Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

EVALUATION OF DUCKWEED BASED WASTE STABILIZATION POND SYSTEM FOR DOMESTIC WASTEWATER TREATMENT

Md. Mahmudul Hasan[1], Mehedi Hasan[2] and Tanveer Saeed[3]

[1] *Department of Civil Engineerng, University of Asia Pacific, Bangladesh,*
e-mail: drhasan@uap-bd.edu
[2] *Department of Civil Engineerng, University of Asia Pacific, Bangladesh,*
e-mail: mehedi42ce@gmail.com
[3] *Department of Civil Engineerng, University of Asia Pacific, Bangladesh,*
e-mail: dr.tanveer@uap-bd.edu

ABSTRACT

Natural systems of wastewater treatment are regarded as sustainable ecotechnologies specially for the developing countries. In this study performance of a natural treatment system, namely, duckweed (S. Polyrrhiza) based waste stabilization pond system for domestic wastewater treatment was investigated. The domestic wastewater was collected from an outlet of a residential building at Dhamondi area in Dhaka city, Bangladesh. The domestic wastewater was poured in a small-scale glass reactor that was subjected to atmospheric conditions with 5 days Hydraulic Retention Time (HRT). Once in a week 20 liters raw domestic wastewater was used as influent; the experiment was carried out for 8 consecutive weeks. Total 16 samples (08 for influent and 08 for effluent) were collected and analyzed to evaluate pollutant removal performances accross the experimental system. In domestic wastewater the average concentrations of P^H *, DO, TDS, TSS, COD,* PO_4*-P,* NO_3*-N,* NO_2*-N and* NH_3*-N were found to be 7.4, 1.7 mg/L, 443.3 mg/L, 170.0 mg/L, 257.0 mg/L, 26.6 mg/L, 1.0 mg/L, 26.3 mg/L and 23.6 mg/L respectively. Whereas, in effluent the average concentrations of such parameters were found 8.34, 6.60 mg/L, 367.75 mg/L, 29.13 mg/L, 49.26 mg/L, 6.14 mg/L, 1.75 mg/L, 5.61 mg/L and 13.65 mg/L respectively. Consequently, the system achieved 17%, 82.9%, 80.8%, 76.9% and 42.0% removal efficiencies of TDS, TSS, COD,* PO_4*-P, and* NH_3*-N respectively. These results indicate that duckweed based wastewater stabilization pond system might be successfully employed for treating domestic wastewater in developing countries as a decentralized treatment unit.*

Keywords: *Duckweed, waste stabilization pond, domestic wastewater, ecotechnology, developing countries*

1. INTRODUCTION

Besides to ensure safe water supply, the concept of wastewater treatment has also been widely recognised as an important issue in recent days due to global water shortage, even in developing countries (Ujang and Buckley, 2002; Verstraete et al., 2009).

Generally, the advanced wastewater treatment technologies have been designed and proposed so that the treated effluent can meet the highly restrictive guidelines for disposal and/or reuse. However, these technologies are still limited to developed countries only. Advanced treatment technologies have not expanded to developing countries due to the high cost, energy requirements, difficulties of installation, operation and maintenance as well as large solids or sludge production (Mara, 2004). In addition, the guidelines of environmental protection are being stringent in developing countries day by day in recent time. To overcome these challenges, interest in natural systems for wastewater treatment is increasing day by day not only for wastewater treatment but also for conserving biological communities in developing countries (Kocaman et al., 2007).

Literature stated that natural systems for effective wastewater treatment are available in three major categories: aquatic pond (e.g., algae based waste stabilization pond, duckweed based waste stabilization pond, hyacinth pond) terrestrial (e.g., soil aquifer treatment, overland flow), and wetland (e.g., natural marshes, free water surface constructed wetland, subsurface flow wetland) (Crites et al., 2006). The major natural processes occurring in natural systems during wastewater treatment include sedimentation (settling of solids), plant uptake, bacterial degradation, and chemical adsorption (fixation).

The natural system of wastewater treatment using aquatic macrophytes such as duckweed has already gain attention and has been widely discussed in literature for nearly 40 years (Culley and Epps, 1973; Hillman and Culley, 1978; Oron et al., 1984; Landolt and Kandeler, 1987; Alaerts et al., 1996; Leng, 1999; Smith and Moelyowati, 2001; Nhapi et al., 2003; Willett, 2005; Ozengin and Elmaci, 2007; Xu and Shen, 2011; Verma and Suthar 2014; Allam et al., 2015; Gaur and Suthar, 2017). Duckweeds are green, small-sized (1-3 mm), fast-growth, free floating aquatic macro-phytes having short but dense roots (1-3 cm) that belongs to *Lemnaceae* family (which is derived from the Greek word 'Limne', meaning pond) (Cheng et al., 2002; Cheng and Stomp, 2009; Ozengin and Elmaci 2007). The *Lemnaceae* family consist of five genera, Lemna, Landoltia, Spirodela, Wolffia and Wolffiella, among which about 40 species have been identified wide-reaching (Les et al., 2002; Willett, 2005). Duckweed is well known for its high productivity and high protein content in temperate climates and easy handling, harvesting and processing (Oron et al., 1984; Oron et al., 1986; Hammouda et al., 1995). Duckweed fronds grow in colonies that, in particular growing conditions, form a dense and uniform surface mat having low fibre content and reduces mosquito development (Altay et al., 1996). Duckweed is applied on the surface of stabilization ponds, and as it has great ability to reduce the BOD, COD, suspended solids, bacterial and other pathogens from wastewater.

