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Comparison of Vertical and Horizontal Subsurface Constructed Wetland for Water Pollutant Reduction of the Brantas River

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Improving the water quality of the Brantas River can be achieved by implementing nature-based technology by using the Brantas River as a raw water source for clean water. In this research, subsurface flow constructed wetlands, which include vertical subsurface constructed wetlands (VSSFCWs) and horizontal subsurface constructed wetlands (HSSFCWs), are used as a sustainable and low-cost approach to improve water quality. The VSSFCW system is configured with a layer of gravel substrate, *Heliconia psittacorum*, and a layer of activated carbon. The configuration for the HSSFCW system is also similar but without the activated carbon layer. This research aimed to determine the post-treatment water quality using CWs as an eco-garden to reduce pollutants from the Brantas River. Water samples from Dam Kadalpang, Brantas River, were measured at the Environmental Laboratory of the State University of Malang, configuring the reactor with laboratory-sized dimensions. These measurements were made on physicochemical parameters such as pH, dissolved oxygen (DO), temperature, conductivity, salinity, turbidity, total dissolved solids (TDS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). There were four observation points in this research, namely VSSFCW with *Heliconia psittacorum* and control VSSFCW without plants, where both were given an activated carbon layer, as well as HSSFCW with *Heliconia psittacorum* and control HSSFCW without plants. The results of data analysis showed that both CWs systems with plants were able to reduce turbidity up to 99% and BOD with a performance efficiency reaching 89%. Both systems also removed COD with a removal efficiency of 73%. TDS was also reduced in both CWs, although there was no significant difference. Similar results were obtained in conductivity and salinity. The pH, temperature, and DO conditions at each observation point met the quality standards and recommendations of previous studies, which became one of the factors supporting the reduction performance of the VSSFCW system. The pollutant degradation capability of the CWs system shows that it can reduce pollutants in the water and it is suitable for use as raw water in the production of clean water.

Keywords: Brantas river, constructed wetland, *Heliconia psittacorum.*

Introduction

Malang, a city in Indonesia, has experienced a significant population growth (Sudiongko, 2021), establishing settlements along the flood-prone Brantas River, which often turns into slum areas (Wicaksono, 2011). The water quality of the Brantas River is highly influenced by the surrounding area and human activities along its stream. Various sources, including household, industrial, and microplastic waste, contribute to toxic pollutants in the river (Nusantara, 2020).

With a length of 320 kilometres, the Brantas River flows through 14 cities and regencies, supporting a significant portion of East Java's population (Arifin, 2020). It has the potential to serve as an alternative source of clean water to address the issue of water scarcity in Malang, which currently relies on the Wendit Spring (Aminudin, 2017). However, the degradation of water quality in the Brantas River has resulted in detrimental effects, such as the death of aquatic organisms and food chain disruption (Dwi, 2016). Excessive nutrient levels have also caused eutrophication, leading to algae growth and turbid, odorous, and potentially toxic surface water (Rosemary, 2017; Pambudi, 2021). In addition, microplastic pollutants in the river have negative environmental and human health impacts, as they can be transferred through the food chain and cause disruptions in various bodily functions (Wiradarma, 2019; Mardiyana and Kristiningsih, 2020).

To address these challenges, the implementation of wastewater treatment technologies is crucial. One effective method is using constructed wetlands (CWs), which have successfully filtered micropollutants in wastewater (Ávila et al., 2015). CWs not only provide efficient treatment but also the opportunity to create green spaces through the use of plants (Stefanakis, 2019). Furthermore, the presence of plants in CWs systems enhances the aesthetic value of wastewater treatment facilities (Suswati and Wibisono, 2013).

This study aims to compare the performance of two CWs systems, vertical subsurface constructed wetlands (VSSFCWs) and horizontal subsurface constructed wetlands (HSSFCWs), in reducing water pollutants in the Brantas River. The VSSFCW system uses a combination of *Heliconia psittacorum* plants with an activated carbon configuration, while the HSSFCW system only uses *Heliconia psittacorum* plants. The inclusion of activated carbon is intended to optimise the efficiency and effectiveness of treatment by adsorbing micro-pollutants (Luo et al., 2014). Laboratory-scale reactors were used, assuming the wastewater originates from a single household. The performance of the subsurface constructed wetlands (SSFCW) system was evaluated by comparing the water quality of the Brantas River before and after the treatment, demonstrating the potential of ecological design for sustainable wastewater treatment.

