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Original Research Article

Application of Free Water Surface Constructed Wetland for Reduction of Brantas River Pollutants

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Abstract

Brantas River is a raw clean water sources that flow through Malang City. The Brantas River water is polluted due to discharging of untreated wastewater, causing a decrease in river water quality. According to these problems, exploring water resources through Brantas River water treatment is essential using Free Water Surface Constructed Wetland (FWSCW) which aims to analyze the performance and improve the water quality of the Brantas River using these wetlands. The research was conducted on a laboratory scale with control treatment and FWSCW with aquatic plants such as Pistia stratiotes, Echinodorus palaefolius, and Heliconia psittacorum. The results showed that pH and temperature were stable, with values between 7.63 to 8.53 and 23°C to 27°C. The removal efficiency of FWSCW and control in reducing turbidity was 99.53% and 98.55%, respectively, and TDS reduction was 0.56% and 2.84%, respectively, for control and FWSCW. The water quality has met the 2nd class of the water quality standards based on Government Regulation of the Republic of Indonesia No. 82 of 2001. At the same time, the efficiency of reducing BOD concentration was 89%. The results show that the FWSCW system can be used as a secondary treatment system to produce clean water.

Keywords: Brantas river water; constructed wetland; free water surface

1. Introduction

Malang City, one of the second most prominent cities in East Java after Surabaya, experiences rapid population growth yearly. The population in Malang City is 843,810 million, which means an increase of approximately 0.27 percent compared to the people in 2010. Population growth in Malang City increases the existence of settlements, causing damage to aquatic resources due to the direct disposal of untreated wastewater into surface water (Made et al., 2013). Disposal of untreated sewage into water bodies can cause contamination of surface water, thereby reducing water quality (Hz et al., 2018). Water source is essential because it is one of the basic human needs that must be met the requirement of quantity and quality (Yulistyorini et al., 2021). The Brantas River, which flows for 320 kilometers across 15 cities in East Java Province, including Malang, has been shown to experience quality and quantity degradation both upstream and downstream of the river (Ratih et al., 2015). According to Yetti et al. (2011), BOD and COD concentrations upstream of the Brantas River watershed exceed the maximum threshold to above 12 mg/L and 100 mg/L compared to the amount of BOD and COD concentration from 1997 to 2002. The people on the river banks still use river water for their daily activities, such as bathing, washing, and latrines and disposing of wastewater from household activities (Lusiana et al., 2020). The disposal of sewage into the river will lead to a decrease in water quality (Alfatihah et al., 2022). In addition, river water quality has decreased due to the lack of water quality management in the Brantas River watershed (Latuconsina, 2020).

Further research is needed to determine the feasibility of Brantas River water as an alternative source of clean water that can be achieved through wastewater treatment technology. One of the wastewater treatment technologies that can be applied is the Constructed Wetlands (CWs) method. Applying the CWs wastewater treatment method has proven to be effective in filtering the levels of micropollutants in wastewater (Ávila *et al.*, 2015). CWs is a natural wastewater treatment technology aimed at optimizing natural processes in the environment so that this system is categorized as an environmentally friendly and sustainable wastewater treatment method (Dotro et al., 2017). The advantages of wastewater treatment using this method is due to the potential for CWs to become an alternative to greening through plants to add aesthetics (Suswati et al., 2012). The presence of plants in the wetland system could even reduce the concentrations of BOD, COD, and TSS, with performance efficiencies reaching 95.83%, 95.01%, and 96.09% (Tampubolon et al., 2020). In addition, through the wetland system, it can also remove TDS by 46%, turbidity up to 91%, and maintain a conductivity of 448 S/cm and salinity of 0.2 psu (Comino et al., 2013; Filho et al., 2018). The reasons for choosing this nature-based technology are relatively low operational costs, environmentally friendly, and low maintenance in reducing surface water pollution levels. However, research on applying the FWSCW for Brantas River water treatment for assessing water quality is still limited.

