Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2018, 5(3):95-104**

ISSN: 2394-2630
CODEN(USA): JSERBR

Research Article

Performance of Three Types of Constructed Wetland Systems for Treating Municipal Wastewater

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Abstract A pilot constructed wetland systems project was constructed during 2015 at the University of Basrah, Iraq. These systems are a vertical subsurface flow system (VSSF), a horizontal subsurface flow system (HSSF) and a surface flow system (SF). These systems were planted with *Phragmites australis*, *Typha domingensis* and *Certophyllum demersum* respectively. It had been operated during 2016 as separated systems. The results recorded a total mean of 78.98% of NH4-N removal efficiency with 78.68% by VSSF, 76.04% by HSSF and 82.20 % by SF. This figure reached 90.58% removal of PO4, with 90.29 by VSSF, 90.18% by HSSF and 92.02 by SF. Also high level of total mean removal efficiency of 95.96% of BOD, the results were 97.65% for VSSF, 97.99% for HSSF and 92.25% for SF. The results indicated that the system was highly effective at removing the target pollutants.

Keywords Constructed wetland, Vertical subsurface, Horizontal subsurface, Surface flow

Introduction

Since first developed, constructed wetlands and their significant benefits have been extensively considered and widely utilized for treating wastewater from a variety of sources such as domestic, industrial and mine wastewaters [1, 2]. They have been effectively utilized for treating public wastewater [3]. Also, they have been commonly used to polish the final discharge of wastewater from treatment plants [4].

For many valid reasons, constructed wetlands could be the greatest mechanism for managing final wastewater treatment [5, 6].

Constructed wetlands are now one of the most internationally diffused technologies for the biological, physical and chemical processes that occur in natural wetland.

This paper focuses on a practical attempt to understand and implement some constructed wetland systems for treating waste water in Iraqi's weather conditions.

Materials and Methodology

The constructed wetland station was contained within two parallel lines of three systems - vertical subsurface flow system (VSSF) planted with *Phragmites australis*, a horizontal subsurface flow system (HSSF) planted with *Typha domingensis* and surface flow system (SF) planted with *Certophyllum demersum*. Systems were made from fiber glass with the following dimensions: 300cm length, 120cm width and 100cm high. Also, three PVC lines were used to connect all the systems together figure (1) and figure (2).

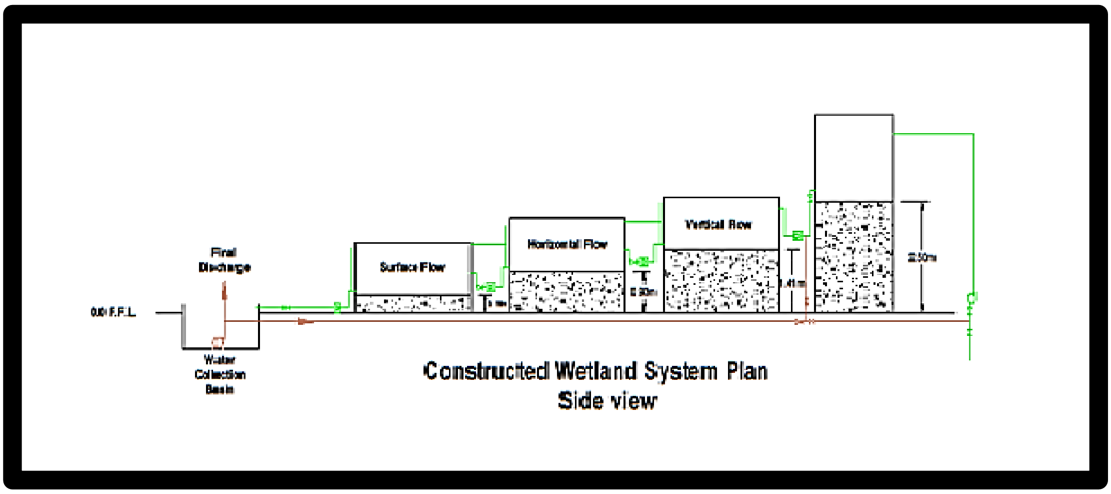

Figure 1: Constructed wetland station (side view)

Figure 2: Constructed wetland systems station at Basrah University

To test the systems separately, specific operation method was conducted, called "stable operation" whereby the systems operated during the first group of experiments during March, April and May. In this method, wastewater feeds into each system and remains for five days. Additionally, two levels of loading rate were used to test the system's volume ability for treating wastewater. These loading rates were 25% and 50% which equal to (162 and 324) L.