One of the major problems with conventional wastewater treatment methods is that none of the available technologies has a direct economic return. Therefore, with no economic return, local authorities are generally not interested in taking up treatment of wastewater in developing countries, thereby causing severe health hazards and environmental pollution (Von Sparling, 1996; Mahmood et al., 2013). In contrast duckweed-based waste stabilization pond system for wastewater treatment showed its potential for its nutrient value and direct economic returns from pisciculture. The objective of this study is to evaluate the pollutant removal performance of a duckweed based waste stabilization pond system while treating domestic wastewater.

2. METHODOLOGYV

2.1 Duckweed collection and culture

The duckweed (*Spairodela polyrhiza*) used in this study was collected from a ditch near Dhanmondi lake, Dhaka. The collected duckweed then cultured in a separate reactor with atmospheric condition using same domestic wastewater that was subjected to treat. During the experiment the cultured duckweed was used periodically.

2.2 Domestic wastewater collection

Domestic wastewater was collected from an outlet (just before fall onto adjacent municipal drain) of a six-storied residential building in Dhanmondi R/A, Dhaka. Figure 1 shows the photograph of sampling point. Once in a week 20 litre wastewater was collected for the experiment and for analyse its characteristics' as well.

2.3 Experimental Setup and operational conditions

In this study a small-scale glass made tank was used as reactor which was placed at the roof-top of University of Asia Pacific, Dhaka to maintain atmospheric condition. The experiment was conducted during November 2016 to February 2017. Figure 1 shows the schematic view of experimental set up. The size of the reactor was 45 cm x 33 cm x 24 cm. Therefore, the surface area is 1485 cm^2. Duckweed-covered wastewater has depth of 15 cm. Once in a week 20 litre domestic wastewater was poured into the reactor. Effluents were taken once after 5 days (at 1:20 pm-1:35 pm). The experiment was repeated for eight consecutive weeks. Loss of water by evaporation and evapotranspiration from the reactor during the experiment was neglected.

The experiment commenced with a duckweed density of 0.07 g/cm^2 (wet weight) duckweed. Everyday duckweed was grown up and every week the duckweeds were eliminating to keep initial density constant. The reactor was washed before pouring initial wastewater every time. Figure 3 represents the diagram of the experiment.

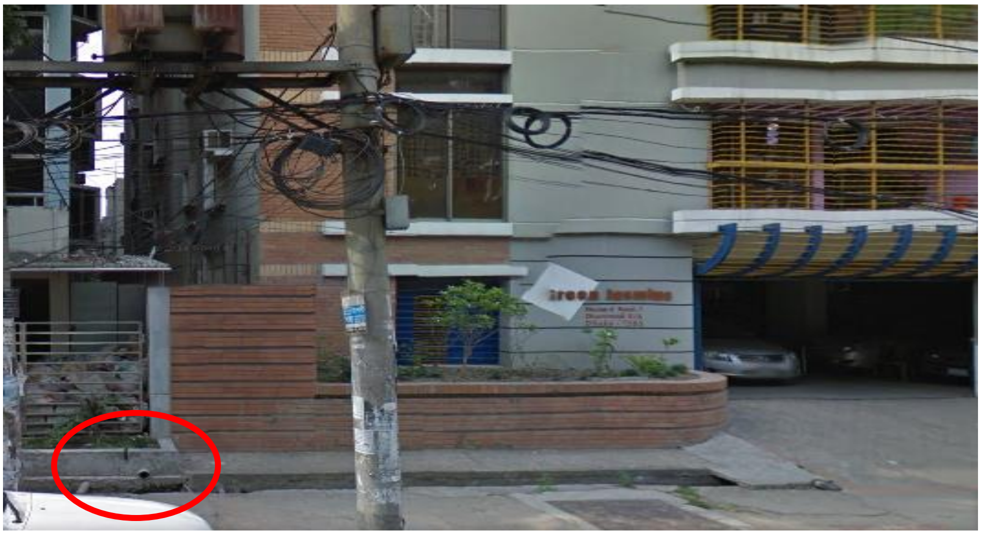

Figure 1 : Outlet from where domestic wastewater was collected (red circle).

