Available on line at:
http://ijwem.ulm.ac.id/index.php/ijwem

ISSN: 2354-5844 (Print)
ISSN: 2477-5223 (Online)

The Hybrid of Vertical and Horizontal Subsurface Constructed Wetlands for Greywater Treatment

JERY PERMANA[1], ANIE YULISTYORINI[2*], EKO SUWARNO[2]

[1] Environmental Laboratory, Civil Engineering Department, Faculty of Engineering, Universitas Negeri Malang, Malang 65145, Indonesia

[2] Civil Engineering Department, Faculty of Engineering, Universitas Negeri Malang, Malang 65145, Indonesia

ABSTRACT

Greywater is categorized as domestic wastewater with a light pollutant concentration. The discharge of untreated greywater into the environment will decrease environmental quality, especially in water bodies. This study aimed to investigate the performance of the combined vertical and horizontal sub-surface constructed wetlands in removing pollutants and recycling the greywater for a clean water alternative. The greywater sample took from the discharge point of the Rectorate Building of the Universitas Negeri Malang. The water bamboo plant (*Equisetum hyemale*) was used in the experiment. The vertical sub-surface constructed wetlands dimensions were 50 cm in length, 50 cm in width, and 80 cm in height. The horizontal one has dimensions of 50 cm in length, 30 cm in width, and 30 cm in height. The water flowrate was designed to be 30 mL min^{-1} with a residence time of three days. The results showed that the hybrid constructed wetlands could reduce the pollutant concentration to meet the discharge consent. The removal efficiency of TSS, TC, and NH_3 was 78.3%, 75%, and 81.07%, respectively. While the removal efficiency of BOD and TP were 41.3% and 48.87%, respectively. Additionally, the final effluent of greywater treated with the hybrid constructed wetlands meets the national discharge consent for domestic wastewater treatment.

Keywords: *Equisetum hyemale*, sub-surface constructed wetlands, greywater

INTRODUCTION

Development of the construction industry has increased in the last few years, especially in constructing high-rise buildings in the cities. High-rise buildings have been built in most cities worldwide in the form of skyscraper buildings (Ferial, 2007). The development of the building acquires facilities including energy, water, and sanitation. Clean water is becoming the basic need of the people who occupy the building, and the water quality should meet the regulation standard. Tall buildings certainly need enormous quantities of clean water, and consequently, the wastewater discharge is very high. Water conservation is essential conduct in the building to maintain water sustainability in the future (Cheng, 2003). Water conservation can be done in various ways, including using multilevel water that should meet the minimum water quality standard. For instance, treated greywater can be used as a water source alternative for flushing toilets and watering plants (Handayani, 2014).

Treated wastewater can be reused as clean water alternatives and applied for domestic usage or building water requirements. Nowadays, much research is conducted to investigate the possibility of treated greywater to reuse in the building for low water quality requirements such as flushing toilet water and gardening. Greywater reuse also shows advantages for an irrigated green roof in implementing sustainable urban farming (Mahmoudi et al., 2021). Greywater is primarily organic material that is degradable, but

Corresponding author: Anie Yulistyorini: Environmental Laboratory, Civil Engineering Department, Faculty of Engineering, Universitas Negeri Malang, Malang (65145), Indonesia, anie.yulistyorini.ft@um.ac.id

-----Accredited by Directorate General of Higher Education Indonesia, No. 158/E/KPT/2021, Valid until July 2025----

ISSN: 2354-5844 (Print)
ISSN: 2477-5223 (Online)