Results and Discussion

To evaluate the ability of a constructed wetland systems station in treating wastewater, some important parameters have been measured as the following:

BOD with system type

The results in (figure 3) indicated that the total mean and Std. deviation of BOD for the different systems, namely : HSSF, SF and VSSF were 1.05±0.90, 4.19±3.72 and 1.23±0.94, and these values were 50.71±10.68 for SW and 2.40±0.32 1.23±0.94, for TW. The highest and lowest BOD levels were 11.33 and 0.10 which were recorded on day two at SF and on day three at HSSF respectively. Statistical analysis showed that there were no significant differences in BOD among retention time in day at $P \leq 0.05$. The system type also showed no significant differences, the interaction between Retention Time * system type showed no significant differences at $P \leq 0.05$.

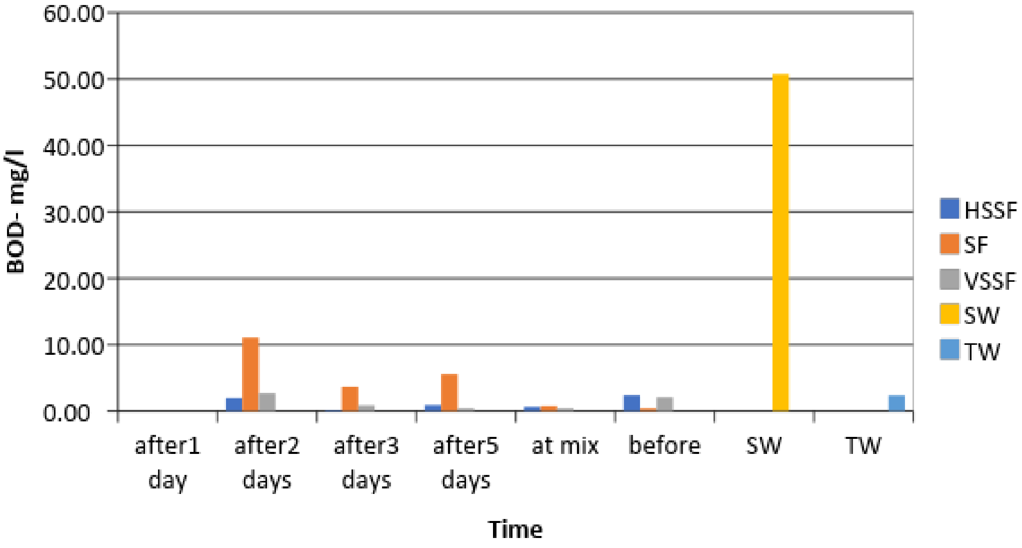

Figure 3: BOD-with type of system in stable operation method.

The removal efficiency of BOD after five days of treatment was 96.38%, while the maximum and minimum removal efficiency was 99.45% and 91.05% respectively. This value reached more than 90% after the second day of treatment. In terms of each system's ability to remove BOD, the results were 97.99% for HSSF, 97.65% for VSSF and 92.25% for SF figure 4 and 5.

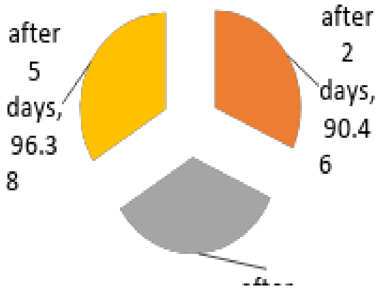

Figure 4: BOD removal efficiency based on number of days

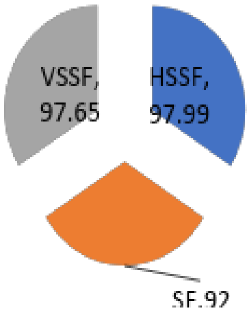

Figure 5: BOD removal efficiency with type of systems.

BOD with loading rate percentage

The results in (figure 6) showed the total mean and Std. deviation of BOD with different loading rate percentages which were 1.74±1.74 for at a 25% loading rate and 2.68±3.47 for at 50% loading rate. These levels were 50.71±10.68 for SW and 2.40±0.32 for TW. The highest BOD value was 11.33, which was recorded within the SF system when the loading rate was 50%, while the lowest BOD level was 0.10 which was recorded within the HSSF system when the loading rate was 25%. Statistical analysis confirmed that there were no significant differences in BOD values between loading rate percentage at P≤0.05.