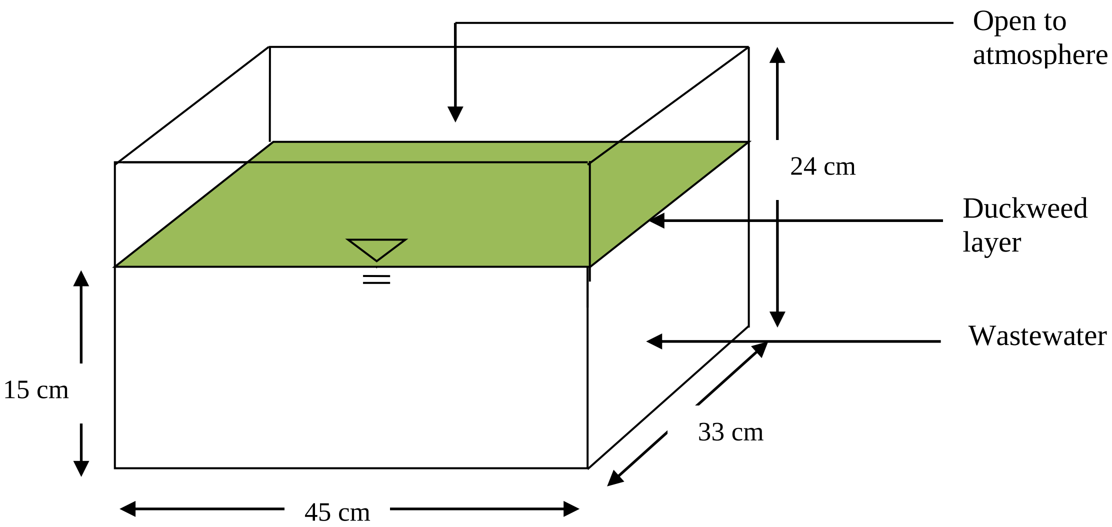

Figure 2: Sketch diagram of the reactor.

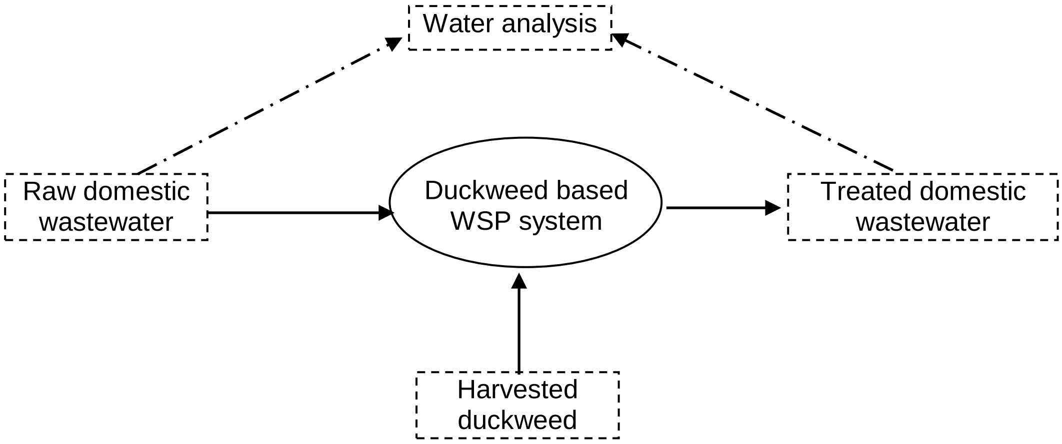

Figure 3: Diagram of the experiment.

2.4 Analytical methods

The collected samples (08 samples of raw domestic wastewater as influent and 08 samples of treated wastewater as effluent) were analysed using standard methods at Environmental and Chemistry Laboratory, University of Asia Pacific, Dhaka.

The samples were tested for total 10 parameters: pH, DO, Temperature, COD, PO_4-P, NO_2-N, NO_3-N, NH_3-N, TSS, TDS. All the samples were taken between 1:00 to 1:30 pm and analysed immediately. The pH and dissolved oxygen (DO) were measured using pH metre (HORIBA F-21) and DO metre (HACH HQ30d), respectively. HITACHI U-2800 spectrophotometer was used for COD, PO_4-P, NO_2-N, NO_3-N, NH_3-N, TSS, TDS measurement following standard methods. All tests were carried out with appropriate reagents and blanks.

3. RESULTS AND DISCUSSION

3.1 Characteristics of domestic wastewater

Table 1 shows the concentrations of different parameters of domestic wastewater that represents it characteristics. Based on literature it could be characterized as medium strength domestic wastewater (Metcalf and Eddy, 1991; Muttamara, 1996).