This research was conducted by applying the Free Surface Flow Construction Wetlands (FWSCW) to treat Brantas River water and used a configuration of aquatic plants (such as Pistia stratiotes, Echinodorus palaefolius, and Heliconia psittacorum). Previous research shows that these plants potentially improve water quality and minimize pollutant levels in wastewater with better results (Prasetya et al., 2020). This research aims to determine the quality of Brantas River water after being treated using FWSCW to produce alternative clean water.

2. Methods

The study used a laboratory scale of FWSCW to determine the performance of wetlands in reducing the pollutants of the Brantas River. The FWSCW dimensions were calculated based on Treatment Wetland Book (Dotro et al., 2017). The area of FWSCW was calculated based on Population Equivalent (PE), which describes the specific load of the river water treatment system. The depth of FWSCW was considered from the height of the gravel bed, which consists of four layers. Then the slope of FWSCW is designed to facilitate the drainage system inside the FWSCW. The dimensions of FWSCW were 60 cm × 20 cm at the bottom and 70 cm × 30 cm at the top of FWSCW with a reactor height of 55 cm. Two FWSCWs as control and treatment were used in this study. No plants were used in the control treatment, while *Pistia stratiotes, Echinodorus palaefolius*, and *Heliconia psittacorum* planted the FWSCW for treatment. Plant use aims to provide oxygen for the plant roots and allows an increase of microorganisms in the root area (Matos et al., 2018). The river water was taken from Brantas River at Jl. Major General Panjaitan Dalam, Penanggungan, Malang City. The FWSCW system consists of water storage, an equalization tank, a sedimentation tank, the wetlands (control and treatment), and two effluent tanks (**Figure 1**).

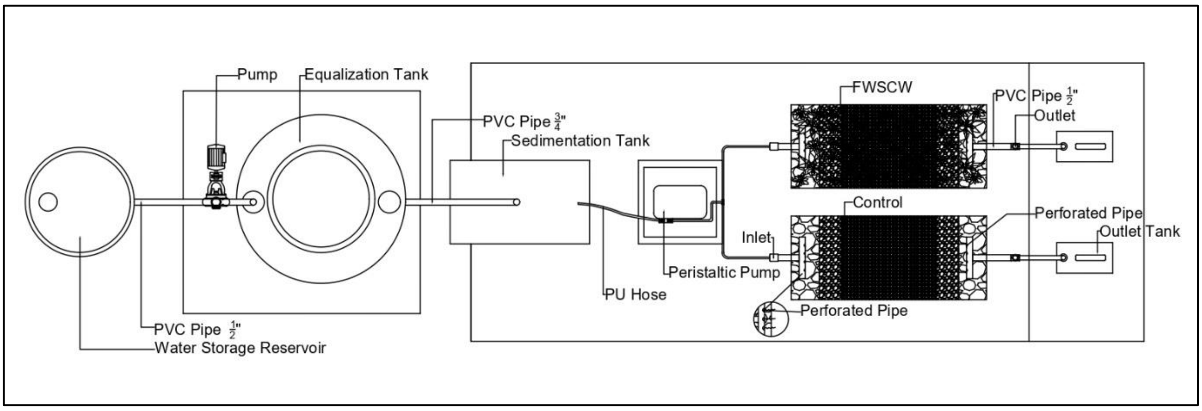

Figure 1. Free water surface constructed wetland configuration

The FWSCW performance was observed by measuring physicochemical parameters in the inlet and outlet such as pH, temperature, dissolved oxygen (DO), turbidity, conductivity, salinity, and total dissolved solids (TDS). BOD was also measured to observe the removal of the organic contaminant. The measurement was conducted in fifteen days with three replicates for each parameter. The water samples were taken from five observation points, as shown in **Table 1.** The sample were analysed in the environmental lab of the Faculty of Engineering at the State University of Malang and the laboratory of testing and calibration, Health Office of DI Yogyakarta.