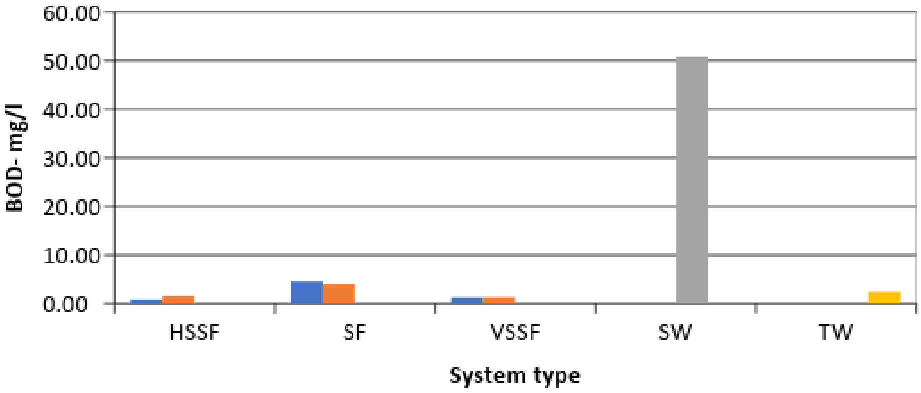

Figure 6: BOD-with the percentage of loading rate in stable operation method

The removal efficiency of BOD with both loading rate were 96.83% and 94.88% when the loading rates were 25% and 50% respectively (figure 7).

Figure 7: BOD removal efficiency with loading rate.

All constructed wetland system showed an excellent capacity to reduce the BOD value to an accepted level in a very short time as clearly seen in figure 3. Generally, the statistical analysis indicated that there were no significant differences among single systems, which is in line with the findings of [7]. Wastewater with BOD above 300 mg/l is considered to be strong, while a BOD of less than 100 mg/l is considered weak. In order to prevent reduction of DO in water bodies, it is necessary to remove oxygen-demanding materials in influent water.

Organic matter could be breakdown by aerobic bacteria which works to utilize oxygen and produce biomass and energy. On the other hand, CH_4 can be produced by anaerobic bacteria [8]. The results of this study achieved high removal efficiencies of 97.65%, 97.99% and 92.25% within the VSSF, VSSF and SF systems respectively as shown in figure 5. The results recorded a high level of BOD removal compared to many other previous studies. It was found by Olson et al. [9] that removal efficiency of BOD was about 87% in integrated system of septic tank flowed by a SF-CW system in Egypt. The average of 10.5-9.9mg/l was the final discharge of BOD after crossing planted beds in the Czech Republic’s HSF-CW system, with an average removal efficiency of about 88% [10]. Also, BOD removal efficiency of 82% was achieved by [11] throughout an average of three years’ treatment using a VSSF-CW system. An example from Pakistan also showed effective BOD removal of about 75% after five days of treatment using a Phragmaties constructed wetland bed [12].

The results give a clear picture showing the ability of these systems to significantly reduce the BOD level regardless of the high percentage of loading rate. In other words, even with a high loading rate of 50%, the results in figure 7 showed that the removal efficiencies were 96.83% when the loading rate was 25%, and this percentage was still very high sitting at about 94.88% when the loading rate was 50%. This means the amount of feeding wastewater can be increased within the system even if it is up to the normal ability of this system for SW. This evidence also could provide a good indicator of constructed wetland systems’ propensity for removing BOD, especially in our environmental circumstances which can reduce the area required to design the constructed wetland system. For example, in China, a study compared seasonal variation of removal efficiency between cold and warm temperatures, where the results showed the following: 92%, 73% and 71% for COD, BOD and NH_4-N at warmer temperatures, while it dropped to 85%, 40% and 20% during cold weather [13].

NH_4-N with system type

The results in (figure 8) illustrate a dramatic drop in the value of NH4-N. The total mean and Std. deviation for each system was 4.20 ± 2.89 for HSSF, 3.54±2.78 for SF and 3.91 ± 2.37 for VSSF. These values were about 19.60±7.41 for SW and 8.40±5.94 for TW. Statistical analysis showed that there were significant differences in NH4-N values among retention time in days at $P \leq 0.05$. There were no significant differences in NH4-N among system type. In addition to that, the interaction between RetentionTime * system type showed no significant differences at $P \leq 0.05$.