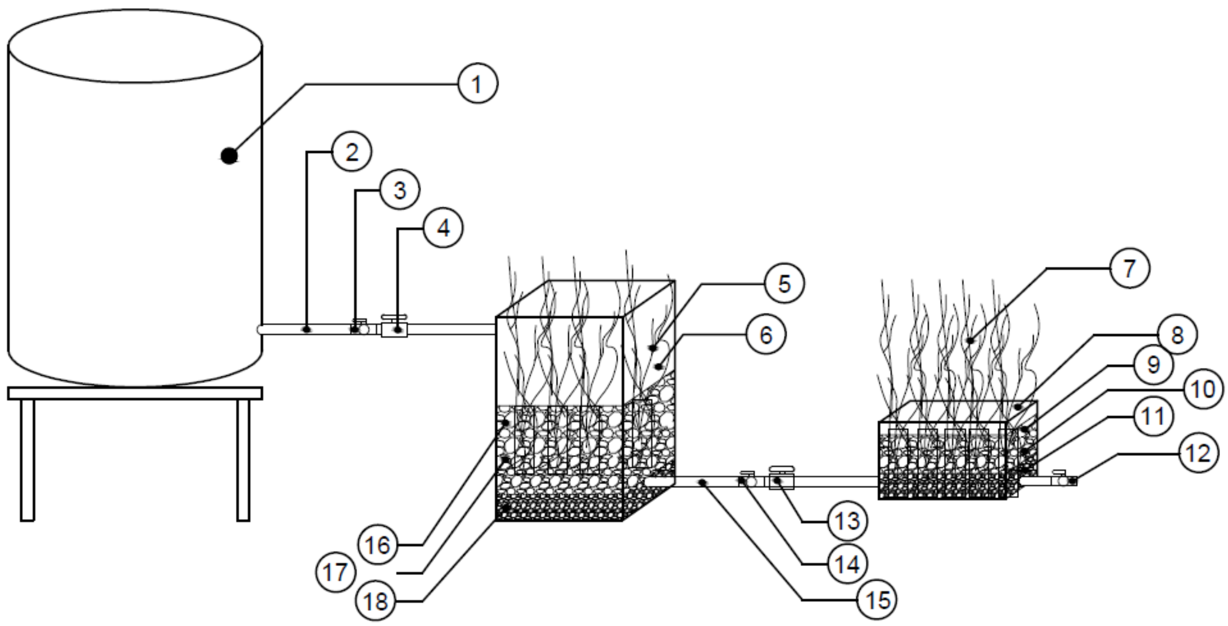
its quantity tends to increase in line with the population growth (Hartono, 2014). Consequently, the volume of greywater in Indonesia is enormously high because of the limitation of municipal wastewater treatment facilities. Constructed wetland is a nature-based wastewater treatment technology suitable for implementation in Indonesia. The wetland is easy to operate, low-cost, and economically feasible to build, has no need for high technician skills, and is beneficial to the community in dealing with wastewater and pollutant removal mechanisms (Qomariyah et al., 2017, Gunawan et al., 2012).

This study aimed to investigate the hybrid system's performance of vertical and horizontal sub-surface constructed wetlands to remove the organic pollutant and purify the greywater. Treated greywater generated from this research met the discharge consent of domestic wastewater, and therefore it can be reused for non-potable water in the building.

MATERIALS AND METHODS

VSSFCWs and HSSFCWs are filled with gravel diameters of 1-20 mm. Water plants of water bamboo (*Equisetum hyemale*) were used as the main feature in the hybrid CWs. Greywater used in the study was collected from the greywater collection tank resulting from the Graha Rectorate Building at the State University of Malang (UM). A designed flowrate of greywater into the hybrid CWs was 30 mL min^{-1} with a residence time of three days. Greywater parameters used include BOD, TSS, total coliform, DO, total-P, pH, and NH_3.

The vertical sub-surface constructed wetlands dimensions were 50 cm in length, 50 cm in width, and 80 cm in height. The horizontal one has dimensions of 50 cm in length, 30 cm in width, and 30 cm in height. The reactor design used in the experiment was as follows.



1. Equalization tank, 2&15. Connection pipe, 3&12&14. Sampling ports, 4&13. Flowrate adjustment valve, 5&7. Water bamboo (*Equisetum hyemale*), 6. Vertical sub-surface constructed wetlands, 8. Horizontal sub-surface constructed wetlands, 9 & 16. Gravel (Ø 1-10 mm), 10 & 17. Gravel (Ø 10-15 mm), 11 & 18. Gravel (Ø 15-20 mm),

Figure 1. Hybrid constructed wetland reactor design

Figures 1 represent the hybrid CWs in which a gravity force is considered to help the water

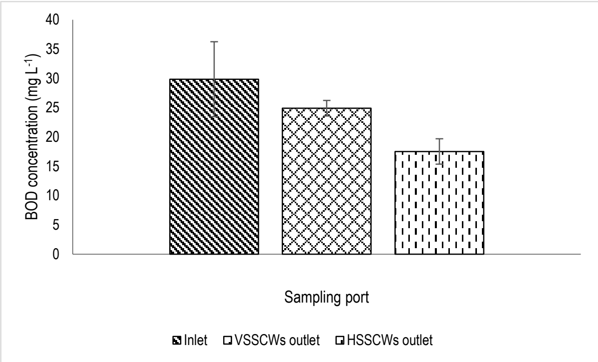
-----Accredited by Directorate General of Higher Education Indonesia, No. 158/E/KPT/2021, Valid until July 2025----

ISSN: 2354-5844 (Print)
ISSN: 2477-5223 (Online)