Table 1. Observation points

No	Observation Point	Label	Description
1	Inlet	IN	Raw water is taken from the Brantas River
2	Sedimentation tank	SD	Water collected from the sedimentation tank
3	FWSCW (reactor)	R	Water collected from the FWSCW
4	FWSCW (control)	K	Water collected from the control
5	FWSCW (reactor-outlet)	OR	Water collected from the FWSCW outlet
6	FWSCW (control outlet)	OK	Water collected from the control

3. Result and Discussion

3.1 Physical Treatment

The turbidity concentration of the Brantas River that was collected from the equalization and sedimentation tank reveal in **Figure 2(a)**. The color of the water was brown with high content of solid substances and had an odor. The water sample taken from the sedimentation tank was less turbid than the raw water from the equalization tank. The turbidity of water decreased significantly after treatment through FWSCW, as shown in **Figure 2 (b)**. Sedimentation of the solid particle has occurred through physical treatment in FWSCW. After the treatment, the turbidity was very low, and no more odor were found in the effluent. The decrease in turbidity indicates that the sedimentation process was working properly along with the FWSCW installation series. The sedimentation process in this study indicated that the function of the planting media or bed gravel in the filtration process was enhanced because the suspended substances were trapped in the pores between the particles of the planting media (Dotro et al., 2017). From physical observations, it can be seen that the FWSCW worked properly in purifying the polluted river water.

(a) (b)

Figure 2. Comparison of Turbidity of the water sample
a) inlet; **b)** sedimentation tank; **c)** outlet of FWSCW; **d)** outlet of control

3.2. FWSCW Performance in Reducing Pollutants

3.2.1. pH

The value of the degree of acidity (pH) shows the acidity or alkalinity of the water (Salim, 2021). Changes in pH affect the growth of microorganisms because most microorganisms cannot tolerate pH levels < 4.0 or pH > 9.5 (Al Kholif et al., 2020). pH value in the FWSCW system is expected to be neutral or close to neutral because, in that condition, the oxygen requirement and production in the plant's root zone for photosynthesis, respiration, and decomposition processes can be optimum.

The pH value is shown in **Figure 3.** It can be seen that there was a decrease during the test in 15 days. The average river water pH at the inlet observation point was 8.00. After the treatment, the pH of the water at the outlet was 7.79, but in control it was an increase to 8.20. The pH of the system may be affected by aerobic and anaerobic microbial respiration, cation exchange and organic acid production (Mayes et al., 2009). From the two observation points, the increase in pH occurred in the Control, indicating that the water was alkaline. While the pH of FWSCW is neutral (pH = 7), it was shown that the performance of the FWSCW is better than the Control. The results of water pH also indicated that the water quality meets the government regulation for the second class of water resources. In the FWSCW, the plants release bioactive substances that stabilize pH and increase the humate content in water, thus increasing absorption and settling (Shahid et al., 2020).