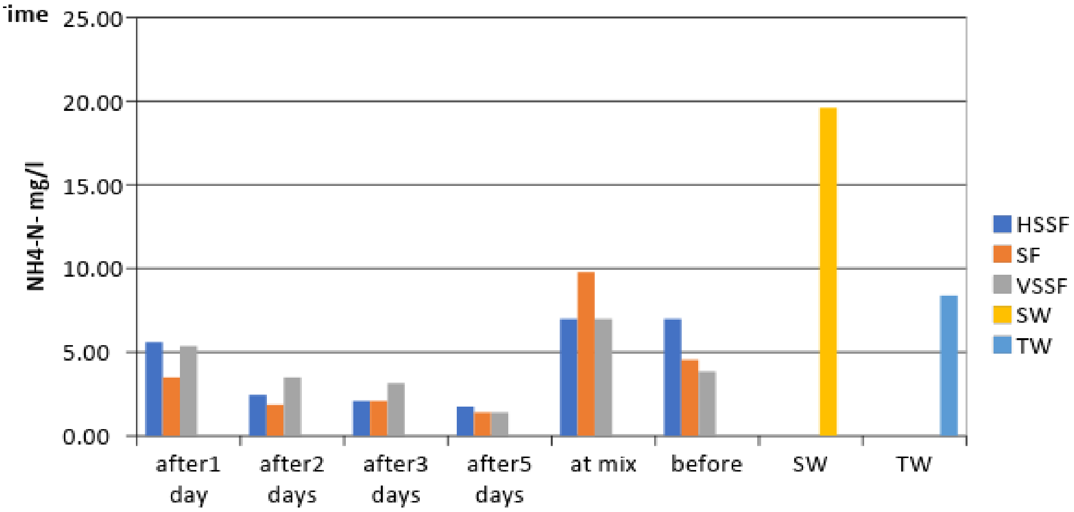

Figure 8: NH_4-N with the type of system in stable operation days.

Removal efficiency of NH_4-N was achieved at about 90.14% after five day of treatment, whereas 87.50% was removed after the second day of treatment. Also the total mean of removal efficiency was 76.04%, 82.20% and 78.68% for HSSF, SF and VSSF respectively (figure 9 and 10).

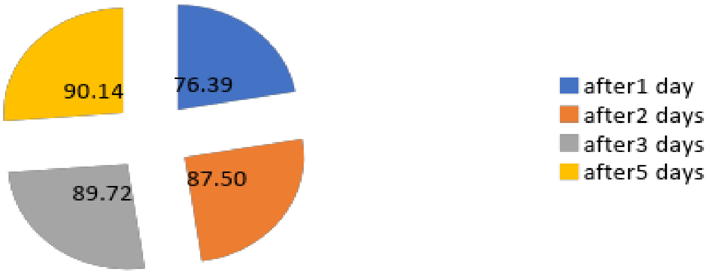

Figure 9: NH_4-N removal efficiency with time in days

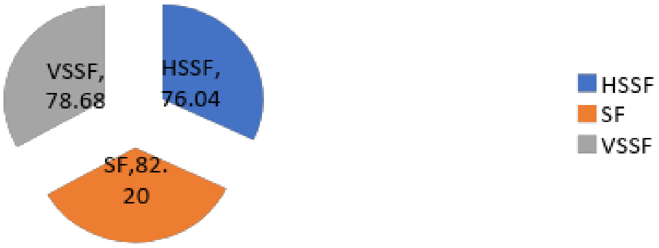

Figure 10: NH_4-N removal efficiency based on systems type

NH_4-N with loading rate

The results in (figure 11) represented the relationship between the loading flow rate percentage and removal of NH_4-N. It shows that there was a high removal percentage of ammonium when the loading flow rate was 25%, and 50%. The totatl mean and Std. deviation were 3.92±2.67 mg/l when the loading rate percentage was 25%, and 2.80 mg/l when the loading rate percentage was 50%. The maximum value was 28 mg/l for SW, while the minimum was 1.40 mg/l which was recorded at HSSF, SF and VSSF when the loading rate percentage was

25%. Statistical analysis confirmed that there were no significant differences in NH_4-N between loading rate percentage at $P \leq 0.05$.

