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Implementation of a Full-scale Circular Constructed Wetlands to Treat Greywater at Natural Tourism in Malang, Indonesia

Anie Yulistyorini[1*], *Çiğdem Öz* Yaşar[2], *Satriaji Ikhlas* Utomo[3], *Vita Ayu Kusuma* Dewi[1], *Titi* Rahayuningsih[1], and *Dwi* Siswahyudi[1]

[1]Department of Civil Engineering and Planning, Faculty of Engineering, Universitas Negeri Malang, Indonesia 65145
[2]Çanakkale Onsekiz Mart University, Faculty of Engineering, Department of Environmental Engineering, 17020, Çanakkale, Türkiye
[3]Environmental Laboratory, Department of Civil Engineering and Planning, Faculty of Engineering Universitas Negeri Malang, Indonesia 65145

Abstract. This research examines a circular-shape constructed wetlands (CCW) system at Bedengan Camping Site (BCS) as Natural Tourism in Malang, Indonesia. There are family fun-park, shallow rivers, and camping grounds at BNT as a tourist attraction. The CW system was built in 2021 and used to treat greywater from public toilets, food courts, and cafes. This study aims to demonstrate the performance of the CW system in treating greywater to meet the standard limits of the treated wastewater. The CW was arranged in a circular shape to follow the contour of the land, and three water plants such as Canna, Heliconia psittacorum, and Equisetum hyemale planted for the CW treatment. A sampling of wastewater took place during covid-19 pandemic and after the pandemic from three sampling ports: the sedimentation tank, inlet of CCW, and outlet of CCW. The results show that the CCW system performs well in reducing organic pollutants from greywater produced by visitors and meets the domestic wastewater threshold limit as stated in the Ministry of Environment and Forestry Regulation No. P.68/2016. The average of the organic pollutant removals was higher than 90%, while the pH of the treated water changed from acid to neutral condition. It is assumed that the CW system can provide a neutralisation process of the greywater at BCS.

1 Introduction

Bedengan Camping Site (BCS) is an eco-tourism site in Selorejo Village of Malang Regency surrounded by orange farmland, mountains, and rivers [1]. Besides being presented with beautiful natural scenery, it provides food court facilities, bathrooms, halls, and places of worship [2]. Campsite facilities such as food courts and toilets produce a potential amount of

* Corresponding author: anie.yulistyorini.ft@um.ac.id

wastewater that can pollute surface water around natural tourist sites because the site is not equipped with wastewater treatment facilities.

Rivers play an important role as a water source in fulfilling the community's water needs. At the same time, human activities that produce wastewater have a negative impact on river water quality [3]. As a natural resource widely used for daily human needs, water must be used wisely to prevent contamination and maintain quality [4]. Discharging untreated wastewater into the surface water will increase pollutants, threatening and endangering human health and the environment [5]. Implementing wastewater treatment plants (WWTP) is essential to prevent potential surface water pollution. Determining the type of WWTP is vital to consider the condition of the location of wastewater generation [6].

Constructed Wetlands (CWs) is a wastewater treatment system suitable for the BCS nature tourism site. It is cost-effective in design, sustainable technology, and proven to significantly reduce pollutants through physical, chemical, and biological processes [7]. CWs treat wastewater and can be used as a medium for sustainable water conservation [8]. By considering a natural design and utilizing the existing ecosystem of plants and filter layers, CWs are an environmentally friendly type of wastewater treatment. They are excellent at treating biological elements in wastewater [9].

The studies related to wastewater treatment using CWs in tourist areas are on the island of Koh Phi Phi, Thailand. This CWs is designed to resemble a butterfly sitting on a flower [10]. Another series of CWs was built at Suluban Uluwatu Beach, Bali, for treating café wastewater, and this system is known as the wastewater garden [11]. In addition to functioning as wastewater treatment, CWs also serve to revive the condition of river banks and as a buffer for flood protection [12].

Nature-based technology such as CWs has yet to be widely implemented in Indonesia for communal and tourist area wastewater treatment. Therefore, this study was conducted to build the CWs and monitor the quality of water produced from BCS nature tourism wastewater using circular CWs design.

2 Materials And Methods

2.1 Field Survey and Design of the CCW

A field survey of the existing wastewater treatment facility in the BSC was conducted in 2021. There was no treatment facility found in the area, and most of the wastewater (greywater) from toilets and the food stalls was directly discharged into the environment (Fig 1).