Methods

This study aimed to evaluate the performance of two types of constructed wetlands (CWs) – VSSFCW and HSSFCW – in reducing pollutant levels in the water of the Brantas River. The schematic diagram (*Fig. 1*) illustrates the implementation of a standard constructed wetland (CW) system within a river environment. The system begins with water intake from the river, which serves as the CW system's primary water source. The river water flows into the system through an inlet connected to a sluice gate. The sluice gate controls water flow from the river into the CW system. It provides a regulated input of water for the treatment. The river water flows into a sedimentation tank upon entering the CW system. The sedimentation tank facilitates settling suspended solids and heavier particles in the water. This process allows for the removal of sediments and enhances the clarity of the water. After sedimentation, the water is pumped into the CWs for further treatment. After passing through the CWs, the treated water is collected in a chamber. The collecting chamber serves as a temporary storage point for the treated water before it is reused or discharged.

The research was carried out with four CWs tanks, as shown in *Fig. 2*. The sample for this research was analyzed through two laboratories: the Environmental Laboratory, State University of Malang, and the Yogyakarta Health and Calibration Laboratory (BLKK). These measurements covered parameters for pH, temperature, turbidity, dissolved oxygen (DO), conductivity, salinity, total dissolved solids (TDS), BOD, and COD.

Fig. 2 illustrates this system's sequence of constructed wetlands. To ensure homogeneity, a water pump transferred the collected river water to an equalization tank with a capacity of 225 liters and equipped with an agitator. The agitator ensures a uniform condition of the

Fig. 1. *Schematic CWs implementation in river environment*

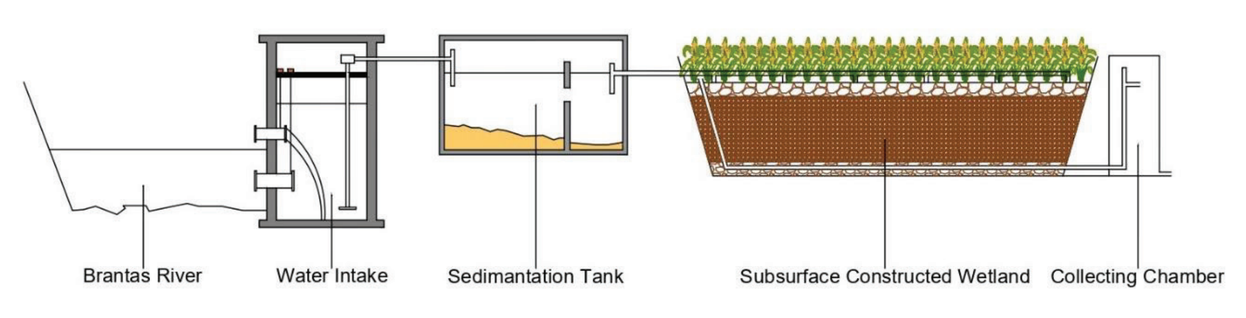
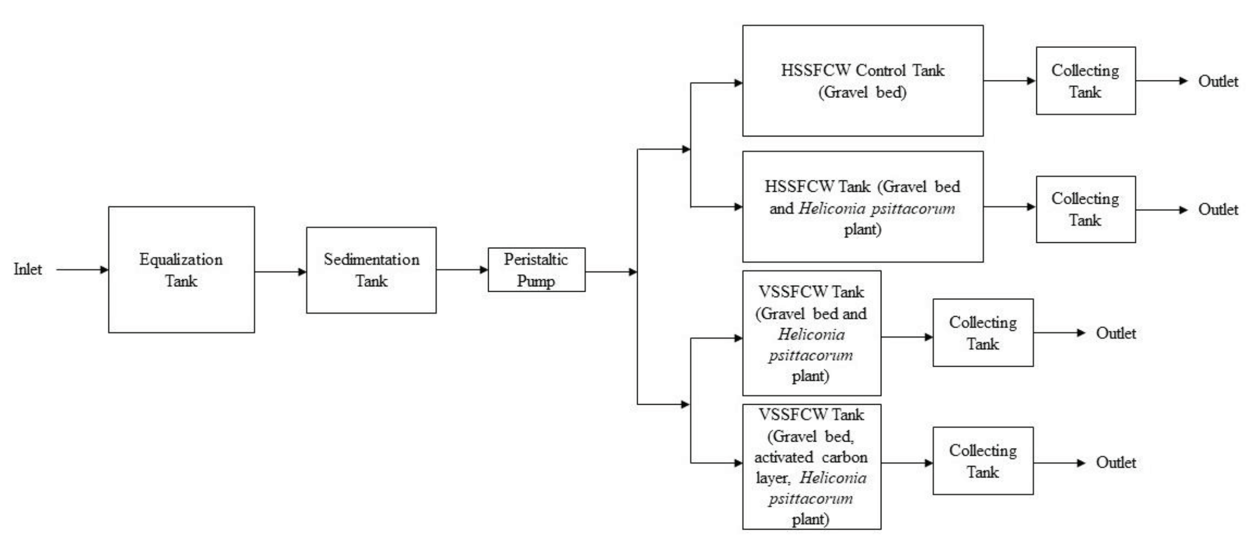