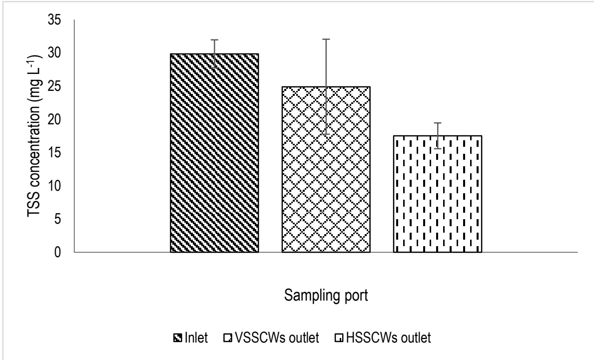
flow into the system. The experiment was carried out for one month, and the sample was collected every three days. The pH measurement was carried out on-site.

RESULTS

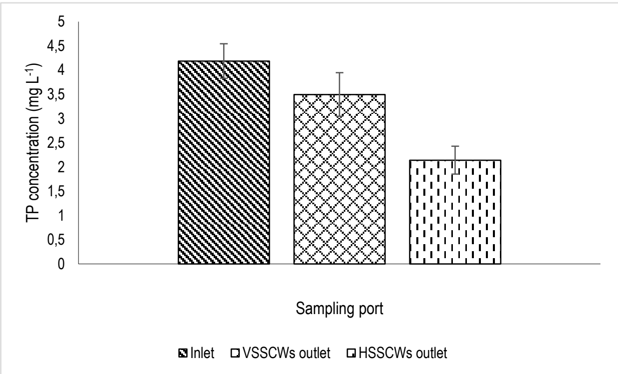
Results of the research on the greywater quality treatment using hybrid constructed wetlands are presented in the following graphs.



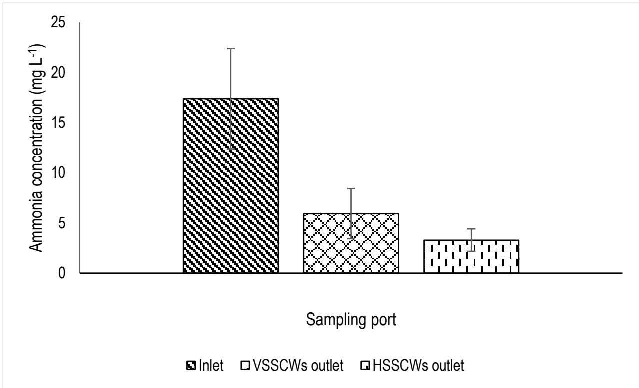
a. BOD



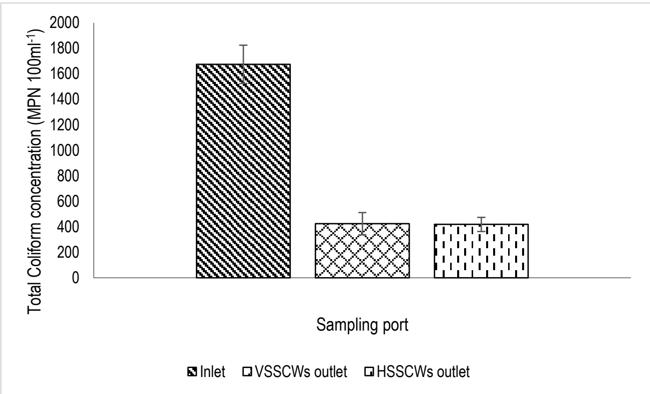
b. TSS



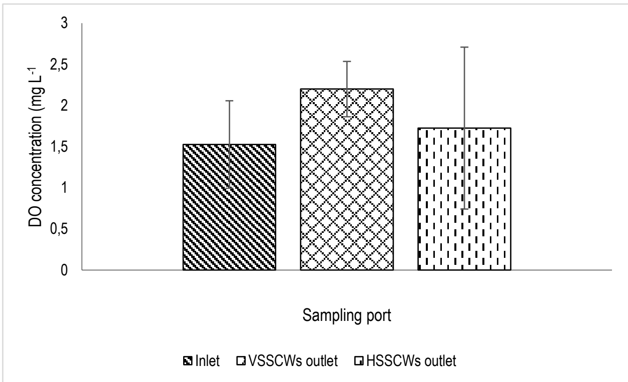
c. TP



d. Ammonia



e. Total coliform



f. DO

Figure 2. Laboratory test results of the greywater parameters.