Fig. 1. The existing condition of wastewater discharging at BSC

Based on the field survey at BSC, the site plan for natural-based wastewater treatment using CWs was designed in forms of circular type. The wastewater (greywater) from toilets and food stalls was flown into the PVC pipe and collected in the sedimentation tank. Afterwards, the liquid was fed into the circular CWs for further treatment. The remaining sludge from the sedimentation tank was discharged into the anaerobic tank. The final effluent from the circular CWs was released into the river. The design of the CWs site plan and an implemented CCW are shown in Fig 2.

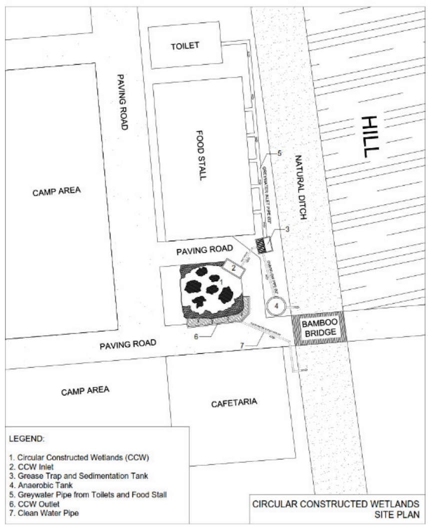


Fig. 2. The CWs site plan at the BCS

The CCW built from concrete with diameter approximately of 5 m and the depth of 0.3 m. The CCW was filled with sand and gravel for the plant media and filter. The wastewater distributed into the wetlands using different PVC pipe used with dimension of 1.5 in, 2 in, and 3 in. Then, three types of water plants such as *Canna, Heliconia psittacorum*, and *Equisetum hyemale* planted in CCW (Fig. 3).

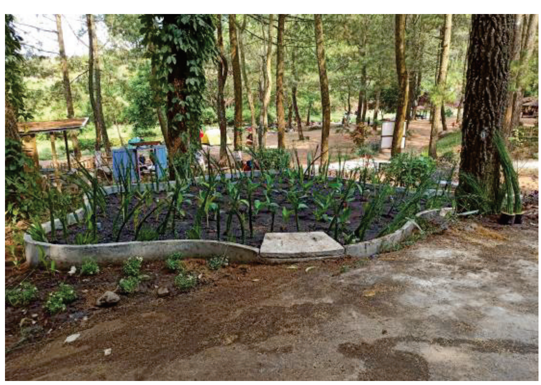


Fig. 3. Implemented CCW at BCS

2.2 Wastewater Sampling

The wastewater samples were collected from the sampling port of sedimentation tank, inlet CCW, and outlet CCW. Wastewater parameters based on Ministry of Environment and Forestry Republic of Indonesia regulation standard No P.68/Menlhk/Setjen/Kum.1/2016 for domestic wastewater used as reference for lab analysis and monitoring the performance of CCW. The standard parameters were pH, DO, TSS, BOD, COD, Total Coliform, and Fat & Grease. The samples were collected and analysis for weekly basis during three months after implementation at BCS.

3 Results And Discussion

3.1 pH and DO

Fluctuation of pH in wastewater treatment depends not only on the pH of raw wastewater but also on the nature and the conversion processes in the CW [13]. Tabel 1 shows that pH of wastewater in the sedimentation tank was acid at 3.41 and increase to approximately normal at 6.61 where the pH in the outlet has met the standard quality of treated domestic wastewater (6-9), this range is acquired by optimal growth nitrifying bacteria and aerobic microorganism in the CWs [14]. The uptake of ammonium and ions by plant roots and nitrification process lead to generate energy and H^+, and therefore contribute to increase the pH [15].

Table 1. Average pH and DO of treated wastewater in CCW

Sampling port	pH	DO (mg/L)
Sedimentation tank	3.41	6.95
CCW (inlet)	6.16	7.16
CCW (outlet)	6.61	8.8

The dynamic of oxygen concentration is different in CWs. This study shows that DO level in untreated and treated wastewater increased due to the treatment in CCW which implemented the horizontal flow (Table 1). In CCW the DO was fully saturated within a few centimetres of the surface. In horizontal flow wetlands, sources of oxygen can be introduced by the influent, surface re-aeration, and plant root release [9,14].

