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An Investigation into the Use of Sand Media Planted with *Thypha latifolia* in Constructed Wetland Ecotechnology in Removing Organic matter, Suspended Solids and Nutrients from Domestic Wastewater

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Abstract. Deterioration of water quality continues to be a major concern in West Timor. Establishment of wastewater treatment is crucial for eliminating this problem. Constructed wetland (CW) ecotechnologies are an alternative low-cost wastewater treatment to solve wastewater problems in West Timor. This research aimed to compare the effectiveness of *Thypha latifolia* in CWs for the removal of BOD₅, suspended solids, NH₄-N, and PO₄-P. The experimental design consisted of 6 (20 L) vertical flow mesocosms, 3 mesocosms planted with *Thypha latifolia* and 3 mesocosms as a control. The mesocosms were irrigated with synthetic wastewater for 7 months. The inflow had a 2-day hydraulic retention time. The inflow and outflow samples were monitored for BOD₅, suspended solids, NH₄-N, and PO₄-P. The trend showed that the CWs planted with *Thypha latifolia* reduced significantly the BOD, suspended solids, and NH₄-N. However, the presence of plant did not significantly reduce PO₄-P. This indicated that the CWs planted with *Thypha latifolia* had a better performance in comparison with pure sand media.

INTRODUCTION

Currently, East Nusa Tenggara Province (ENTP) is facing significant problems with water pollution due to increasing population growth and urbanization. The majority of wastewater is released to environment without proper treatment. This condition could lead to environmental deterioration and human health problems. Hendrawan et. al [1] reported that domestic wastewater contributes more than 50 % to water pollution. Statistical data showed that the people suffered from diarrhoea in 2009 were 149,426 cases and the number of cases rose significantly in 2012 to 206,216 cases but declined to 109,909 cases in 2015 [2]. Deterioration of some water sources in Kupang (Capital City of ENTP) due to pollution has occurred, particularly, in the Liliba River, Oeba Springs, and the Dendeng River. Annual reports by the Environmental Agency of ENTP revealed that several rivers in ENTP i.e. Dendeng River, Noelmina River and Aesesa River in ENTP were categorized as heavily polluted [3].

To solve this problem, the wastewater should be treated before being discharged to the environment. However, treatment wastewater using conventional technologies, such as activated sludge or membrane bioreactors needs high capital investments and operational costs. For that reason, this technology is not suitable for local governments in

ENTP due to financial constraints. Thus, it is important to find alternative wastewater treatment technologies which are more affordable and efficient than conventional technologies.

Constructed wetlands (CWs) for wastewater treatment are an alternative solution for environmental protection in tropical regions like ENTP. CWs have become tremendous attention in the world as this technology offers low cost for investment, lower energy consumption and simple operation and maintenance [4]. CWs are recognized as a green technology because this technology uses wetland vegetation, soil media and microbial processes for pollutant removal. Several studies have reported that CWs have been able to remove organic matter, suspended solids, nutrients and coliforms from domestic wastewater [5-8]

Based on the water flow regime, CWs are classified into two broad types; free water surface (FWS) CWs and subsurface flow (SSF) CWs [4, 9, 10]. The SSF can be further classified into horizontal subsurface flow (HSSF) and vertical subsurface flow (VSSF). To complement each other to increase the removal of pollutants in CW systems, these types of CWs were further combined together as hybrid systems. Of these, SSF CWs have been commonly utilized because of greater available surface areas, smaller land requirements, decreased odour problems.

In CW systems, media and plants are important factors for the performance of pollutant removal. The media can serve for filtering sediments and particulates, controlling water infiltration rate, providing adsorption surface for heavy metals and nutrients, and encouraging the plant growth and microorganism development [11, 12]. The hydraulic retention time (HRT) and hydraulic conductivity are also influenced by the media [13]. Plants in CWs have several functions including nutrient and heavy metal uptake, degradation of organic pollutants, transpiration and stimulation of microbial activities [9]. Several studies have reported that planted CW systems have a better performance in removing nutrients, organic matter and suspended solids than CWs barren systems [14, 15]