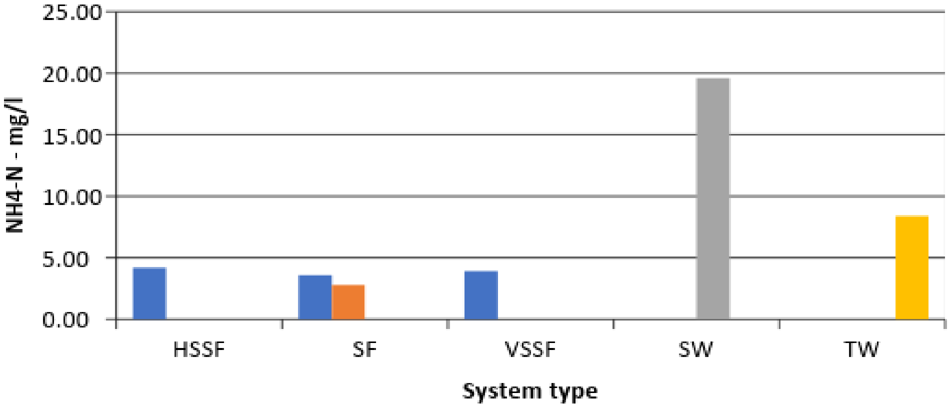

Figure 11: NH_4 with percentage of loading rate in stable operation method

The removal efficiency for both loading rates, which were 25% and 50%, were 77.22% and 98.33% (figure 12).

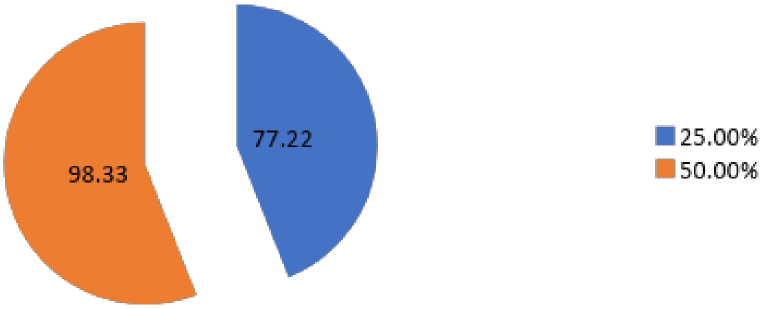

Figure 12: NH_4-N removal efficiency with loading rate.

Figure (8) indicated a gradual decline of NH_4-N with time. On the fifth day, the removal efficiency for all systems reached about 90.14% (9). Valipour and Ahn, 2016 pointed out that microorganisms continue to grow and utlize organic matter and nitorgen with expanded of hydraulic retention time. The system's performance recorded a high removal efficiency within the SF system with about 82.20% flowed by VSSF with about 78.68%. The lowest removal efficiency was recorded within the HSSF system. As a result of its limited capacity to transfer oxygen, HSSF has less ability to oxidize NH_4-N to NO_3-N [14]. In addition, the VSSF system is well-known for its ability to transfer oxygen due to intermittent feeding which adds advantage to this type of system and increases its removal efficiency [15]. It has been reported that the SF constructed wetland systems have had high removal efficiency of organic compounds through settling and biological degradation. Also, some important processes such as nitrification, denitrification and ammonia volatilization take place especially under alkaline circumstances. This high pH is a result of algal photosynthesis decay [16].

The same trend of NH_3-N removal efficiency results (about 96%) have been achieved through using a gravel-based hybrid system constructed wetland to treat wastewater [17]. Also, the performance of Will's Barn vertical flow constructed wetland recorded a high average decline of NH_4-N from about 93.9 mg/l to 10.29 mg/l in effluent treated water [18]. In addition, high removal of TN-N and NH_4-N was observed in the vertical flow system, whereas horizontal flow showed a high removal efficiency of COD compared with VSSF [19]. Moreover, after crossing the two stages of VSSF-CW, NH_4-N sharply decreased from 38mg/l to 7.3mg/l after the first stage and to about 2mg/l after the second stage of the constructed wetland [20].

Aorthou-phosphate with system type

The results in (figure 13) illustrated that orthou-phosphate was declined in all system but in different levels. The total mean and Std. deviation for HSSF, SF and VSSF were as respect 2.39±2.84, 2.02±3.98 and 2.42± 4.27 mg/l respectively. These values were 16.16±14.14 and 1.01±1.23 mg/l for SW and TW respectively. The maximum and minimum values were 26.86 and 0.03 mg/l for SW and VSSF during fifth day respectively.