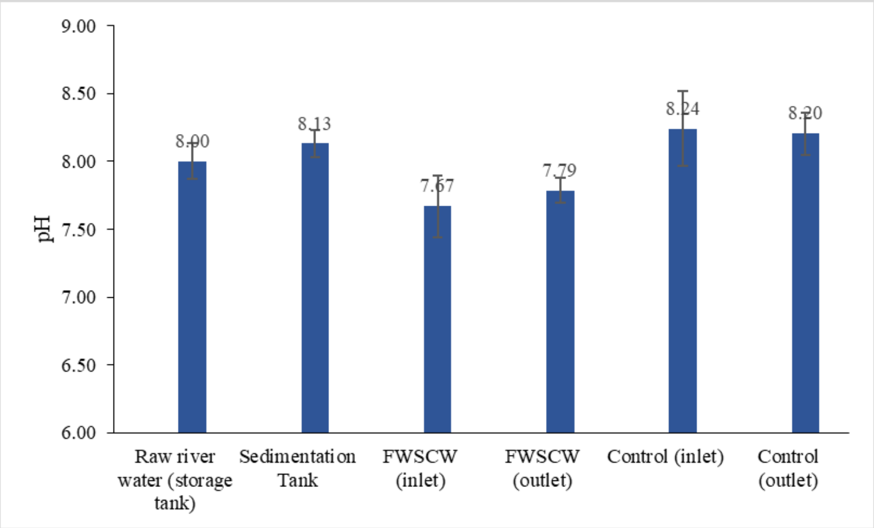

Figure 3. Comparison of average pH measurement

3.2.2. Temperature

The temperature significantly affects plant activity and autotrophic denitrification of the system. The biological activity is lower when the temperature decreases and limits the performance for removing pollutants in the CWs system (Ma et al., 2020). But, an increase in temperature can substantially reduce the solubility of oxygen in water (Katsenovich et al., 2009). Temperature is essential in the development of organisms growth (Bahriyah *et al.*, 2018). The temperature at the FWSCW observation points with the controls ranged from 24°C to 25oC (**Figure 4**) compared to the observation points on the Brantas River.

In the microbial process, the optimum temperature for reproduction ranges from 25°C to 35°C, the temperature values obtained from the test results are still within the optimum temperature range for the growth of microorganisms (Akinbile *et al.*, 2012). Based on to the Government Regulation of the Republic of Indonesia No. 82 of 2001 concerning Water Quality Management and Water Pollution Control, each observation point has a temperature value that meets the second class of water quality standards, namely at a temperature deviation of 3, which ranges from 22°C to 28°C.

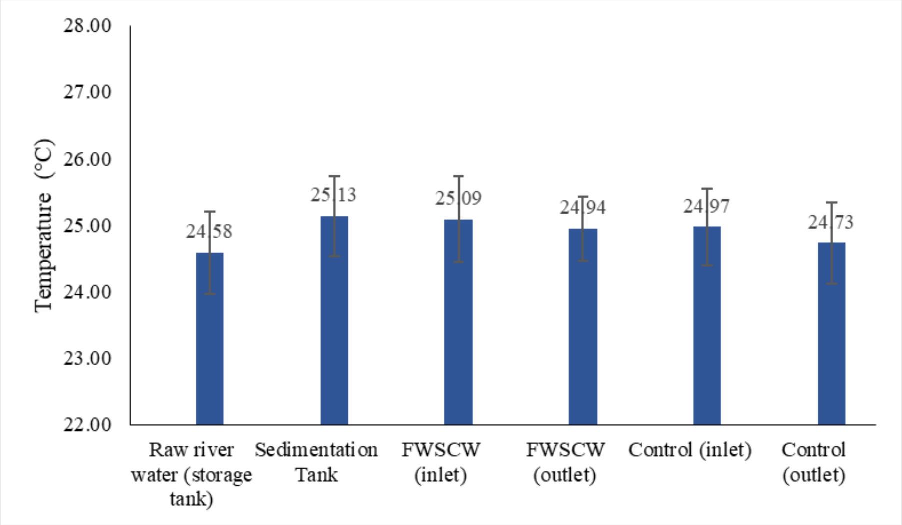

Figure 4. Comparison of average temperature measurement

3.2.3. Dissolved Oxygen

Dissolved oxygen (DO) in water is vital because it plays a role in the oxidation-reduction process of organic and inorganic materials. The previous research stated that temperature dramatically affects the concentration of DO in the aquatic system (Katsenovich et al., 2009). The lower the temperature, the higher the DO concentration in the water. Conversely, DO will decrease if the temperature increase (El-Sheikh et al., 2010). **Figure 5** shows the DO measurement from this experiment**.** The results show that DO reduce at the outlet observation point on FWSCW and control for 7.26 mg/L and 7.31 mg/L, respectively, while the DO concentration of the raw water was 7.82 mg/L. The increase in temperature influences the decrease of DO in the effluent water. The reduction of DO might occur in the system due to consuming oxygen by microorganisms during respiration to stabilize organic matter (Schwantes *et al.*, 2019).

