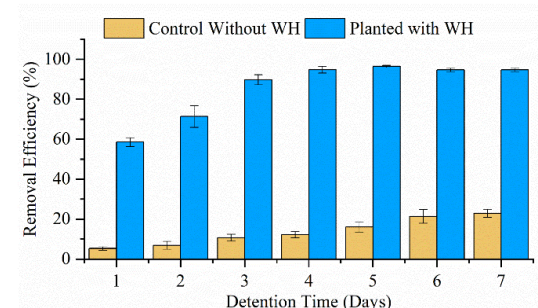
Turbidity is a measure of suspended materials present in greywater, which was found low. The average influent concentration of turbidity was  $57.80 \pm 11.14$  NTU, relatively lower than 80.3 NTU values obtained by Ghaitidak et al. (2014) for greywater. The average effluent turbidity was continuously reduced throughout the detention time, with  $98.69 \pm 0.93\%$  removal on the 7 day in the planted reactor and 60.73% removal on the unplanted reactor. The reduction in control may be due to the settling mechanism. During the initial two days, 90% of the turbidity was removed, as shown in Figure 2, and after that, the removal was almost constant. The dense root system of WH contributed a major role in reducing turbidity from the greywater (Bhutiani et al., 2015). Whereas in the control reactor, increased removal was observed throughout the study period. The removal was observed due to the physical mechanisms like settling, aggregation and interception mechanisms. Significant ( $p < 0.05$ ) removal was observed compared to the average influent concentration.



**Figure 2:** Removal efficiency of turbidity during the different detention time

The atmospheric temperature was in the range of  $22 - 36^\circ\text{C}$ . The loss of water from the reactor is considered as an essential factor in determining the removal rate. In this study, the average loss of water was 3.2 mm/d. This loss of water was countered by the addition of distilled water to the reactor. The loss of water due to evaporation depends on atmospheric air temperature, humidity, wind speed, season of the year and type of plant used for treatment.

### 3.3 Nutrient reduction

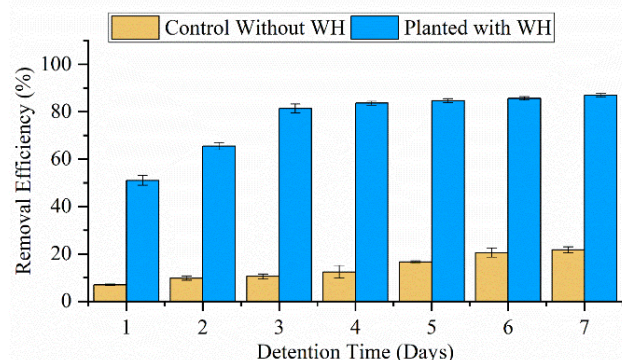


**Figure 3:** Removal efficiency of ammonia-nitrogen during the different detention time

Nitrogen is considered as one of the principal constituents of the wastewater. Ammonium-nitrogen is regarded as a principal form of nitrogen. The presence of ammonium-nitrogen in wastewater amplifies the plant growth, thereby removing the nitrogen from the greywater. The changes in the ammonium-nitrogen concentration over the different detention time are shown in Figure 3. It can be seen that with an increase in HDT, the removal efficiency also increases till HDT of 4 days after that, the constant removal percentage was observed. The optimum removal of  $87.50 \pm 2.47\%$  was observed on the 3<sup>rd</sup> day. The removal observed was 25% on the 6 day of the treatment, and after that constant value was observed.

The removal efficiency observed in this study was considerably lower compared with Jayaweera et al. (2004), where 100% removal was observed. Under different HDT, the optimum removal was observed on the 3 days followed by maximum removal on 5<sup>th</sup> day before becoming constant. The removal can be attributed mostly to the uptake by the plant. Plant plays a vital role in the removal of ammoniacal-nitrogen by plant uptake and microbial activity in the plant's dense root zone (Ting et al., 2018).

Mayo et al. (2014) reported denitrification (81.9%) and sedimentation (13.1%) as an effective mechanism for nitrogen removal. The removal of nitrogen generally occurs through nitrification after denitrification (Jayaweera et al., 2004). The majority of nitrogen are removed through plant uptake, as followed by denitrification (Fox et al., 2008). Nitrogen removal is affected by the temperature of the water.