Fig. 2. *Experimental setup scheme*



water taken from the river. The water flows from the reservoir into the sedimentation tank through a 3/4" PVC pipe connected to a 1/2" PVC pipe equipped with a stop faucet. The sedimentation tank was 30 x 60 x 15 cm with an overflow and a hose that directs the water back to the equalization tank, minimizing water waste. The water moves gradually from the sedimentation tank to the CWs using a peristaltic pump and a hose pump with a T-connector. This setup splits the flow from the hose pump into two directions, allowing the water to flow to the CWs system and control. The CWs and control tanks were constructed of 5 mm thick glass, designed based on laboratory-scale dimensions.

Data analysis was conducted using Microsoft Excel to generate a comparative graph showing the means of the different data groups. In addition, SPSS was used to compare the mean differences between the data groups. The generated graphs facilitate a comparison of the average data at the inlet, outlet of VSSFCW, and outlet of HSSFCW. The use of SPSS analysis allows the evaluation of the variations between the average data at the outlet of VSSFCW and HSSFCW, allowing a performance comparison between the two CWs systems. Moreover, efficiency calculations were performed to determine the percentage of performance efficiency for each CWs system using the following formula.

$$\text{Efficiency} = \frac{Influent - Efluent}{Influent} \times 100\% \quad (1)$$

The analytical method used in this research involved conducting a *t* test under the condition that the two groups being compared are unpaired and have a normal distribution. The assessment of the normality of the data is crucial because it serves as a basis for selecting the appropriate *t* test method in SPSS. Furthermore, an additional requirement is the homogeneity of the two groups. If the homogeneity analysis shows that the groups are not homogeneous, the decision is made based on the "Equal variances not assumed" line in the SPSS output.

Results and Discussion

A. Physical comparison and turbidity reduction

The physical comparison between the Brantas River water at the inlet and sedimentation tank showed a little difference. The river water was turbid and had an odour, while the water in the sedimentation tank, which had passed through the equalization tank, was less turbid than the inlet but still had the same odour. In contrast, clean water with no detectable odor was observed at the outlet of each CWs system, as shown in *Figs. 3* and *4*.

The turbidity reduction of the CWs system is shown in *Table 1*. The Regulation of the Minister of Health of the Republic of Indonesia No. 32/2017 on Environmental Health Quality Standards and Water Health Requirements for Sanitary Hygiene states that the maximum turbidity of water intended is 0.5 NTU. The average turbidity of the Brantas River water was observed to be 26.39 NTU. After the treatment, the turbidity can be reduced to 0.33 NTU in VSSFCW and 0.24 in HSSFCW.