3.2 pH, DO and temperature

Figure 4 shows pH and DO concentrations and temperature in influent and effluent. pH value was found high after the treatment: average value in influent was 7.4 whereas in effluent it was 8.34. The maximum 30.7% increase in pH was found during this experiment (sample 4 in figure 4) and the increase in pH value in duckweed based system is already reported (Bal Krishna and Polprasert, 2008; Ozengin and Elmaci, 2007; Selvarani et al., 2015). The reasons of pH increase might be due to the photosynthetic activity in the reactor that utilized CO_2 and produced less amount of carbonic acid (Selvarani et al., 2015).

DO concentrations were found four times higher in effluent (6.60 mg/L) and maximum 587% increase in DO level was observed (sample 4 in figure 4). The increase in DO level during duckweed based treatment system also matched with literature and the reason might be the production of gaseous oxygen due to photosynthetic activity (EL-Kheir et al., 2007).

Temperature was dependent on the local atmospheric condition as the experiment was conducted at roof-top area. In effluent it was found higher around 1°C than influent as the reactor was made of glass which might absorb the heat. Literature shows that duckweed will decrease while temperature below 17 °C or above 34-35 °C (Smith and Maolyawat, 1998; Azeez and Sabbar, 2012). In this experiment, both cases (influent and effluent) the temperature was within 17.1 °C to 25 °C (figure 4) which was within the tolerable limit for *Lemnaceae* family (Culley et al., 1981) and was suitable for the experiment.

Table 1: Characteristics of domestic wastewater

Parameters	**Concentrations**		
	Minimum	**Maximum**	**Mean ± SD**
pH	7.12	7.61	7.4 ± 0.2
DO (mg/L)	0.54	4.55	1.7 ± 1.2
Temp (^{o}C)	17.1	24.5	21.7 ± 2.3
TDS (mg/L)	332	500	443.3 ± 51.8
TSS (mg/L)	64	272	170.0 ± 89.8
COD (mg/L)	105	434	257.0 ± 91.2
PO_4-P (mg/L)	19	35	26.6± 5.0
NO_3-N (mg/L)	0.2	2.4	1.0 ± 0.6
NO_2-N (mg/L)	9	76	26.3 ± 26.5
NH_3-N (mg/L)	15.5	32.4	23.6 ± 5.4

3.3 Organic removal

Maximum rate of COD removal was found 94.2% (sample 7 in figure 5) with an average removal rate of 80.8% in this system. Figure 5 shows the COD concentration in influent and effluent. Literature reported that significant enhancement of COD removal in duckweed treatment system and the removal rate was within the range of 70% to 80% (Korner et al., 2003; Pandey, 2001) or 50% to 95% (Alaerts al., 1996; Boniard et al., 1994; Oron et al., 1987), The result of organic removal indicated that duckweed provided additional surfaces for bacterial growth, additional oxygen supply and 5 days HRT period was sufficient to biodegrade the organic content.

3.4 Nutrient removal

Figure 6 shows the concentrations of N and P in influent and effluent. Ammonia-nitrogen was reduced maximum of 76% with an average value of 59% except sample no. 6 (figure 6) where the effluent concentration was found higher than influent. NO3-N reduction was observed in most samples. Average 76.9% removal of phosphorus was observed during this experiment though literature stated that lemnacae family are generally able to absorb 30-50% dissolved phosphorus (Goopy and Murray, 2003). Therefore, the reason of higher absorption of nutrient by duckweed in this study might be the HRT value of 5 days.

The mechanism of nutrient (N and P) removal might be plant uptake by the attached biofilm on duckweed and the walls of the reactor, absorption into clay particles and organic matter, ammonia volatilization, ammonia assimilation into algal biomass, and biological nitrification coupled with denitrification, microbial immobilization into detritus plant tissue, chemical precipitation and sludge removal (Fanta et al. 2016; Iqbal, 1999; Smith & Moelyowati, 2001; Zimmo et al. 2005).