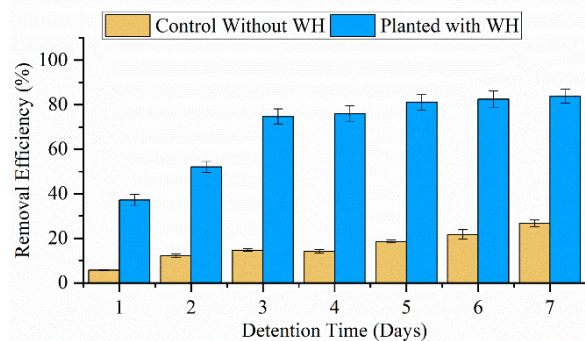


**Figure 4:** Removal efficiency of phosphate-phosphorous during the different detention time

Phosphorous is considered as an essential and inhibiting component for plant growth through vegetative reproduction. In the wetland, phosphorous transformation occurs through water, plant, microbes, plant biomass litter, and soil. The most assertive fraction is present in the soil and sediments followed by plant and plant litter and least in the microbes and water. In this study, changes in the phosphate-phosphorous are shown in Figure 4. The average influent concentration of  $\text{PO}_4^{3-}\text{P}$  was  $1.21 \pm 0.28$  mg/L. Accelerated phosphorous removal was observed upto the detention time of 3 days, and after that, removal efficiency became constant.

For control, the slow removal was observed in the initial 4 days with the removal of 9.56%, and at the end of 21.94% removal was observed. The reduction in control can be attributed to the settling process in the water column. Removal of  $79.86 \pm 4.55\%$  was observed for HDT of 3 days; after that, removal efficiency became constant with a maximum reduction of 85.83% on the 7<sup>th</sup> day.

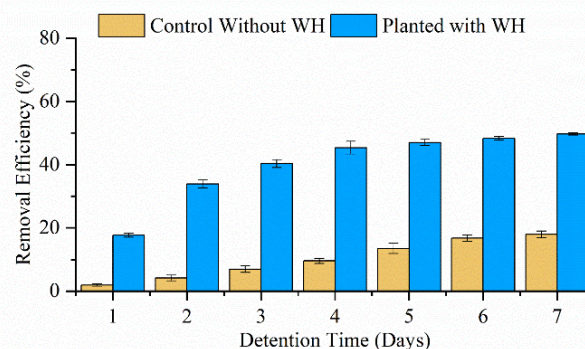
Accelerated removal in the initial 3 days can be associated with higher plant uptake for its growth, sedimentation, and plant uptake. A higher reduction in phosphorous (98.5%) reduction was observed by (Sooknah et al., 2004) for flushed dairy manure waste. (El-Refaie, 2010) showed direct relation with the water temperature and removal efficiency.



**Figure 5:** Removal efficiency of COD during the different detention time

COD is a measure of the amount of  $\text{O}_2$  equivalent of organic matter and microorganism in wastewater (Shah et al., 2014). The influent concentration of COD observed was  $273.60 \pm 11.53$  mg/L. The average effluent concentration was reduced to  $44.44 \pm 9.91$  mg/L and  $200.43 \pm 9.05$  mg/L in the planted reactor and control. During the initial 3 days HDT, rapid COD reduction was observed in the planted reactor, and after that, the decline in the was reduced. In the planted reactor, average  $74.72 \pm 3.38\%$  reduction was observed on the 3 day HDT. The effluent concentration was reduced with an increase in HDT, as shown in Figure 5. The rate of increase in COD reduction was observed till the 5 day HDT, and after that, the removal was constant. The maximum removal percentage observed was  $83.82 \pm 3.20\%$  on the 7 day HDT. The increased removal performance was due to increased contact time between the microorganism present in the WH root. For control, the removal of  $26.73 \pm 1.53\%$  was observed on the 7 day HDT, which can be associated to the sedimentation process (Sooknah et al., 2004).

The increase in the planted reactor's removal percentage can be attributed to sedimentation and filtration through the plant's dense root system and microbes' presence on WH roots. The removal efficiency of planted reactor correlates to the one-day HDT was higher than the control reactor on the 7 day HDT. (Shah et al., 2014) obtained 50.61% reduction of COD for municipal wastewater whereas (Rezania et al., 2014) observed 95% reduction on domestic wastewater. (Victor et al., 2016) obtained 82.45% reduction for industrial wastewater. Reduction in nutrients was due to the assimilation of nutrients by the microorganisms present on the roots of the WH Microorganism helps to convert the nutrient into a simpler form that can be easily uptake by the plant roots. The reduction in COD can also be due to microorganisms that help in the collaborative relationship with plant root (Mahunon et al., 2018).