DO concentration of the control effluent was slightly higher than FWSCW, with a difference of 0.05 mg/L. This might be due to the absence of plants in the control and higher solar radiation supporting the development of phytoplankton during the day (Baldovi et al., 2020). Government Regulation of the Republic of Indonesia No. 82 of 2001 concerning Water Quality Management and Water Pollution Control, the concentration in the effluent is still above the second-class water quality standard limit, which is a minimum of 4 mg/L.

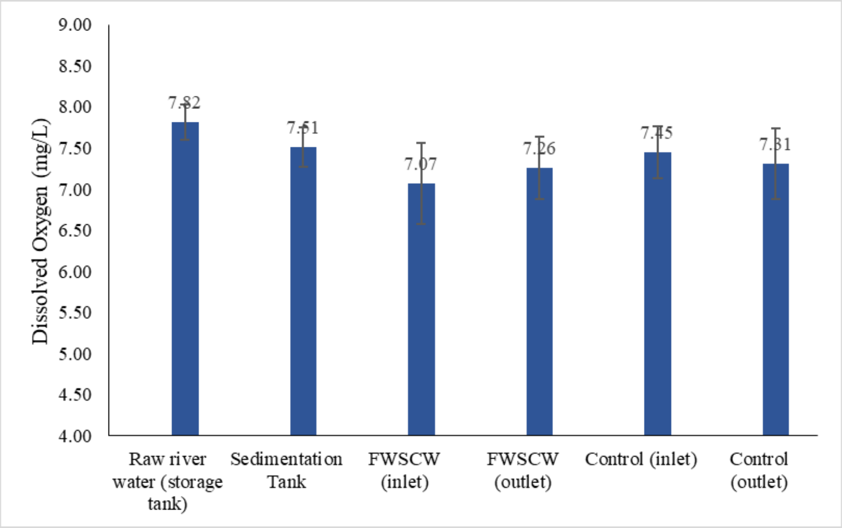

Figure 5. Comparison of average DO measurement

3.2.4. Turbidity

The Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017 concerning Environmental Health Quality Standards and Water Health Requirements for Sanitary Hygiene, Swimming Pools, Solus per Aqua, and Public Baths states that the maximum turbidity of water intended for swimming pool water media is 0.5 NTU. When referring to regulation, the turbidity value at the observation point of Brantas River water with an average value of 24.18 NTU has exceeded the quality standard. But after the treatment, the turbidity reduced to 0.11 NTU and 0.35 NTU in FWSCW and Control, respectively (**Figure 6**). It can be seen the comparison of the average values at the two observation points shows that the performance of FWSCW is better in reducing turbidity to reach an efficiency of 99% compared to the control, which was 98.55%. The decrease in turbidity in the system is not only caused by the development of plant roots but also by physical mechanisms, such as filtration and sedimentation (Arunbabu et al., 2015).

The emergent vegetation cover significantly reduces the solids particle (TSS) in the water and influences turbidity elimination (Gargallo et al., 2016). Using media with different sizes showed a higher absorption capacity than a single medium. In this study, the sedimentation process plays an essential role in turbidity removal. Furthermore, combinations of three plants in the FWSCW showed the ability to remove pollutants through the root zone (Schwantes et al., 2019; Koesputri and Dangiran, 2016; Méndez-Mendoza et al., 2015).