3.2 Ratio of BOD/COD

Table 2 shows the ratio of BOD/COD of wastewater produced by human activities in BCS. The ratio influences the selection of appropriate wastewater treatment options and the value of biodegradation of the organic matter in wastewater [16]. The ratio of BOD/COD in wastewater that flew into the sedimentation tank was 0.51, which means the wastewater is biodegradable and consists of sufficient microbial community [17]. As is reported in previous literature, wastewater biodegradability is classified as the BOD/COD ratios higher than 0.50, between 0.30 and 0.50, and lower than 0.30 as readily biodegradable, biodegradable and refractory, respectively [16,17]. The treatment performance of CCW at BCS worked properly and generated the effluent with a ratio of BOD/COD at 0.31. There was a 99% reduction of BOD and a 98% COD concentration, respectively, and these values revealed the optimum treatment of wastewater in the constructed wetlands (see Fig 4).

Table 2. The ratio of BOD/COD in wastewater

Sampling port	Ratio BOD/COD
Sedimentation tank	0.51 ± 0.27
CCW (inlet)	0.44 ± 0.15
CCW (outlet)	0.31 ± 0.11

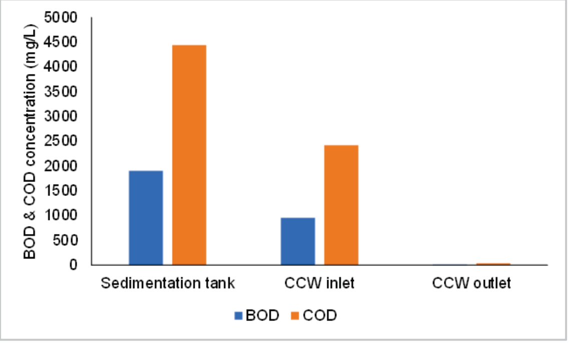


Fig. 4. BOD and COD concentration

3.3 NH3 Reduction

Nitrogen is one of important parameter to evaluate the effectiveness of the wetlands system for wastewater treatment [18]. The treatment of wastewater using wetlands (CCW) in BCS reduced the NH_3 concentration from 35.68 mg NH_3-N/L in the inlet to 0.55 mg NH_3-N/L in the outlet of CCW, respectively (Figure x). This value revealed that the CCW reduced the nitrogen concentration in wastewater with efficiency of 97.5%.

In NH_3 reduction, biological nitrification is playing an important role in nitrogen cycle of the wetlands. Oxidation of ammonia-nitrogen to nitrate and nitrite mediated by ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB), and therefore it decreased the NH_3 concentration in wastewater [19,20]. Our study reported that DO concentration of wastewater in the CCW was 6.95 mg/L to 8.8 mg/L (Fig 5). This process revealed that DO concentration in the wetlands become the main affecting factor in nitrification pathways [19]. Moreover, nitrification and denitrification process in CWs accelerated by the presence of organic carbon in wastewater [14,21]. It can be seen that COD in raw wastewater of BCS was high (Fig 4) and it could help the nitrogen reduction process in CCW.

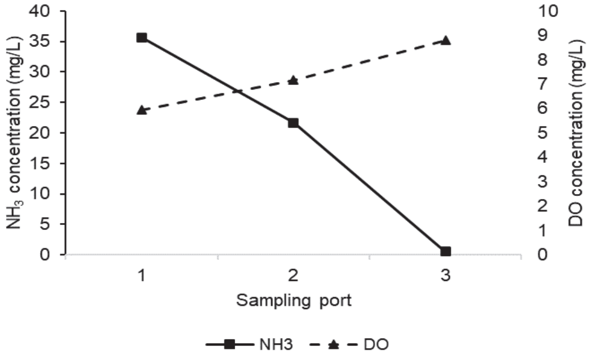
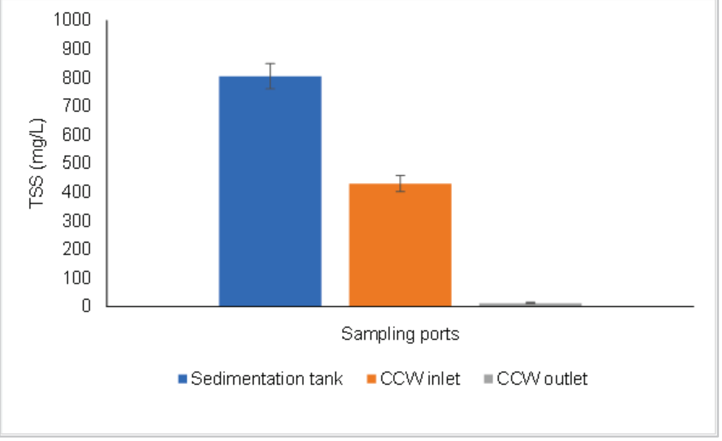