BOD concentration of the raw greywater was 29.86 mg/l, and it was decreased to 24.9 mg/l and 17.52 mg/l after being treated in vertical and horizontal CWs, respectively. The CWs were able to remove up to 41.3% of greywater BOD (Figure 2a). Removal of suspended solids in the

-----Accredited by Directorate General of Higher Education Indonesia, No. 158/E/KPT/2021, Valid until July 2025----

ISSN: 2354-5844 (Print)
ISSN: 2477-5223 (Online)

hybrid CWs was higher than BOD. A total reduction of 78.3% occurred to remove the TSS from 35 mg/l in the inlet to 7.55 mg/l in the final outlet (Figure 2b). The hybrid CWs also showed high performance in reducing NH_3, where NH_3 concentration can be removed up to 81.07%, while TP was removed up to 48.87% (Figures 2c and 2d). The combination of vertical and horizontal CWs revealed excellent performance in eliminating nutrients from greywater. Moreover, the total coliform reduction is also relatively high at 75%. The concentration of TC reduced from 1675 MPN/100 ml to 418.75 MPN/100 ml (Figure 2e). Additionally, the average dissolved oxygen concentration of the raw greywater was 1.525 mg/l, and it was increased to 2.2 mg/l after being treated in VSFCWs. The oxygen concentration decreased to 1.725 mg/l when the water from the outlet of HSFCWs continued to be treated in HSFCWs (Figure 2f).

DISCUSSION

Bod and TSS Removal

Removal of BOD and TSS showed the same pattern that the decreasing of the pollutant concentration was higher in HSFCWs than VSFCWs. In the CW's organic pollutant are degraded aerobically and anaerobically by microorganisms that grow on plant roots and media surfaces (Vasudevan et al., 2011, Rani et al., 2011). Aerobic degradation of organic matter mainly occurs in VSFCWs and anaerobic in HSFCWs (Dotro et al., 2017). The increase in the anaerobic process is also supported by higher dissolved oxygen in the vertical wetland, as shown in Figure 2f. Anaerobic degradation occurs because dissolved oxygen concentration in the filter bed is very limited (Vymazal and Kröpfelová, 2008a) and, in this research, was lower than 3 mg/l.

Moreover, particulate organic matter will be more accumulated in the subsurface flow wetlands (Dotro et al., 2017), and therefore it may help for BOD concentration reduction. The TSS is primarily retained in the CWs through filtration and sedimentation process, and usually, the removal of the solids particle is generally very high (Vymazal and Kröpfelová, 2008b). Total removal in this hybrid system was 78%, making the final effluent meet the discharge consent. Treatment wetland with a sub-surface system produces effluent with a high removal efficiency of BOD, TSS, and pathogens (Suswati et al., 2012).

Nutrient Removal

Nutrient removal in constructed wetlands commonly occurs through plant uptake and export through plant biomass harvesting (Dotro et al., 2017). The vertical wetland often treats domestic wastewater, especially when ammonia becomes the principal discharge limit (Vymazal, 2010). Vertical flow constructed wetland provides aerobic conditions, and the oxygen availability will enhance the nitrification process in which ammonia will be converted into nitrate (Parde et al., 2021). In this research, ammonia removal in the vertical wetland was 66%, followed by further removal of 45% in the horizontal wetland. This research's removal of nitrogen through nitrification and denitrification process reached 81% in total because the pH condition during the experiment ranged from 7.1 to 7.5. It was categorized as a normal condition.

Furthermore, removing phosphorus in the vertical wetland is considered low, with a 6.5% reduction in this research. But, after being treated through horizontal wetland, the final reduction reached 49%. Phosphorus removal can be achieved through adsorption, precipitation, and plant uptake (Dotro et al., 2017). The phosphorus reduction in the constructed wetland will be

ISSN: 2354-5844 (Print)
ISSN: 2477-5223 (Online)

achieved by using high sorption media (Vymazal and Kröpfelová, 2008b).

Total Coliform Removal

Removal of pathogen bacteria (e.g., fecal coliform) in CWs occurs through a physical, chemical, and biological process. The physical removal process consists of mechanical filtration, sedimentation, and sorption into organic matter and the CWs matrix (Wu et al., 2016). Chemical reduction of pathogens occurs via oxidation and exposure to biocide excreted by the CWs plants. The biological removal is led by the antimicrobial activity of root exudates (Axelrood et al., 1996) or pathogen retention in biofilms (Brix, 1997). In this research, the suspended solids removal was 78%, and it predicted that pathogen bacteria remove through sedimentation in CWs. Also, the total coliform concentration decreased from 1675 MPN/100 ml to 425 MPN/100 ml due to the rise of dissolved oxygen released by the plant in the vertical wetland (Dotro et al., 2017). The release of oxygen in the root zone will increase bacterial activity and help reduce pathogen concentration.