According to the SPSS analysis, the significance value (2-tailed) of 0.271 (>0.05) suggests that there is not a notable difference in the performance of turbidity reduction between VSSFCW and HSSFCW. However, the performance of HSSFCW was better in reducing turbidity than VSSFCW. Both CWs could reduce the turbidity, which reaches the efficiency of 99%, and the results showed that the sedimentation process enhances the reduction of particles in both CWs (UN-HABITAT, 2008). This indicates the function of the planting media or bed gravel in filtration, where suspended solids are trapped in the pores between the planting media (Dotro et al., 2017). *Table 1* shows the results of turbidity reduction of the VSSFCW and HSSFCW. Various biological processes, especially microbial-assisted processes, occur in the growth media where the microorganisms attach to the media and the biofilm forms on the surface to assist adsorption processes (Lesikar, 2008).

B. BOD Reduction

BOD concentration reveals the amount of dissolved oxygen required by microorganisms in the biodegradation of organic matter in wastewater (Yulistyorini et al., 2019). The results of the BOD analysis showed that the average BOD concentration at each port of the CWs decreased from the initial BOD of 9.04 mg/L. However, there was a non-significant difference in performance between VSSFCW and HSSFCW. The final BOD concentration of 2 mg/L in the effluent met the standard regulation of Government Regulation No. 82/2001 on Water Quality Management and Water Pollution Control of Classes 1 and 2.

Fig. 3. *Physical comparison of inlet and outlet of vertical subsurface constructed wetland*

Fig. 4. *Physical comparison of inlet and outlet of horizontal subsurface constructed wetland*

Table 1. *Turbidity means comparison of VSSFCW and HSSFCW reactors*

Sampling ports	Turbidity Mean Value (NTU)
Inlet	26.39
VSSFCW	0.33
VSSFCW Control	0.57
HSSFCW	0.24
VSSFCW Control	0.25

Physically, the VSSFCW system reduced organic matter particles through sedimentation and filtration in the planting media or gravel beds (Dotro et al., 2017). The process of organic substance reduction also occurs by plants through the phyto-treatment method, which reduces pollutants through absorption processes by roots, translocation, bioaccumulation, and pollutant degradation processes in the plant body (Ahmad and Haq, 2018). The presence of microorganisms in the system is caused by the growth of a biofilm layer on the surface of the growth media and plant roots which can increase the metabolism of microorganisms (Qin and Chen, 2016). The symbiosis between plant roots and microorganisms takes place with the process of overhauling organic substances by microorganisms into simpler compounds absorbed by plants as nutrients. In contrast, roots will produce oxygen used in the metabolic process of microorganisms (Ningsih, 2017).

C. COD reduction

Laboratory examination of COD in the SSFCWs research showed that both systems have acceptable performance. According to Government Regulation No. 82/2001, the maximum COD concentration which discharges into the Class 2 river is 25 mg/L. The results revealed that the COD concentration in the effluent of both CWs met the standard regulation. The COD reduction result shows that the highest reduction is achieved by the VSSFCW with 73% (*w*). VF wetlands with intermittent loading are highly effective in removing organic carbon due to the highly oxidizing conditions in the filter bed (Dotro et al., 2017). Although the VSSFCW reactor demonstrates superior performance, both systems can reduce COD with no significant difference, as the SPSS *t* test result proved, which showed Sig. (2-tailed) > 0.05.