**Figure 6:** Removal efficiency of sodium during the different detention time

The source of sodium in greywater is generally through laundry water, which is present in the forms of cations and anions. The presence of sodium in water, which are used for irrigation purposes, generally has a detrimental effect on a plant's growth. In the present study, the average influent concentration of sodium was  $57.80 \pm 11.14$  mg/L. The average effluent concentration reduced to  $20.57 \pm 2.70$  mg/L and  $33.58 \pm 4.53$  mg/L in planted and control reactor, respectively. In the planted reactor,

the rapid reduction was observed during the initial 2 days HDT, and after that, the reduction rate was reduced. In the planted reactor,  $40.36 \pm 1.23\%$  reduction was observed on the third day HDT (Figure 6). Lacerda et al. (2018) reported 12%, 8%, and 9% reduction in sodium concentration with initial concentration of 300 mg/L, 500 mg/L, and 1000 mg/L. A higher reduction was observed in this study due to the low concentration of sodium in the influent.

#### 4. CONCLUSION

Phytoremediation has shown to be an effective method of wastewater treatment; However, WH for greywater treatment has not been explored. With the increasing concern over the reuse of wastewater, WH showed an excellent candidate for greywater treatment. The present study was based on the free-floating plant treatment system operated in batch mode to know the optimum HDT required for greywater treatment. This batch study showed WH as a successful floating plant to remove pollutants from greywater with optimum HDT of 3 days. The average reduction of  $97.77 \pm 0.30\%$  (turbidity),  $74.72 \pm 3.38\%$  (COD),  $89.80 \pm 2.48\%$  (ammonium-nitrogen),  $81.38 \pm 1.89\%$  (phosphate-phosphorous), and  $40.36 \pm 1.23\%$  (sodium) was observed in this preliminary study. Thus, HDT of 3 days can be used further for study. Longer detention time provides a longer duration for the microorganism to act on the nutrients available as food. Further study is needed to know the dynamics of treatment performance under different detention times for a continuous process.

#### CONFLICT OF INTEREST

There is not any conflict of interest in this manuscript.