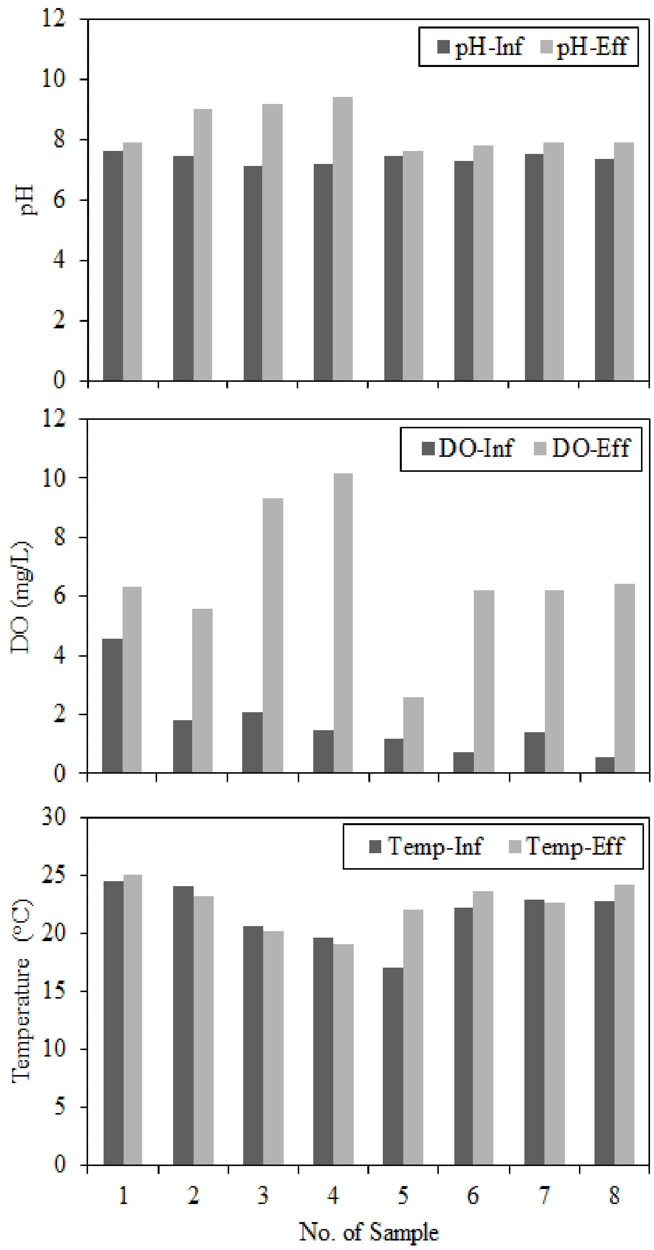

Figure 4: pH, DO and Temperature in influents and effluents.

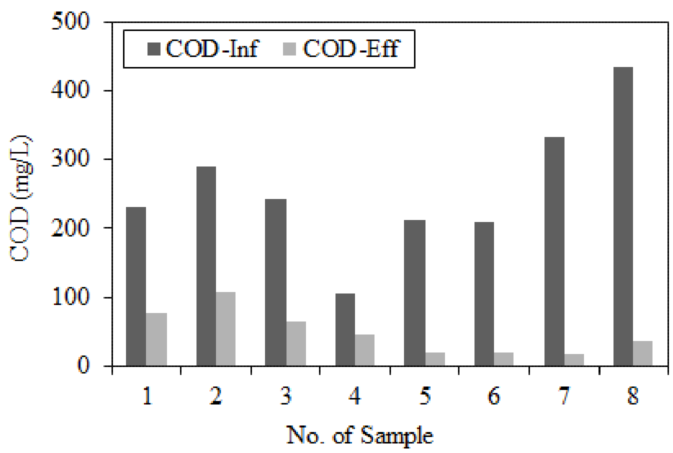

Figure 5: COD concentration in influents and effluents.