Fig. 5. *BOD means comparison between VSSFCW and HSSFCW*

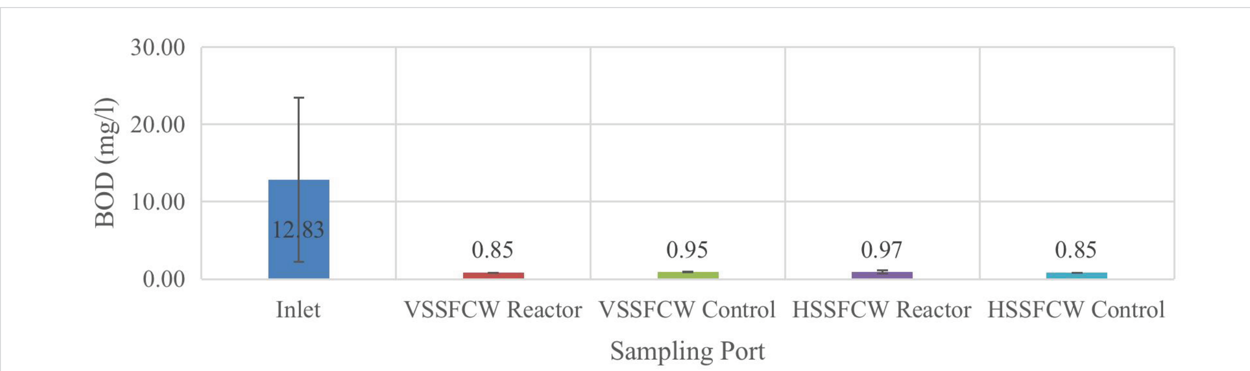
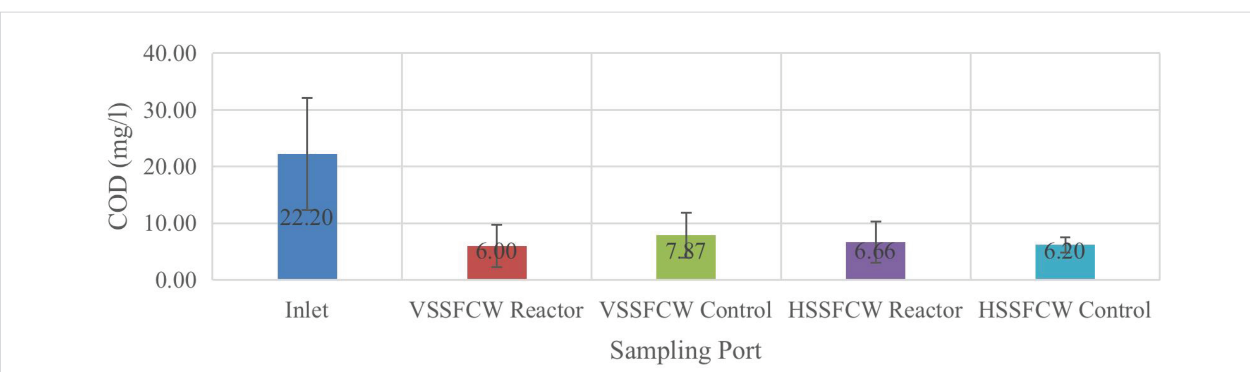


Fig. 6. *COD means comparison between VSSFCW and HSSFCW*



D. Effect of conductivity and salinity on TDS concentration

According to *Figs. 7, 8*, and *9*, it can be seen that the reduction of conductivity and salinity were more significant in the control of the two CW systems. This may have been caused by the decomposition of plants in the CWs, which can trigger the production of nutrients such as magnesium and calcium, which affect the TDS values (Bot and Benites, 2005; Chu, 2018). The evapotranspiration process that occurs in plants selectively causes water evaporation, resulting in the accumulation of salts in the root zone, along with low-quality inlet water conditions that affect the salinity of the CWs (Corwin and Yemoto, 2017). The increase in conductivity due to increased substances such as nitrogen and phosphorus can also occur due to plant decomposition (Sa'eed and Mahmoud, 2014). The higher the salinity concentration, the higher the electrical conductivity, indicating high TDS in the water (Inc.