Statistical analysis confirmed that there were significant differences in orthou-PO_4 between retention time in days at $P \leq 0.05$. However, there were no significant differences in orthou-po4 among system type at the same level. The interaction between system type and months also showed no significant differences in orthou-PO_4 values.

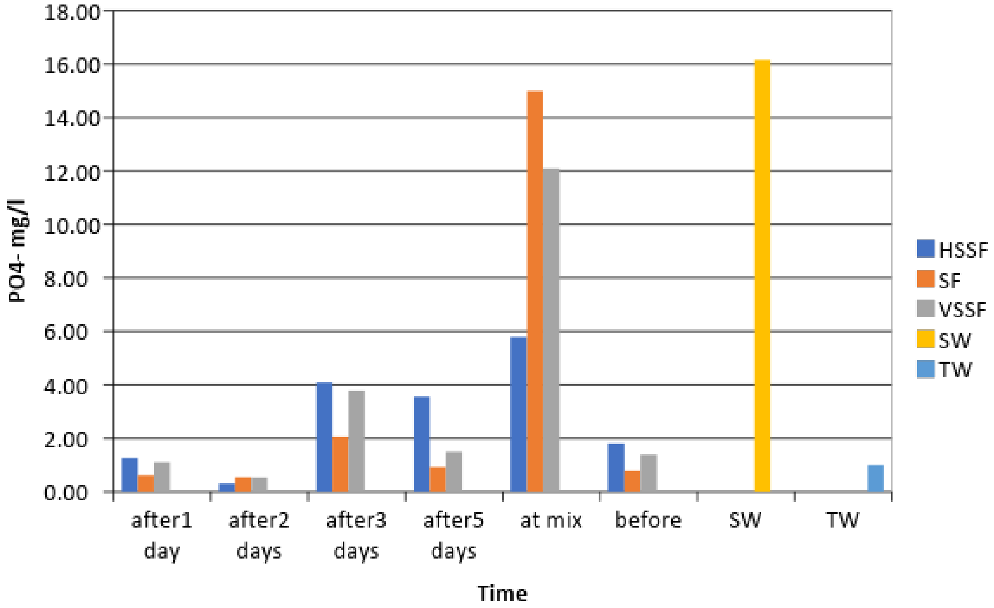

Figure 13: PO_4-with the type of system in stable operation method

Removal efficiency of PO_4 after five days of treatment reached 92.56%. Systems performance of removal efficiency recorded high achievement in SF with high percentage of 92.02 % followed by 90.29% and 90.18% for VSSF and HSSF respectively (figure 14 and 15).

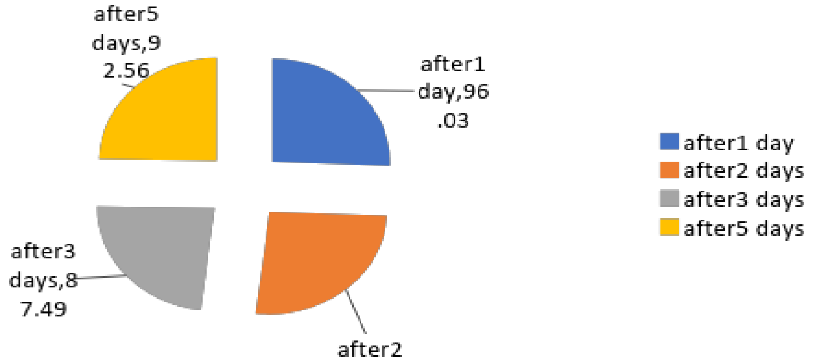

Figure 14: PO_4 removal efficiency with time in days in stable operation

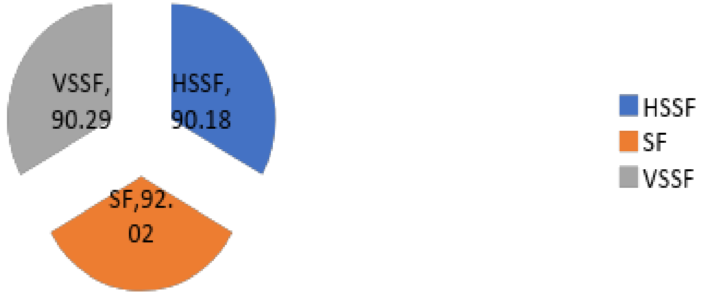

Figure 15: PO_4 removal efficiency with system type in stable operation

Orthou–phosphate with loading rate percentage

The results in (figure 16) showed that all systems removed approximately the same amount of PO_4 during the feeding systems with 25% loading flow rate of sewage water. Also, SF removed high amount of PO_4 even the loading rate was 50% other systems (including HSSF and VSSF) were not tasted with 50% of loading rate. The total mean and Std. deviation of ortho-PO_4 for both loading rate percentage 25% and 50% were 2.38±3.82 and 0.87±0.30 mg/l respectively. The highest and lowest points recorded were 26.86 and 0.03 mg/l which were measured in SW and VSSF when the loading rate was 25%. Statistical analysis showed that there were no significant differences in orthou-PO_4 between loading rate percentage at $P \leq 0.05$.