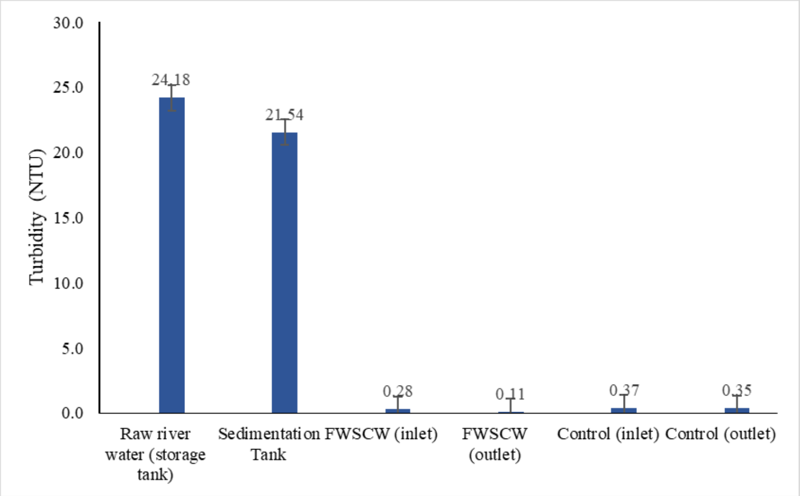

Figure 6. Comparison of average turbidity measurement

3.2.5. Conductivity and Salinity

Conductivity is closely related to the salinity concentration of water. The higher the salinity in the water, the higher the conductivity because of the high amount of dissolved salts that can be ionized (Astuti, 2018). The conductivity values at the two observation points showed results with an average value of 439.91 µS/cm at FWSCW and 430.20 µS/cm at Control, when compared to points on the Brantas River of 442.84 µS/cm (**Figure 7**). Chemical elements in salinity water, such as anions (chloride, nitrate, sulphate, and phosphate) and cations (sodium, magnesium, calcium, iron, and aluminium), will affect the conductivity of water (Ahmad et al., 2018). The removal of salt causes a decrease in the conductivity concentration through the absorption process by plants.

Figure 8 shows salinity measurements from all observation points. It shows that raw river water and treated water salinity were stable, with an average value of 0.21 - 0.22 psu. Salinity above a specific concentration can also affect the system's performance by decreasing the efficiency of BOD removal. The influence of salinity on BOD removal was reported by Chyan et al. (2017), in which the horizontal flow system of the FWSCW could significantly reduce BOD concentration due to the presence of salinity in the water.