Fig. 7. *Conductivity means comparison between VSSFCW and HSSFCW*

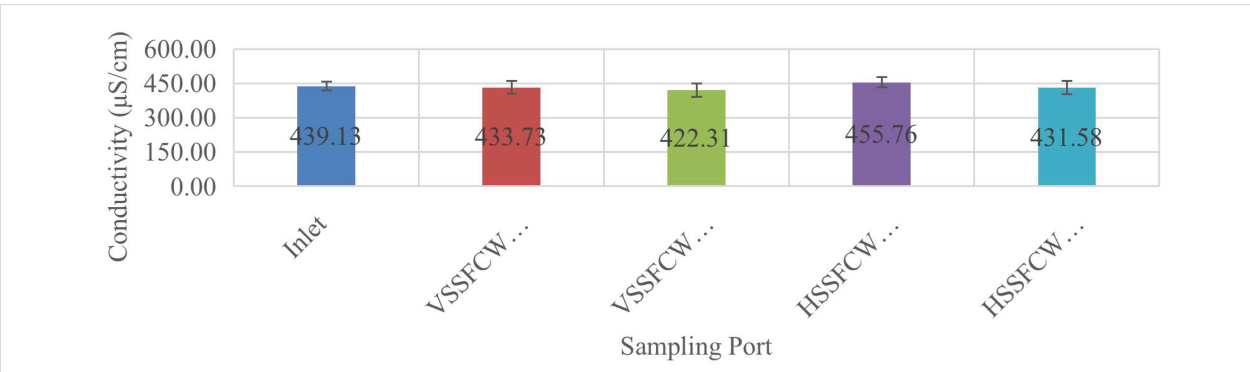


Fig. 8. *Salinity means comparison between VSSFCW and HSSFCW*

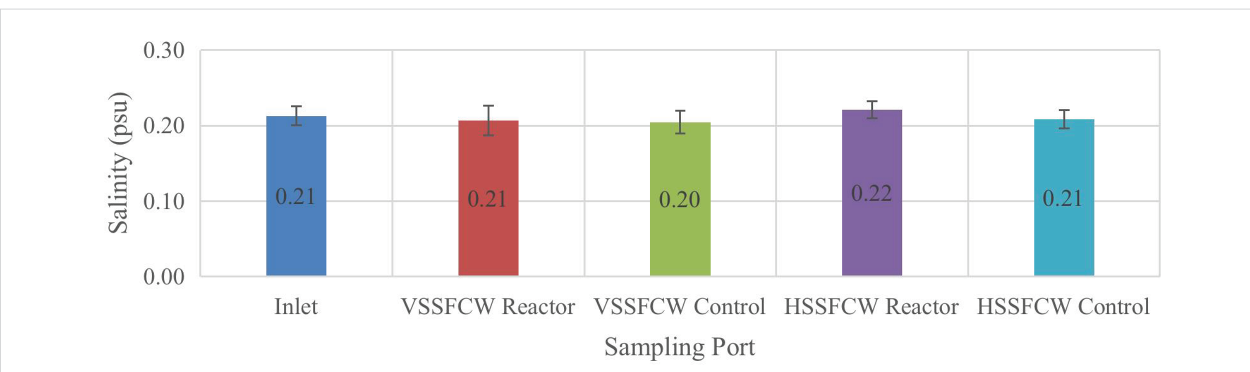
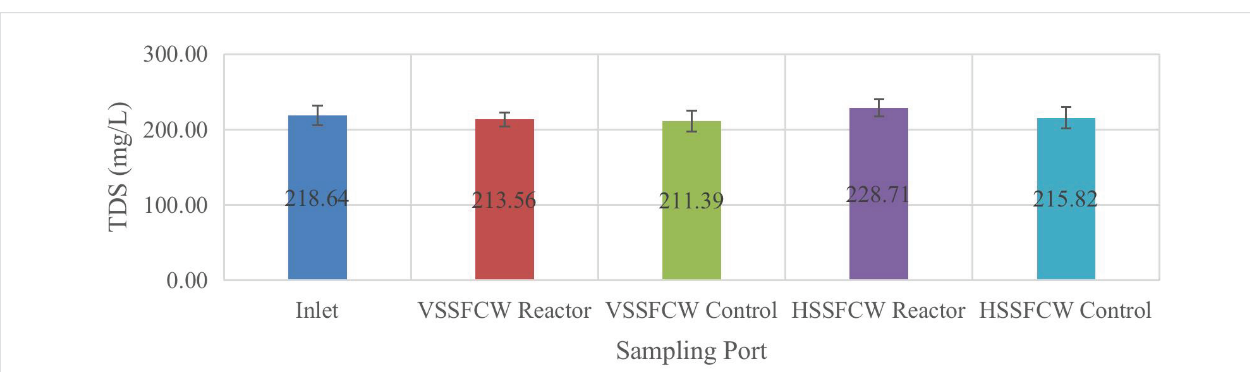


Fig. 9. *TDS means comparison between VSSFCW and HSSFCW*



Fondriest Environmental, 2014). Referring to Government Regulation No. 82/2001, all samples from different sampling ports have a TDS concentration lower than the standard of Class 2, which is below 1000 mg/L.