#### REFERENCES

- Agarry, S.E., Oghenejoboh, K.M., Latinwo, G.K. and Owabor, C.N., 2018. Biotreatment of Petroleum Refinery Wastewater in Vertical Surface-Flow Constructed Wetland Vegetated with *Eichhornia Crassipes*: Lab-Scale Experimental and Kinetic Modelling. *Environmental Technology (United Kingdom)*.
- APHA (American Public Health Association), 2012. *Standard Methods for the Examination of Water and Wastewater*. 22nd Ed. Washington, DC: APHA.
- Ayyasamy, P.M., Rajakumar, S., Sathishkumar, M., Swaminathan, K., Shanthi, K., Lakshmanaperumalsamy, P. and Lee, S., 2009. Nitrate Removal from Synthetic Medium and Groundwater with Aquatic Macrophytes. *Desalination*, 242(1-3), Pp. 286-296.
- Bhutiani, R., Kangri G., Tyagi V., 2015. Removal of Turbidity in Dairy Waste Water Through Aquatic Macrophytes. *International Journal of Research*, 3(9), Pp. 1-3.
- Dersseh, M.G., Melesse, A.M., Tilahun, S.A., Abate, M. and Dagnew, D.C., 2019. Water Hyacinth: Review of Its Impacts on Hydrology and Ecosystem Services-Lessons for Management of Lake Tana, Pp. 237-251.
- Dierberg, F.E., Juston, J.J., DeBusk, T.A., Pietro, K. and Gu, B., 2005. Relationship between Hydraulic Efficiency and Phosphorus Removal in a Submerged Aquatic Vegetation-Dominated Treatment Wetland. *Ecological Engineering*, 25(1), Pp. 9-23.
- El-Gendy, A.S., Biswas, N. and Bewtra, J.K., 2004. Growth of Water Hyacinth in Municipal Landfill Leachate with Different PH. *Environmental Technology*, 25(7), Pp. 833-840.
- El-Refaie, G., 2010. Temperature Impact on Operation and Performance of Lake Manzala Engineered Wetland, Egypt. *Ain Shams Engineering Journal*, 1(1), Pp. 1-9.
- Fox, L.J., Struik, P.C., Appleton, B.L. and Rule, J.H., 2008. Nitrogen Phytoremediation by Water Hyacinth (*Eichhornia Crassipes* (Mart.) Solms). *Water, Air, and Soil Pollution*, 194(1-4), Pp. 199-207.
- Ghaitidak, D.M. and Yadav, K.D., 2014. Effect of Coagulant in Greywater Treatment for Reuse: Selection of Optimal Coagulation Condition Using Analytic Hierarchy Process. *Desalination and Water Treatment*, 55(4), Pp. 913-925.
- Gupta, P., Roy, S. and B. Mahindrakar, A., 2012. Treatment of Water Using Water Hyacinth, Water Lettuce and Vetiver Grass - A Review. *Resources and Environment*, 2(5), Pp. 202-215.
- Harvey, J.W., Saiers, J.E. and Newlin, J.T., 2005. Solute Transport and Storage Mechanisms in Wetlands of the Everglades, South Florida. *Water Resources Research*, 41(5), Pp. 1-14.
- Hernández L., L., Soeter, A. M., Kools, S. A.E., Kraak, M. H.S., Parsons, J. R., Temmink, H., Zeeman, G. and Buisman, C. J.N., 2012. Ecotoxicological Assessment of Grey Water Treatment Systems with *Daphnia Magna* and *Chironomus Riparius*. *Water Research*, 46(4), Pp. 1038-1044.
- Hill, D. T. and Payton, J. D., 2000. Effect of Plant Fill Ratio on Water Temperature in Constructed Wetlands. *Bioresource Technology*, 71(3), Pp. 283-289.
- Jayaweera, MW and Kasturiarachchi, J.C., 2004. Removal of Nitrogen and Phosphorus from Industrial Wastewaters by Phytoremediation Using Water Hyacinth (*Eichhornia Crassipes* (Mart.) Solms). *Water Science and Technology*, 50(6), Pp. 217-226.
- Kadlec, Robert H. and Wallace, Scott, 2009. *Treatment Wetlands*.
- Kutty, S R M, Ngatenah, S N I, Isa, M H and Malakahmad, A., 2009. Nutrients Removal from Municipal Wastewater Treatment Plant Effluent Using *Eichhornia Crassipes*. *Engineering and Technology*, 60, Pp. 826-831.
- Lacerda, Laís Pessôa De, Lange, Liséte Celina, Giovanni, Marcel and França, Costa., 2018. Growth and Differential Salinity Reduction between *Portulaca Oleracea* and *Eichhornia Crassipes* in Experimental Hydroponic Units. *Environmental Technology*, Pp. 1-9.
- Liu, S., Butler, D., Memon, F. A., Makropoulos, C., Avery, L. and Jefferson, B., 2010. Impacts of Residence Time during Storage on Potential of Water Saving for Grey Water Recycling System. *Water Research*, 44(1), Pp.267-277.
- Mahunon, S.E.R., Aina, M.P., Akowanou, A.V.O., Kouassi, E.K., Yao, B.K., Adouby, K. and Drogui, P., 2018. Optimization Process of Organic Matter Removal from Wastewater by Using *Eichhornia Crassipes*. *Environmental Science and Pollution Research*, 25(29), Pp. 29219-29226.
- Mayo, A.W., Hanai, E.E. and Kibazohi, O., 2014. Nitrification-Denitrification in a Coupled High Rate - Water Hyacinth Ponds. *Physics and Chemistry of the Earth*, 72-75, Pp. 88-95.
- Mishra, S. and Maiti, A., 2017. The Efficiency of *Eichhornia Crassipes* in the Removal of Organic and Inorganic Pollutants from Wastewater: A Review. *Environmental Science and Pollution Research*, 24(9), Pp. 7921-7937.
- Nayanathara, O.S. and Bindu, A.G., 2017. Effectiveness of Water Hyacinth and Water Lettuce for the Treatment of Greywater - a Review. *International Journal of Innovative Research in Science and Engineering*, 3(1), Pp. 349-355.