Recently, studies on the suitability of indigenous species of emergent macrophytes in removing pollutants have been carried out in several countries. In Greece, Akrotos and Tsihrintzis [16] demonstrated the capability of *Phragmites australis* and *Typha latifolia* for nitrogen and phosphorus removal. The findings showed that *Typha latifolia* seemed to have better performance in removing nitrogen and phosphorus than *Phragmites australis* [16]. In Tanzania, Mayo and Bigambo [17] investigated *Phragmites mauritanicus* and *Typha domingensis* for removal of nitrogen from primary treated domestic wastewater. The results showed that total nitrogen removal in the CWs was 48.9% and the uptake of nitrogen by the plants contributed 10.8% [17]. On a pilot scale in Shanghai (China), Li et al. [18] demonstrated the feasibility of CWs with indigenous *Phragmites australis*, *Typha latifolia* and *Scirpus validus* in treating wastewater from the Sanhaowu River. The results revealed that these plants, particularly *Typha latifolia* and *Scirpus validus* played a crucial role in the removal of organic matter because they had more vigorous root systems. Nandakumar et al. [19] reported that CW planted with *Brachiaria mutica* could efficiently reduce nutrients under various load concentrations across different seasons. Research conducted by Sudarsan et al [20] revealed that CW planted with *Thypha latifolia* could remove 75% and 70% of BOD and COD, respectively. However, investigation of CW performance during 33 months using surface flow (SF) horizontal subsurface flow (HF), and vertical flow planted with *Canna indica* and *Thalia dealbata* showed that plant had minimal impact for pollutant removal [21]. It means that type of vegetation influenced the removal of pollutants in CW systems. Since *Thypha latifolia* is abundantly found in West Timor, it is important to investigate the performance of *Thypha latifolia* in removing pollutants. This study aims to investigate the performance of CWs planted with *Typha latifolia* in the sand media for organic matter, suspended solids, and nutrient removal.

METHODS

Experimental Design

The experiments were conducted from January to July 2019 at Department of Chemistry Nusa Cendana University Kupang Indonesia, using vertical subsurface flow (VF) mesocosms. The VF mesocosms were made from plastic buckets and the height and diameter of each VF mesocosms were 65 cm and 30 cm, respectively. Six VF mesocosms were constructed to form two parallel treatments using sand media without planted (CTR) and planted with *Thypha latifolia* (PLT). The mesocosms were filled with sand media to a depth of approximately 27 cm. The bottom of each mesocosm was fitted with a drainage port and tap connected with a hose to a height approximately 7 cm from the bottom. A vertical position of PVC was placed in each bucket to control the clogging and to collect the inflow water samples. The schematic of the experimental layout is shown in Fig 1.

FIGURE 1. Experimental Layout of VF Mesocosms.

The experiments were carried out for seven months from December 2018 to June 2019 and divided into two phases which are (1) establishment phase and (2) load phase. In the establishment phase (December 2018 – January 2019), the mesocosms were irrigated intermittently with water (1 L/ 24 hours). The load phase was conducted from March to May 2019 and the mesocosms were loaded intermittently with synthetic wastewater using adjustable drip irrigations with the rate of 2 L/ 24 hours.

Water sample collection

For the first two months (February - April 2019), wastewater samples were collected every two weeks and then monthly from May to June. The wastewater samples were collected from inflows (INF) and outflows both from media control (CTR) and media planted with *Thypha latifolia* (PLT). In each sampling event, nine water samples were collected consisting of 6 outflow samples and 3 inflow samples. In each sampling event, the parameters measured consisted of pH, dissolved oxygen, conductivity, total suspended solids, biochemical oxygen demand (BOD₅), ammonium (NH₄-N), and phosphate (PO₄-P). All wastewater samples were analyzed based on the standard methods for the examination of water and wastewater [22].

Statistical and data analysis

The data were statistically analyzed using SPSS 21 software. The mean and standard deviations of BOD₅, NH₄-N, NO₃-N, and PO₄-P from inflows and outflows were calculated. Then, performance of planted media and pure sand media in removing BOD₅, TSS, NH₄-N, and PO₄-P was determined using the percentage removal efficiency (%R) calculated as $\frac{C_{in}-C_{ef}}{C_{in}} \times 100\%$ where C_{in} and C_{ef} were inflow and outflow concentrations respectively. The significant difference between planted media and control was assessed using t_{test} .

RESULTS AND DISCUSSION

The inflow and outflow concentration of BOD₅, TSS, NH₄-N, and PO₄-P and their performance are presented in Fig. 2 -5. The range concentrations of BOD₅, TSS, NH₄-N, and PO₄-P in the inflow were 144 mg/L to 162 mg/L, 738 mg/L to 808 mg/L, 1.7 mg/L to 2.0 mg/L, 3.2 mg/L to 3.7 mg/L, respectively. The outflow concentrations of corresponding compounds and their performance are discussed in each relevant section.