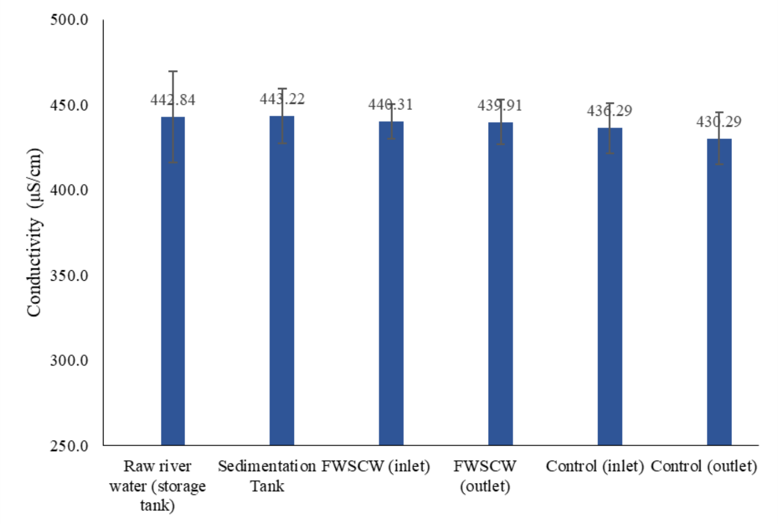

Figure 7. Comparison of average conductivity measurement

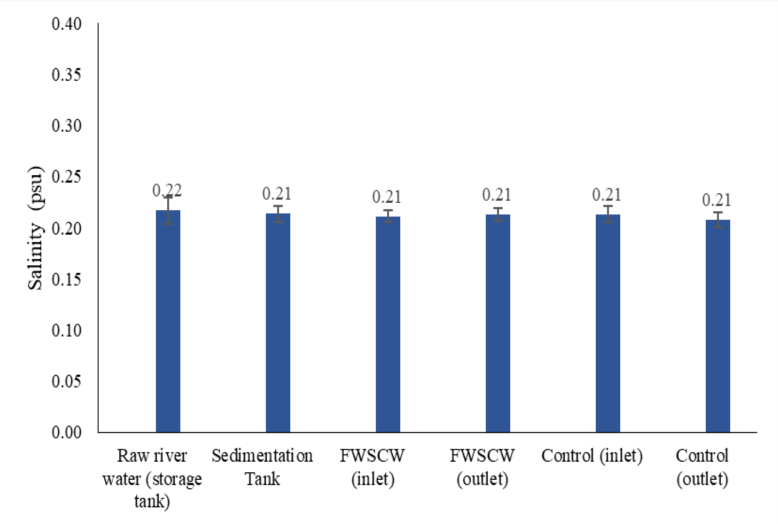

Figure 8. Comparison of average salinity measurement

The average value of conductivity and salinity after treatment decreases slightly compared to raw river water. The temperature will contribute significantly to the conductivity of water, where higher temperature will lead to higher conductivity (Wang et al., 2020).

3.2.6. Total Dissolved Solid

Raw water's total dissolved solids (TDS) have an average concentration of 222.60 mg/L, and the value is related to inorganic materials concentration (Astuti, 2018). After treatment in the constructed wetlands, TDS concentration slightly decreased at 221.36 mg/L and 216.29 mg/L, respectively, in the effluent of FWSCW and the control. The dissolved solids' particles were removed for about 0.54% and 2.84%. A decrease in TDS concentration occurred because the plant roots absorbed the solutes, which will then be used as material in the metabolic process of autotrophic microorganisms (Dwimerti, 2010). TDS concentration, when compared with the average performance value in the Control is better than FWSCW. The decomposition process of organic matter may cause the higher TDS levels at the FWSCW outlet to be more negligible in size as an energy source by microorganisms (Taufiq, 2020). Moreover, the concentration of TDS was below the Government Regulation of the Republi2c of Indonesia No. 82 of 2001 concerning Water Quality Management and Water Pollution Control (2nd class water quality standards, which is a maximum of 1000 mg/L).

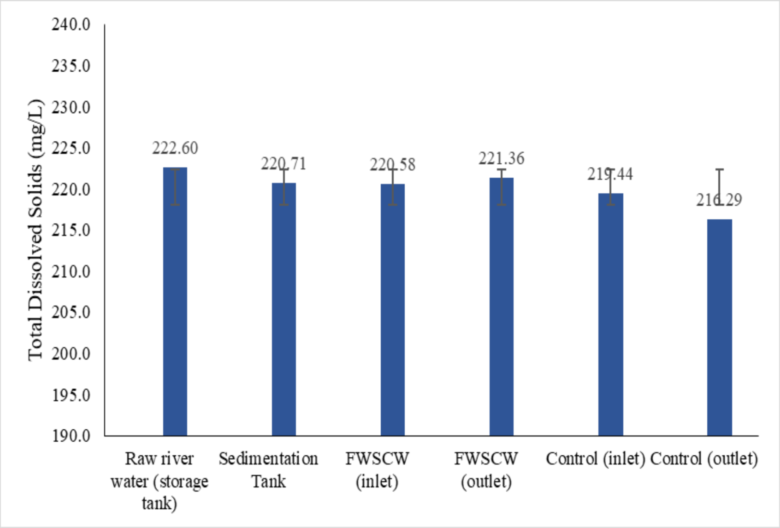

Figure 9. Comparison of average TDS measurement

3.2.7. BOD

Biological Oxygen Demand (BOD) is the amount of dissolved oxygen microorganisms need to decompose organic matter (Salim, 2021). At the point of observation, the outlets in FWSCW and Control were able to reduce BOD concentrations by up to 89% efficiency. The results obtained in **Figure 10** show a slight difference in BOD reduction between FWSCW and Control. It was only a difference of about 0.02 mg/L. Reduction of BOD concentration in the constructed wetlands can be triggered by sedimentation and filtration process through the media. Additionally, an aerobic and anaerobic process also contributed to the degradation of organic compounds in the FWSCW (Shelef *et al.*, 2013 through (Yulistyorini et al., 2019). The results of turbidity and BOD removal can be seen in **Table 2**.