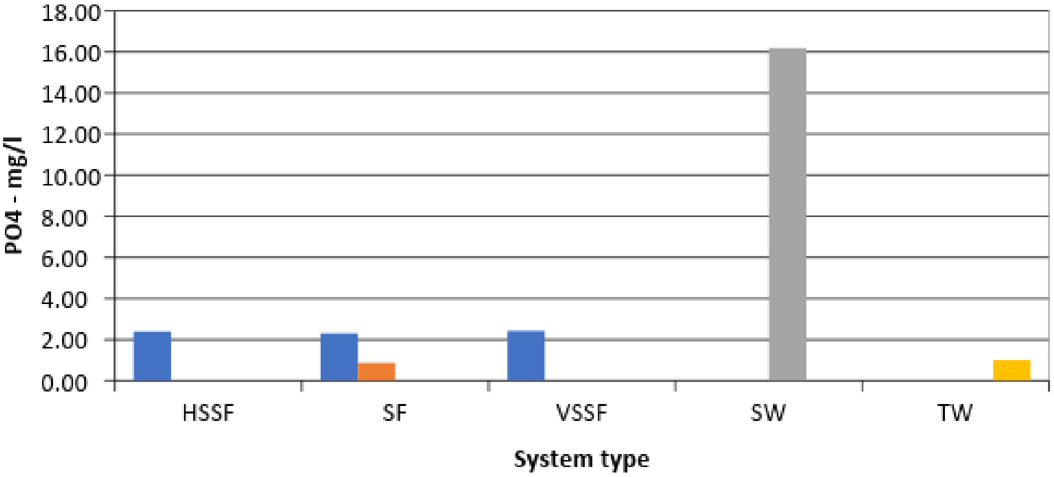

Figure 16: PO_4-with the percentage of loading rate in stable operation method.

High removal efficiency of PO_4 were achieved with both loading rate as the removal efficiency was 90.48% when the loading rate was 25 % and the results were much better when the loading rate was 50% as it reached about 95.87%; however, this result include measuring of PO_4 for SF system only (figure 17).

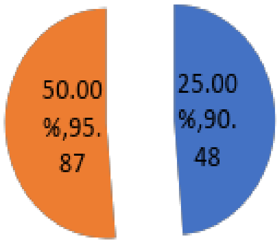

Figure 17: PO_4 removal efficiency with loading rate in stable operation

Results of this study achieved excellent results compared to many previous studies conducted in order to evaluate PO_4 removal efficiency of constructed wetlands (figure 13 and figure 14). While sewage water had a total mean of about 16mg/l of PO_4, this amount is removed to about 0.92, 1.51 and 3.56 in the SF,VSSF and HSSF systems respectively by the fifth day of experimentation. However, a clear decrease of PO_4 was recorded after the first and second days of treatment. Also, it has been noticed that the systems had a similar ability to remove PO_4 with the highest removal percentage achieved by SF, followed by the VSSF and HSSF systems respectively.

PO_4 is removed within a constructed wetland system by several mechanisms including adsorption, precipitation and plant uptake, which is considered temporal storage as the nutrients could be released to the aquatic environment after the plants have decayed [16]. Phosphorus removal efficiency within constructed wetlands, as reported in many previous studies, significantly varied from 6-99%, dependent primarily on wetland design, loading rate and environmental condition [21]. As an example, the reduction of phosphorus was about 66% in a lab-scale of constructed wetland [22].

The results of removing PO_4 within the SF system with that level of loading rate was higher compared with a 25% loading rate. As shown in figure (17), removal efficiency reached around 95.87% with a loading rate of 50%, whereas the removal efficiency of PO_4 was 90.48% when the loading rate was 25%. A possible reason for this is the high growth of plant *Certophyllum demersum* within the SF system which could take more po4 for its growth.