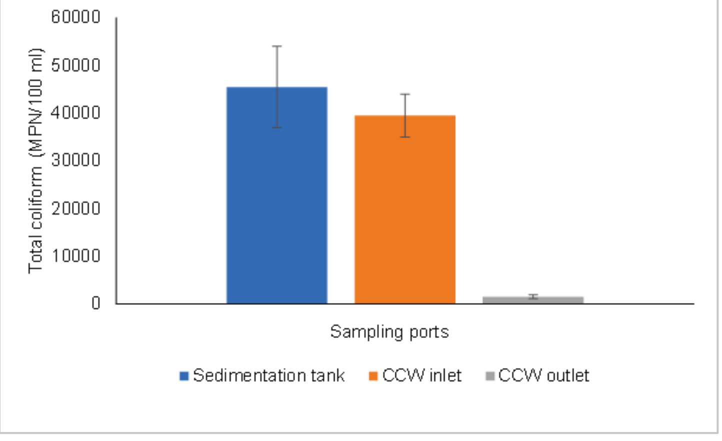
Fig. 5. Correlation of NH_3 and DO concentration of wastewater in (1) sedimentation tank; (2) CCW inlet; (3) CCW outlet

3.4 TSS, Total Coliform, and Fat and Grease

Suspended solids mainly retained in CWs through physical process such as sedimentation and filtration. The particle accumulated and go through hydrolysis process, and producing dissolved organic compounds that further degrade within treatment bed [9]. Our study shows that TSS removed significantly from the inlet (761 mg/L) to the outlet (15 mg/L) of CCW with the efficiency of 97% (Fig 6). The degradation of the particle will also contribute to decrease BOD and COD concentration in CWs.

Similar process also occurred in reducing of wastewater pathogen in CCW, because the settling of particle will remove microorganism within the wetlands. In addition natural die-off and predation by protozoa and metazoan have reported to eliminate the total coliform in wastewater [9]. In this study, average concentration of the total coliform in the inlet was 45,500 MPN/100ml and biological degradation process in CCW with the efficiency of 96.2% reduced the total coliform until 1,500 MPN/100ml (Fig 6). The treatment results for TSS and total coliform has met the regulation standard of treated wastewater.





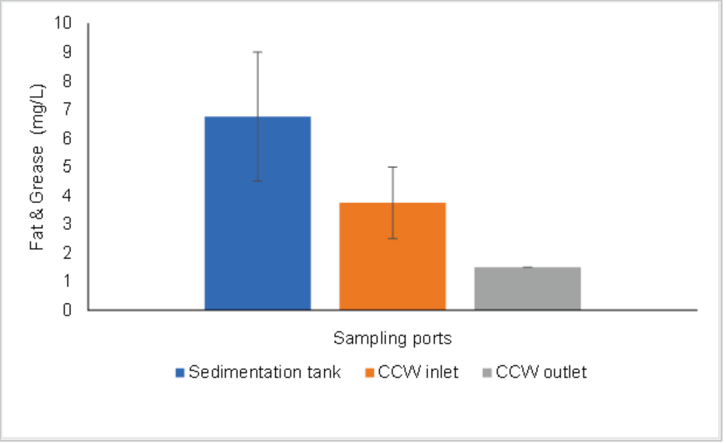


Fig. 6. Reduction concentration of TSS, Total Coliform, and Fat and Grease

Numerous studies investigated that the removal rate of pathogen in horizontal sub surface flow and free water surface flow CWs reveals higher than vertical sub surface flow, because the macrophytes rooted in the underlying media has to reduce a significant number of fecal bacteria [22].

Furthermore, fat and grease of the wastewater concentration in this research was 6.75 mg/L. This value reduced up to 45% (3.5 mg/L) before flew into the CCW, and final concentration in the outlet was 1.5 mg/L (Fig 6). This value was below the limit of regulation standard. Low concentration of fat and grease in CCW help the system to treat the wastewater appropriately.

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