The diffusion and convection process will release oxygen that required by aerobic degradation in FWSCW, and the leakage also supplies oxygen from macrophyte roots to the rhizosphere (Abou-Elela *et al.,* 2012). Thus, the efficiency of artificial wetland treatment to remove organic matter generally depends on oxygen concentration in the layered bed, wetland design, treatment conditions, and the characteristics of the layer media (Vymazal, 2011). In addition, the presence of multiple plant species provides more effective root distribution and a more favourable habitat encouraging the development of a large diversity of microbial communities in the system. The plant roots will delay the passage of wastewater through the system, increasing retention times and decreasing hydraulic loads, thereby providing an opportunity for organic matter removal (Zurita *et al*., 2009). Microbes around the surface of roots stems, and fallen leaves assist in reducing BOD through various contaminant degradation. Plants in this system also play an essential role in biological processes because they provide a growing medium for microorganisms and oxygen for the roots through photosynthesis (Vymazal, 2011; Saeed and Sun, 2012).

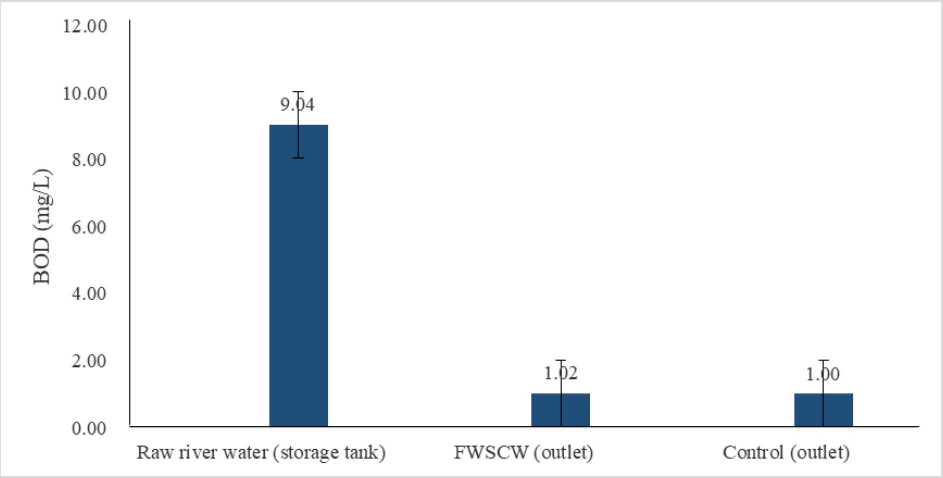

Figure 10. Comparison of average BOD measurement

The effluent quality of treated water has met the Government Regulation of the Republic of Indonesia No. 82 of 2001 concerning Water Quality Management and Pollution Control, which states that the BOD standard is 3 mg/L.

Table 2. Removal of turbidity and BOD in FWSCW and Control

Parameter	Unit	(IN)	(OR)	(OK)	Efficiency	
					Reactor	Control
Turbidity	NTU	24.18	0.11	0.35	99.53%	98.55%
BOD	mg/L	9.04	3.07	3.01	89%	89%

4. Conclusions

This study observed the possibility of treating Brantas river water as a clean water alternative through constructed wetland treatment. The concentration of organic matter and solids particles in the Brantas river water was above the standard requirement of second-class water (on Government Regulation of the Republic of Indonesia No. 82 of 2001). This value indicates that the amount of discharging untreated wastewater in the river is very high. The treatment results using the FWSCW with the addition of *Pistia stratiotes, Echinodorus palaefolius, and Heliconia psittacorum* meet the Class II Water Quality Standards. This indicates that the water can be used for water recreation infrastructure/facilities, freshwater fish cultivation, animal husbandry, water for irrigating landscaping, and clean water alternative. The FWSCW can reduce turbidity levels up to 99.53% and BOD of 89% and achieves Class II Water Quality Standards based on Government Regulation of the Republic of Indonesia No. 82 of 2001.

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