CONCLUSION

Hybrid constructed wetland planted with *Equisetum hyemale* showed high efficiency in removing TSS, TC, and NH3 with values of 78.3%, 75%, and 81.07%, respectively. BOD and TP removal of the greywater was less than 50%. Low removal of BOD was predicted due to a lower oxygen concentration dissolved in the wetland bed. However, the final concentration of greywater parameters treated using the hybrid wetlands met with the national discharge consent, and it was not harmful to the environment. Additional oxygen is needed to help microorganisms be actively involved in organic matter degradation in future research.

ACKNOWLEDGMENTS

The authors would like to thank Universitas Negeri Malang for providing the funding under PNBN UM 2021 grant No: 5.3.795/UN32.14.1/LT/2021.

REFERENCES

Axelrood, P. E., Clarke, A. M., Radley, R. & Zemcov, S. J. 1996. Douglas-fir root-associated microorganisms with inhibitory activity towards fungal plant pathogens and human bacterial pathogens. *Can J Microbiol*, 42**,** 690-700.

Brix, H. 1997. Do macrophytes play a role in constructed treatment wetlands? *Water Science and Technology*, 35**,** 11-17.

Cheng, C.-L. 2003. Evaluating water conservation measures for Green Building in Taiwan. *Building and Environment*, 38**,** 369-379.

Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O. & Sperling, M. V. 2017. *Treatment Wetlands*, London, UK, IWA Publishing.

Ferial, R. 2007. Bangunan Tinggi dan Lingkungan Kota. *Teknika Penghijauan Lingkungan*, 1**,** 92-97.

Gunawan, Oktiawan, W. & Hadiwidodo, M. 2012. Studi Kemampuan Vertical Sussurface Flow Constructed Wetlands dalam menyisihkan COD, Nitrit, dan Nitrat pada Air Lindi. *Jurnal Presipitasi* 9**,** 84-95.

Handayani, D. S. 2014. Kajian Pustaka Potensi Pemanfaatan Greywatersebagai Air Siram Wc Dan Air Siram Tanaman Di Rumah Tangga. *Jurnal Presipitasi: Media Komunikasi dan Pengembangan Teknik Lingkungan*, 10**,** 41-50.

Hartono, M. B. 2014. *Peran Masyarakat Dan Pemerintah Dalam Pengelolaan Air Limbah*

ISSN: 2354-5844 (Print)
ISSN: 2477-5223 (Online)

Domestik Di Sub Das Gajah Wong. Master Thesis, Universitas Gadjah Mada.

Mahmoudi, A., Mousavi, S. A. & Darvishi, P. 2021. Greywater as a sustainable source for development of green roofs: Characteristics, treatment technologies, reuse, case studies and future developments. *Journal of Environmental Management,* **295,** 112991.

Parde, D., Patwa, A., Shukla, A., Vijay, R., Killedar, D. J. & Kumar, R. 2021. A review of constructed wetland on type, treatment and technology of wastewater. *Environmental Technology & Innovation,* **21,** 101261.

Qomariyah, S., Sobriyah, S., Koosdaryani, K. & Muttaqien, A. Y. 2017. Lahan Basah Buatan Sebagai Pengolah Limbah Cair dan Penyedia Air Non-Konsumsi. *Jurnal Riset Rekayasa Sipil,* **1.**

Rani, S. H. C., Din, M. F. M., Yusof, M. B. M. & Shreeshivadasan. 2011. Overview of Subsurface Constructed Wetlands Application in Tropical Climates. *Univers. J. Environ. Res. Technol,* **1**.

Vasudevan, P., Griffin, P., Warren, A., Thapliyal, A. & Tandon, M. 2011. Localized domestic wastewater treatment: part I - constructed wetlands (an overview). *Journal of Scientific & Industrial Research,* **70,** 583-594.

Vymazal, J. 2010. Constructed Wetlands for Wastewater Treatment. *Water*, **2,** 530-549.

Vymazal, J. & Kröpfelová, L. 2008a. *Is Concentration of Dissolved Oxygen a Good Indicator of Processes in Filtration Beds of Horizontal-flow Constructed Wetlands?,* Dordrecht, The Netherlands, Springer.

Vymazal, J. & Kröpfelová, L. 2008b. *Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow,* Dordrecht, The Netherlands, Springer.

Wu, S., Carvalho, P. N., Müller, J. A., Manoj, V. R. & Dong, R. 2016. Sanitation in constructed wetlands: A review on the removal of human pathogens and fecal indicators. *Science of The Total Environment,* **541,** 8-22.

-----Accredited by Directorate General of Higher Education Indonesia, No. 158/E/KPT/2021, Valid until July 2025----