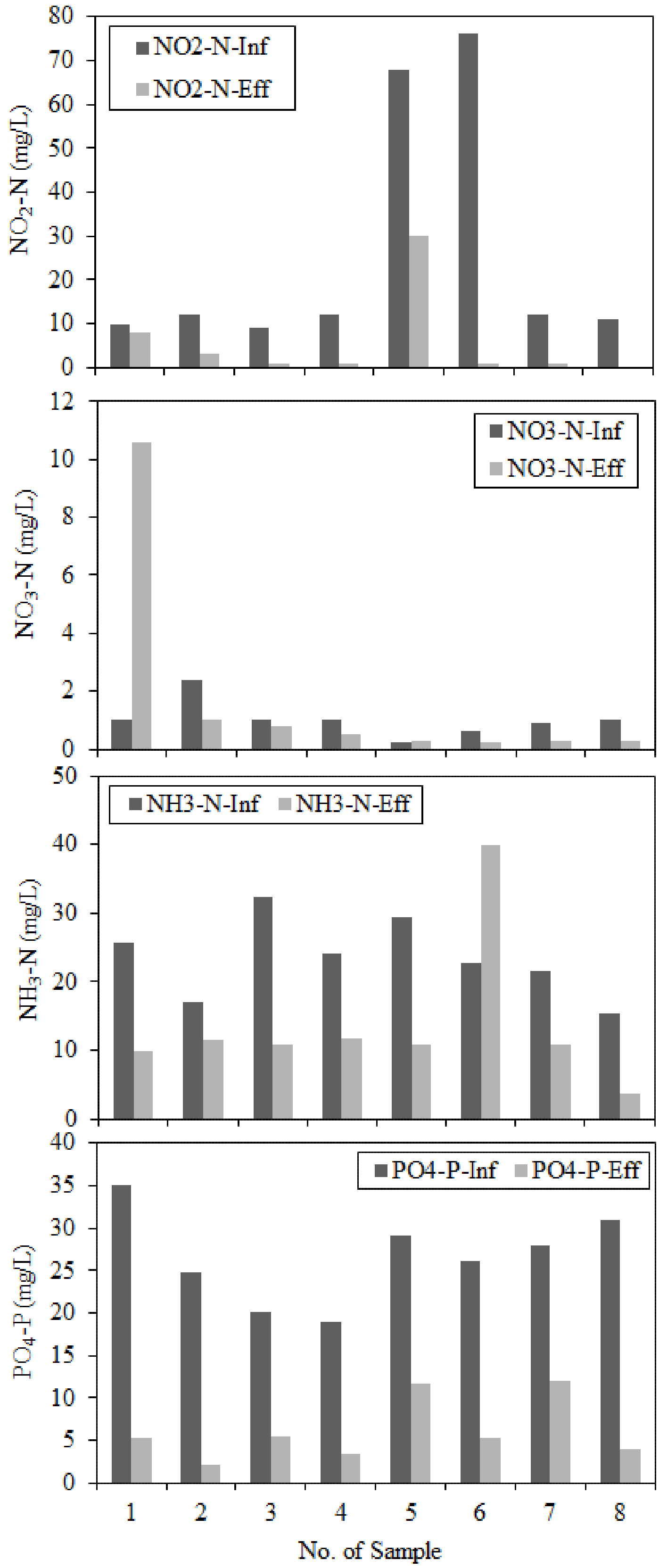

Figure 6: Nitrogen and Phosphorus concentrations in influents and effluents.

3.5 Solids removal

Figure 7 shows the concentrations of Total suspended solids (TSS) and Total dissolved solids (TDS) in influent and effluent. The maximum removal of TSS in this experiment was found 93.8% (sample 3 in figure 7) with an average value of 82.9%. TSS are mainly reduced by: (1) the process of sedimentation; (2) biodegradation of organic matters; (3) absorption of a minor fraction by duckweed roots and (4) inhibition of algal growth due to covering of surface by duckweed mat (Iqbal, 1999). TDS was removed maximum 40.9% (sample 1 in figure 7) with an average removal rate of 17% in this experiment.

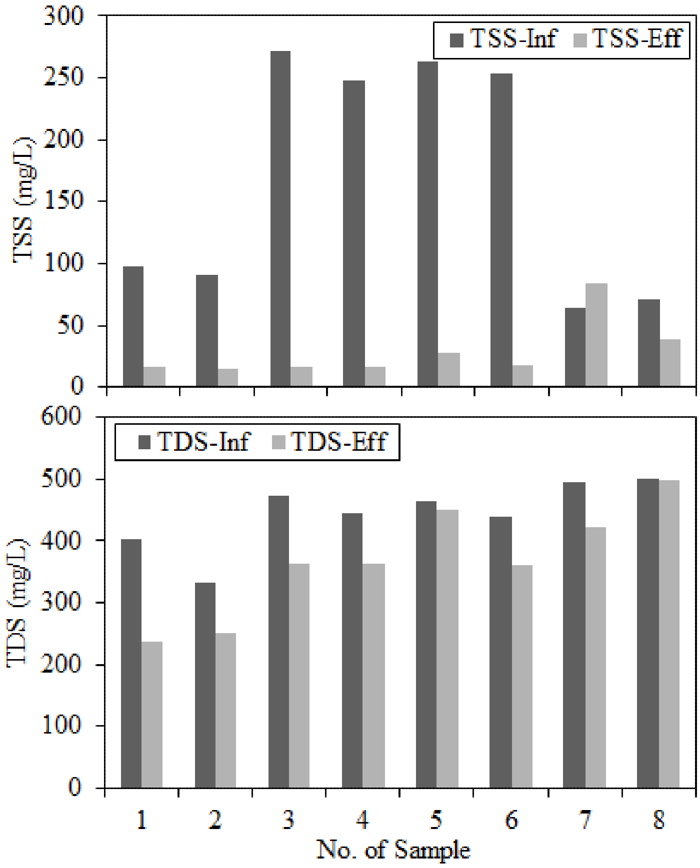

Figure 7: Solids concentration in influents and effluents.

3.6 Fate of used duckweed

Although the fate of duckweed that used in such treatment systems is crucial as it may create further hazards for environment, but in literature several ways of dispose as well as reuse of the duckweed has been stated such as: animal fodder, green fertilizer, source of protein for poultry/fish feeds etc. (Bonomo et al., 1997; Moss, 1999). During this lab-scale study the used duckweed was disposed normally in environment but for pilot scale or full-scale systems the literature stated disposal or reuse processes could be followed.