Conclusion

Overall it can be clearly indicated that, implementation of constructed wetland systems could be a valid solution for treating wastewater as all systems (VSSF, HSSF and SF) which have been implemented at this experiment showed an excellent result in order to remove a high percentage of the target pollutants.

References

[1]. Bialowiec, A., et al., *The influence of plants on nitrogen removal from landfill leachate in discontinuous batch shallow constructed wetland with recirculating subsurface horizontal flow.* Ecological engineering, 2012. 40: p. 44-52.

[2]. Du, C., et al., *Research progress on application of constructed wetland in wastewater treatment in China.* Agricultural Science and Technology, 2014. 15(2): p. 310.

[3]. Chen[a, b.,] Y., et al., *Effects of plant biomass on bacterial community structure in constructed wetlands used for tertiary wastewater treatment.* Ecological engineering, 2015. 84: p. 38-45.

[4]. Chen, Y., et al., *Effects of cattail biomass on sulfate removal and carbon sources competition in subsurface-flow constructed wetlands treating secondary effluent.* Water research, 2014. 59: p. 1-10.

[5]. Kadlec and S.D. Wallace, *Treatment wetlands 2nd edition*. 2nd edition ed. 2009, Boca Raton, Florida: CRC Press.

[6]. Iridra, S. *wetland for water pollution control*. 2013 [cited 2016 19/10/2016].

[7]. Vymazal, J. and L. Kröpfelová, *Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow*. 2008, Czech Republic: Springer Science and Business Media B. V.

[8]. Lindeburg, M.R., *Chemical Engineering Reference Manual for the PE Exam*. 2012: www. ppi2pass. com.

[9]. Olson, J.J., et al., *Biodegradation rates of separated diesel components.* Environmental toxicology and chemistry, 1999. 18(11): p. 2448-2453.

[10]. Vymazal, J., *Constructed wetlands for wastewater treatment.* Water, 2010. 2(3): p. 530-549.

[11]. Stefanakis, A.I. and V.A. Tsihrintzis, *Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of pilot-scale vertical flow constructed wetlands.* Chemical Engineering Journal, 2012. 181: p. 416-430.

[12]. Haydar, S., et al., *Proposed model for wastewater treatment in Lahore using constructed wetlands.* Journal of Faculty of Engineering & Technology, 2015. 22(1): p. 9-19.

[13]. Peng, J.-F., B.-Z. Wang, and L. Wang, *Multi-stage ponds-wetlands ecosystem for effective wastewater treatment.* Journal of Zhejiang University. Science. B, 2005. 6(5): p. 346.

[14]. Vymazal, J., *Types of constructed wetlands for wastewater treatment: their potential for nutrient removal.* Transformations of nutrients in natural and constructed wetlands, 2001: p. 1-93.

[15]. Cooper, P., M. Smith, and H. Maynard, *The design and performance of a nitrifying vertical flow reed bed treatment system.* Water Science and Technology, 1996. 35: p. 5.

[16]. Kadlec, R.H. and S.D. Wallace, *Treatment wetlands*. 2008, Boca Raton, Florida: CRC Press.

[17]. Melián, J.H., et al., *Hybrid constructed wetlands for wastewater treatment and reuse in the Canary Islands.* Ecological engineering, 2010. 36(7): p. 891-899.

[18]. Weedon, C., *Compact vertical flow constructed wetland systems-first two years' performance.* Water Science and Technology, 2003. 48(5): p. 15-23.

[19]. Kantawanichkul[*,] S. and S. Wannasri, *Wastewater treatment performances of horizontal and vertical subsurface flow constructed wetland systems in tropical climate.* Songklanakarin Journal Science Technology, 2013. 35(5): p. 599-603.

[20]. Brix, H., C. Arias, and N. Johansen. *BOD and nitrogen removal from municipal wastewater in an experimental two-stage vertical flow constructed wetland system with recycling*. in *Arusha, Tanzania, 16-19 september 2002*. 2002.

[21]. Valipour, A. and Y.-H. Ahn, *Constructed wetlands as sustainable ecotechnologies in decentralization practices: a review.* Environmental Science and Pollution Research, 2016. 23(1): p. 180-197.

[22]. Zurita, F., J. de Anda, and M.A. Belmont, *Performance of laboratory-scale wetlands planted with tropical ornamental plants to treat domestic wastewater.* Water quality research journal of Canada, 2006. 41(4): p. 410-417.