The SPSS analysis reveals that the significance value (2-tailed) is less than 0.05, indicating a significant difference in the performance of the two systems regarding TDS reduction. This suggests that there is a statistically meaningful variance in the effectiveness of the systems in lowering TDS levels. This is also shown in *Fig. 9*, where the average TDS value of post-treatment water for the VSSFCW is lower than for the HSSFCW.

E. Effect of pH in the CWs

The pH was measured to monitor the optimal aerobic decomposition process of 6, 5–8, and 5 (Padmapriya, Tharian, and Thirunalasundari, 2015). In this research, the pH met these recommendations and affected the performance of pollutant reduction, especially in the aerobic process, such as BOD reduction, which can occur in oxygen-rich root zone (Ningsih, 2017). Plants release bioactive substances that stabilize pH and increase the humic content in water, thereby increasing absorption and precipitation (Shahid et al., 2020). These characteristics cause the VSSFCW to reduce pollutants, such as turbidity reduction, one of which occurs through sedimentation where plant roots can increase the sedimentation ability of the system (Shahid et al., 2020). *Fig. 10* shows the pH of each CW at the recommended value to experience an optimal aerobic decomposition process. Referring to Government Regulation No. 82/2001, the average pH in the effluents of the two CWs systems meets the water quality standards up to Class 1, which ranges from 5–9.

F. Effect of temperature in the CWs

Water temperature affects most of the level of pollutant degradation reactions in the CWs, with warmer temperatures in the tropics allowing for faster biological activity in the system (Dotro et al., 2017). Low temperatures in CWs can adversely affect the system's hydraulic capacity and malfunction of biotic and abiotic components (Varma et al., 2021). The growth of tropical plants such as *Heliconia psittacorum* is hindered by temperatures below 21°C, but higher temperatures can reduce the presence of dissolved oxygen used by organisms to survive (Fondriest Environmental, 2014). Temperatures between 22°C and 30°C are ideal for developing *Heliconia psittacorum*