4. CONCLUSIONS

The present study demonstrated the performance of duckweed based treatment system in removing pollutant from domestic wastewater. In domestic wastewater the average concentrations of pH, DO, TDS, TSS, COD, PO_4-P, NO_3-N, NO_2-N and NH_3-N were found to be 7.4, 1.7 mg/L, 443.3 mg/L, 170.0 mg/L, 257.0 mg/L, 26.6 mg/L, 1.0 mg/L, 26.3 mg/L and 23.6 mg/L respectively. Whereas, in effluent the average concentrations of such parameters were found 8.34, 6.60 mg/L, 367.75 mg/L, 29.13 mg/L, 49.26 mg/L, 6.14 mg/L, 1.75 mg/L, 5.61 mg/L and 13.65 mg/L respectively. Consequently, the system achieved 17%, 82.9%, 80.8%, 76.9% and 42.0% removal efficiencies of TDS, TSS, COD, PO_4-P, and NH_3-N respectively. These results indicate that duckweed based waste stabilization pond system might be cost-effective, energy efficient and environmentally sound technology to treat domestic wastewater in developing countries as decentralized treatment unit.

ACKNOWLEDGEMENTS

This research is conducted in University of Asia Pacific, Dhaka, Bangladesh, with full support of laboratory and finance.

REFERENCES

Alaerts, G. J., Mahbubar-Rahma, M., & Kelderman, P. (1996). Performance Analysis of a Full-Scale Duckweed Covered Lagoon. Water Research, 30, 843–852.

Allam, A., Tawfik, A., Negm, A., Yoshimura, C., & Fleifle, A. (2015). Treatment of Drainage Water Containing Pharmaceuticals Using Duckweed (Lemna gibba). Energy Procedia, 74, 973–980.

Altay, A., Bayhan, H., & Akca, L. (1996). “Nutrient removal efficiency of the natural treatment system utilizing duckweed”. 1st Uludag Environmental Engineering Symposium, Bursa, Iraq.

Bal Krishna, K.C., & Polprasert, C. (2008). An integrated Kinetic model for organic and nutrient removal by duckweed-based wastewater treatment (DUBWAT) system. Ecological Engineering, 34, 243-250.

Boniardi, N., Vatta, G., Rota, R., Nano, G., & Carra, S. (1994). Removal water of water pollutants by Lemna gibba. Chemical Engineering Journal, 54:B41–B48.

Bonomo, L.G., Pastorelli, & Zambon, N. (1997). Advantages and limitations of duckweed based treatment systems. Water Science and Technology, 35(5), 239–246.

Cheng, J., Bergmann, B.A., Classen, J., Stomp, A.M., & Howard, J.W. (2002). Nutrient recovery from swine lagoon water by Spirodela punctata. Bioresource Technology, 81, 81–85.

Cheng, J., & Stomp, A.M. (2009). Growing duckweed to recover nutrients from wastewaters and for production of fuel ethanol and animal feed. Clean -Soil, Air and Water, 37, 17–26.

Crites, R.W., Joe Middlebrooks, J., & Reed, S.C. (2006). “Natural Wastewater Treatment Systems.” CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300 Boca Raton, FL 33487–2742.

Culley, D. D., & Epps, E. A. (1973). Use of duckweed for waste treatment and animal feed. Journal-Water Control and Pollution Federation, 45(2).331–347.

Culley, D., Rejmankova, Jr., Kvet, J., & Frye, J. (1981). Production, Chemical Quality and use of Duckweed (Lemnaceae) in Aquaculture, Waste management, and animal feeds. Journal of World Marine Society, 12(2) 27–49.

EL-Kheir, W.A., Ismail, G., EL-Nour, F.A., Tawfik, T., & Hammad, H. (2007). Assessment of the efficiency of Duckweed (Lemna gibba) in wastewater treatment. International Journal of agriculture and Biology, 5, 681– 687.

Gaur, R.Z., & Suthar, S. (2017). Nutrient scaling of duckweed (Spirodela polyrhiza) biomass in urban wastewater and its utility in anaerobic co-digestion. Process Safety and Environmental Protection, 107, 138–146.

Goopy, J.P., & Murray, P.J. (2003). A review on the role of duckweed in nutrient reclamation and as a source of animal feed. Asian-Australian Journal of Animal Science, 16 (2), 297–305.

Hammouda, O., Gaber, A., & Abdel-Hameed, M.S. (1995). Assessment of the effectiveness of treatment of wastewater-contaminated aquatic systems with Lemna gibba. Enzyme and Microbial Technology, 17, 317–323.

Hillman, W. S., & D. D. Culley. (1978). The Uses of Duckweed. American Science, 66, 442–51.

Iqbal, S. (1999). Duckweed aquaculture: potential, possibilities and limitations for combined wastewater treatment and animal feed production in developing countries. SANDEC Report No. 6/99, Switzerland.

Kocaman, B., Yaganoglu, A.V., & Angin, I. (2007). An investigation on natural wastewater treatment system and re-usability of wastewater in irrigation. Journal of Sustainable Agriculture, 31(2), 83–90.