- Peng, L., Hua, Y.M., Cai, J.B., Zhao, J.W., Zhou, W.B. and Zhu, D.W., 2014. Effects of Plants and Temperature on Nitrogen Removal and Microbiology in a Pilot-Scale Integrated Vertical-Flow Wetland Treating Primary Domestic Wastewater. *Ecological Engineering*, 64, Pp. 285–290.
- Prasad, R. and Yadav, K.D., 2020. Use of Response Surface Methodology and Artificial Neural Network Approach for Methylene Blue Removal by Adsorption onto Water Hyacinth. *Water Conservation And Management ( WCM )*, 4(2) Pp. 73–79.
- Qin, H.J., Zhang, Z.Y., Liu, M.H., Liu, H.Q., Wang, Y., Wen, X.Z., Zhang, Y.Y. and Yan, S.H., 2016. Site Test of Phytoremediation of an Open Pond Contaminated with Domestic Sewage Using Water Hyacinth and Water Lettuce. *Ecological Engineering*, 95, Pp. 753–762.
- Rangel-Peraza, J.G., Mendivil-García, K., Cedillo-Herrera, C.I.G., Rochín-Medina, J.J., Rodríguez-Mata, A.E. and Bustos-Terrones, Y.A., 2019. Optimization of Organic Matter Degradation Kinetics and Nutrient Removal on Artificial Wetlands Using *Eichhornia Crassipes* and *Typha Domingensis*. *Environmental Technology (United Kingdom)*, 40(5), Pp. 633–641.
- Rezania, S., Md Din, Mohd Fadhil, K., Siti Fatimah, T., Shazwin M., Singh, L., Yong, E.L. and Dahalan, F.A., 2016. Evaluation of Water Hyacinth (*Eichhornia Crassipes*) as a Potential Raw Material Source for Briquette Production. *Energy*, 111, Pp. 768–773.
- Rezania, S., Ponraj, M., Fadhil M.D., Mohd, C., Shreeshivadasan and Md Sairan, F., 2014. Effectiveness of *Eichhornia Crassipes* in Nutrient Removal from Domestic Wastewater Based on Its Optimal Growth Rate. *Desalination and Water Treatment*, Pp. 1–6.
- Sabokrouhiyeh, N., Bottacin-Busolin, A., Tregnaghi, M., Nepf, H. and Marion, A., 2020. Variation in Contaminant Removal Efficiency in Free-Water Surface Wetlands with Heterogeneous Vegetation Density. *Ecological Engineering*, 143(11), Pp. 105662.
- Shah, M., Hashmi, H.N., Ali, A. and Ghumman, A.R., 2014. Performance Assessment of Aquatic Macrophytes for Treatment of Municipal Wastewater. *Journal of Environmental Health Science and Engineering*, 12(1), Pp. 1–12.
- Sooknah, R.D. and Wilkie, A.C., 2004. Nutrient Removal by Floating Aquatic Macrophytes Cultured in Anaerobically Digested Flushed Dairy Manure Wastewater. *Ecological Engineering*, 22, Pp. 27–42.
- Ting, W.H.T., Tan, I.A.W., Salleh, S.F. and Wahab, N.A., 2018. Application of Water Hyacinth (*Eichhornia Crassipes*) for Phytoremediation of Ammoniacal Nitrogen: A Review. *Journal of Water Process Engineering*, 22, Pp. 239–249.
- Valipour, A., Raman, V.K. and Ahn, Y.H., 2015. Effectiveness of Domestic Wastewater Treatment Using a Bio-Hedge Water Hyacinth Wetland System. *Water (Switzerland)*, 7(1), Pp. 329–347.
- Victor, K.K., Séka, Y., Norbert, K.K., Sanogo, T.A. and Celestin, A.B., 2016. Phytoremediation of Wastewater Toxicity Using Water Hyacinth (*Eichhornia Crassipes*) and Water Lettuce (*Pistia Stratiotes*). *International Journal of Phytoremediation*, 18(10), Pp. 949–955.
- Vymazal, J., 2013. Plants in Constructed, Restored and Created Wetlands. *Ecological Engineering*, 61, Pp. 501–504.
- Wang, Z., Zhang, Z.Y., Zhang, J.Q., Zhang, Y.Y., Liu, H.Q. and Yan, S.H., 2012. Large-Scale Utilization of Water Hyacinth for Nutrient Removal in Lake Dianchi in China: The Effects on the Water Quality, Macrozoobenthos and Zooplankton. *Chemosphere*, 89, Pp. 1255–1261.
- Zheng, Y.C., Wang, X.C., Dzakpasu, M., Zhao, Y.Q., Ngo, H.H., Guo, W.S., Ge, Y. and Xiong, J.Q., 2016. Effects of Interspecific Competition on the Growth of Macrophytes and Nutrient Removal in Constructed Wetlands: A Comparative Assessment of Free Water Surface and Horizontal Subsurface Flow Systems. *Bioresource Technology*, 207, 134–141.