Fig. 10. *pH means comparison between VSSFCW and HSSFCW*

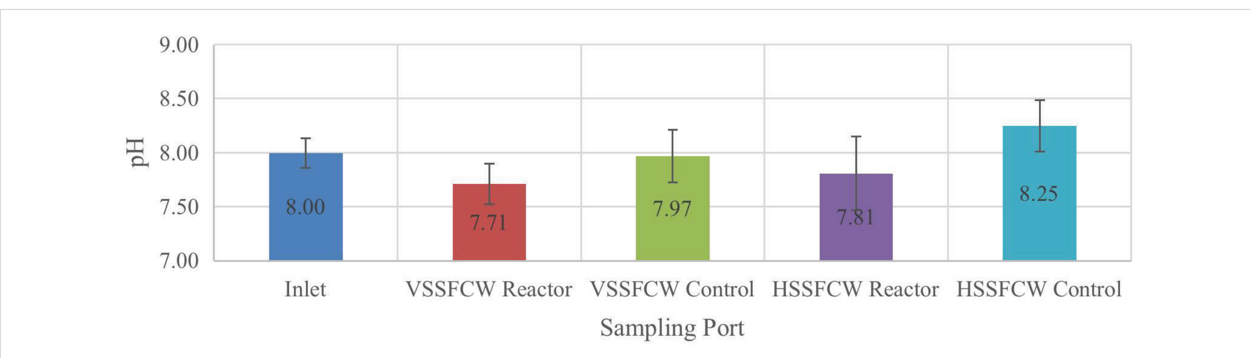


Fig. 11. *Temperature means comparison between VSSFCW and HSSFCW*

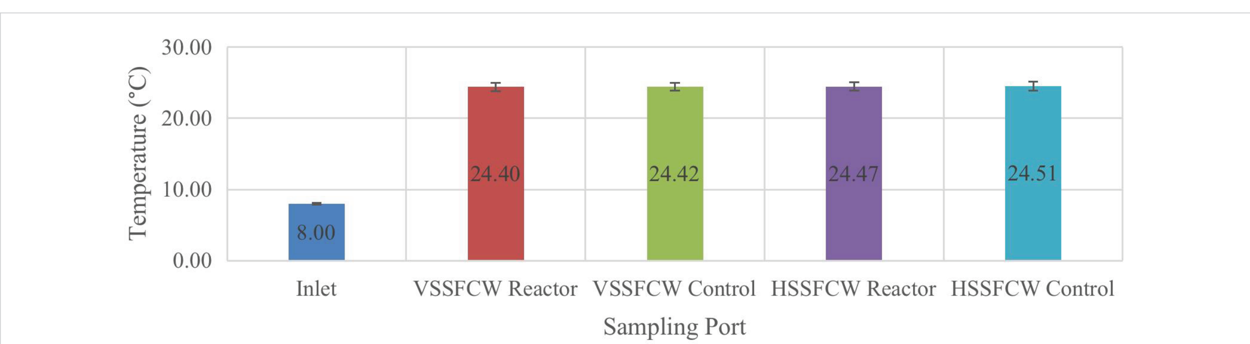
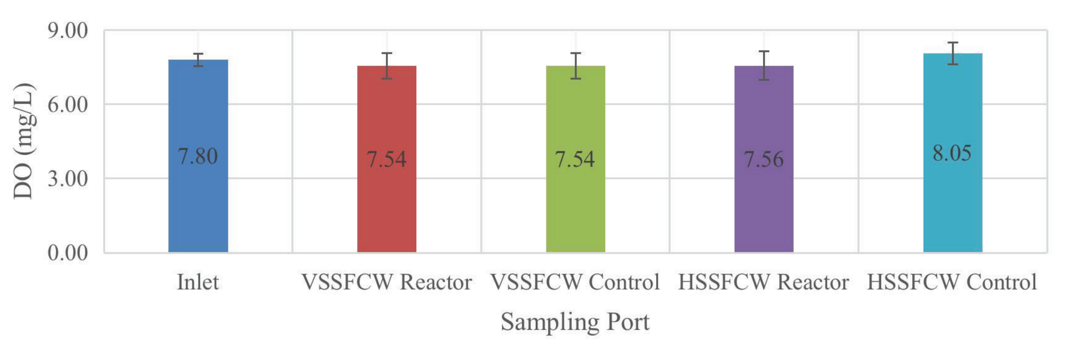


Fig. 12. *DO means comparison between VSSFCW and HSSFCW*



plants (Orejuela et al., 2018). Concerning the various recommended temperature conditions, *Fig. 11* shows the average temperature values in the two CW systems that met the temperature conditions recommended by several previous studies. This can be seen from the growth of *Heliconia psittacorum* in this research, which was optimum, as indicated by the growth of flowers, roots, and new shoots. Referring to Government Regulation No. 82/2001, all samples from each sampling port have a temperature value that meets water quality standards up to Class 1.

G. DO concentration in the CWs

The presence of oxygen in the VSSFCW system can assist pollutant reduction processes (Dotro et al., 2017), as the DO parameter is an important aspect that must be present in the system. The additional oxygen produced by plant roots also increases the oxygen concentration that microorganisms can use (Ahmad and Haq, 2018). The VSSFCW watering system implemented with the intermittent loading method allows oxygen to dissolve into the filter media layer, which triggers the reduction of pollutants, especially for aerobic degradation (Rehman et al., 2017). The impact of this system can be seen in the reduction of BOD due to biological degradation under aerobic conditions. This occurs in the aerobic zone around the plant roots of the wetlands (Dotro et al., 2017). According to Government Regulation No. 82/2001, DO concentrations met Class 1 and 2, which were at least 6 mg/L and 4 mg/L, respectively (*Fig. 12*).

Conclusions

This study shows that Constructed Wetlands (CWs) technology can be used to improve water quality in the Brantas River. The results indicate that VSSFCW and HSSFCW systems effectively reduce organic matter particles and meet Class 1 and 2 water quality standards. The study also shows the potential for CWs systems to be applied for wastewater treatment in tropical regions, but regular maintenance and cleaning are required to ensure better operation. Further research is needed to explore the potential use of CWs technology in various regions and water-related fields. Optimization of the design and operating parameters of CWs systems is required to improve their efficiency and maximize their benefits. Overall, CWs technology is promising as a sustainable and effective solution for water treatment.

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