Korner, S., Vermaat, J.E., & Veenstra, S. (2003). The Capacity of Duckweed to Treat Wastewater: Ecological Considerations for a Sound Design. Journal of Environmental Quality, 32:90–1583.

Landolt, E., & Kandeler, R. (1987). The family of Lemnaceae– a monographic study. Vol. 2. Phytochemistry, physiology, application, bibliography. Veroffentlichungen des Geobotanischen Institutes ETH, Stiftung Rubel, Zurich. 95, 1–638.

Leng, R. A. (1999). Duckweed, A Tiny Aquatic Plant with Enormous Potential for Agriculture and Environment. FAO, Tran Phu Printing Co.

Les, D.H., Crawford, D.J., Landolt, E., Gabel, J.D., & Kimball, R.T. (2002). Phylogeny and systematics of Lemnaceae, the duckweed family. Systematic Botany, 27, 221–240.

Mahmood, Q., Pervez, A., Zeb, B.S., Zaffar, H., Yaqoob, H., Waseem, M., Zahidullah, & Afsheen, S. (2013). Review Article: Natural Treatment Systems as Sustainable Ecotechnologies for the Developing Countries. Hindawi Publishing Corporation, BioMed Research International, Article ID 796373.

Mara, D. (2004). “Domestic Wastewater Treatment in Developing Countries”. 1st edition. Earthscan, UK and USA.

Metcalf and Eddy, (1991). “Wastewater Engineering Treatment, Disposal and Reuse” 3rd edition. McGraw-Hill Inc., New York.

Moss, M.E. (1999). Economics and feed value of integrating duckweed production with a swine operation. A thesis in Animal Science, Graduate Faculty of Texas Tech University.

Muttamara, S. (1996). Wastewater characteristics. Resources, Conservation and Recycling, 16, 145–159.

Nhapi, I., Dalu, J., Ndamba, J., Siebel, M.A., & Gijzen, H. J. (2003). An evaluation of duckweed-based pond systems as an alternative option for decentralized treatment and reuse of wastewater in Zimbabwe. Water Science and Technology, 48 (2), 323–330.

Oron, G., Wildschut, L.R., & Porath, D. (1984). Waste-water recycling by duckweed for protein production and effluent renovation. Water Science Technology, 17, 803–817.

Oron, G., Porath, D., & Wildschut, L.R. (1986). Wastewater treatment and renovation by different duckweed species. Journal of Environmental Engineering, 112 (2), 247–263.

Oron, G., Porath, D., & Jansen, H. (1987). Performance of duckweed species Lemna gibba on municipal waste water for effluent renovation and protein production. Biotechnology and Bioengineering, 29:258–268.

Ozengin, N., & Elmaci, A. (2007). Performance of Duckweed (Lemna minor L.) on different types of wastewater treatment. Journal of Environmental Biology, 28(2) 307-–314.

Pandy, M. (2001). Duckweed Based Wastewater Treatment. Central Pollution Control Board New Delhi Entrepreneur. Invention Intelligence, pp: 9–10.

Selvarani, A.J., Padmavathy, P., Srinivasan, A., & Jawahar, P. (2015). Performance of duckweed (Lemna minor) on different types of wastewater treatment. International Journal of Fisheries and Aquatic Studies, 2(4), 208–212.

Smith, M.D., & Moelyowati, I. (2001). Duckweed based wastewater treatment (DWWT): design guidelines for hot climates. Water Science and Technology, 43 (11), 291–299.

Ujang, Z., and Buckley, C. (2002). Water and wastewater in developing countries: present reality and strategy for the future. Water Science and Technology, 46 (9), 1–9.

Verma, R., & Suthar, S. (2014). Synchronized urban wastewater treatment and biomass production using duckweed Lemnagibba L.. Ecological Engineering, 694, 337–343.

Verstraete, W., Caveye, P.V., & Diamantis, V. (2009). Maximum use of resources presents in domestic used water. Bioresource Technology, 100, 5537–5545.

Von Sperling, M. (1996). Comparison among the most frequently used systems for wastewater treatment in developing countries. Water Science and Technology, 33 (3), 59–62.

Willett, D. (2005). Duckweed-based wastewater treatment systems: Design aspects and integrated reuse options for Queensland conditions. Bribie Island Aquaculture Research Center, Queensland Department of Primary Industries and Fisheries, Australia.

Xu, J., & Shen, G. (2011). Growing duckweed in swine wastewater for nutrient recovery and biomass production. Bioresource Technology, 102, 848–853.

Zekaryas Fanta, Z. (2016). Study of duckweed-based pond system for the treatment of domestic wastewater. Master’s Thesis. School of Chemical and Bio Engineering, Addis Ababa Institute of Technology.

Zimmo, O.R., Steen, P. & Gijzen, H.J. (2005). Effect of organic surface load on process performance of pilot scale algae and duckweed-based waste stabilisation ponds. Journal of Environmental Engineering,131, 587–594.