BOD₅

The inflows and outflows of BOD₅ is presented in Fig 2. The BOD₅ outflow concentrations ranged from 34 mg/L – 54 mg/L and the removal efficiencies were in the range of 61 – 79 %. This result was still below to those reported by Abou-Elela et al [5] using VF constructed wetland planted with *Phragmites australis* and *Canna* with the removal efficiencies 93 and 94 %, respectively. The results also revealed that planted media had significantly higher removal efficiency compared to pure sand media. The higher removal efficiency in the planted media could be due to the availability of oxygen which plays an important role for organic matter removal particularly via aerobic degradation. Saeed and Sun [9] reported that the availability of oxygen could be sourced from atmospheric diffusion, convection and plant rhizosphere.

FIGURE 2. BOD₅ (mg/L) concentrations ($\bar{x} \pm SD$) in VF mesocosms irrigated with synthetic wastewater

Total Suspended Solid (TSS)

Fig 3 reveals that TSS concentrations in inflows and outflows ranged from 738 – 808 mg/L and 131 – 229 mg/L, respectively. There were significant differences between inflow and outflow concentrations and planted media significantly had higher removal efficiencies in comparison with pure sand media (Figure 3). This indicated that presence of plant considerably contributed to remove TSS from synthetic wastewater. In CW systems, to get rid of suspended solids are mainly via physical processes such as filtration, interception and sedimentation and plants are important factor influencing TSS removal [4].

FIGURE 3. TSS (mg/L) concentrations ($\bar{x} \pm SD$) in VF mesocosms irrigated with synthetic wastewater

Ammonium ($\text{NH}_4\text{-N}$)

Concentrations of $\text{NH}_4\text{-N}$ in the inflows ranged from 1.7 – 2.0 mg/L (Fig 4). In the outflows, the concentrations of $\text{NH}_4\text{-N}$ ranged from 0.5 – 0.8 mg/L. Kadlec and Wallace [4] stated that the removal of nitrogen could occur via adsorption, nitrification, denitrification and plant uptake mechanisms. As shown in Figure 4, the outflow concentrations of $\text{NH}_4\text{-N}$ in the planted media in each sampling period were significantly lower than the concentrations of $\text{NH}_4\text{-N}$ in pure sand media, confirming that the presence of plants influenced the removal of $\text{NH}_4\text{-N}$. Significant different were also observed between inflows and outflows. This indicated that this CW systems significantly reduced $\text{NH}_4\text{-N}$ concentration with the removal efficiencies ranged from 54 – 63 % and 68 – 75 % for unplanted media and the media planted with *Thypha latifolia*, respectively. It can be inferred that mechanism of plant uptake would contribute the removal of $\text{NH}_4\text{-N}$ concentrations.

FIGURE 4. $\text{NH}_4\text{-N}$ (mg/L) concentrations ($\bar{x} \pm SD$) in VF mesocosms irrigated with synthetic wastewater

Phosphate (PO₄-P)

Fig. 5 shows the inflow and outflow concentrations of PO₄-P ranged from 3.24 – 3.68 mg/L and 0.57 – 0.77 mg/L, respectively. Removal efficiencies of PO₄-P were in the range of 79.2 – 82.3 % and 79.7 – 83.8 % for unplanted (CTR) and planted media, respectively. It was found that, there were significant differences of PO₄-P concentration in the inflows and outflows. However, no significant difference outflow concentrations of PO₄-P were observed between planted and unplanted media. This suggested that the presence of *Thypha latifolia* did not contribute to the removal of PO₄-P removal. In CWs, the removal of PO₄-P can occur via adsorption, desorption and precipitation mechanisms as well as plant and microbial uptake mechanisms [23]. These processes occur simultaneously in the CW systems.

FIGURE 5. PO₄-P (mg/L) concentrations ($\bar{x} \pm SD$) in VF mesocosms irrigated with synthetic wastewater

CONCLUSION

Our experiment in VF mesocosm systems demonstrated that both pure sand media and the media planted with *Thypha latifolia* significantly reduced BOD₅, TSS, NH₄-N, and PO₄-P. The removal efficiencies of media planted with *Thypha latifolia* in removing BOD₅, TSS, NH₄-N, and PO₄-P ranged from 73 – 79%, 78 – 84%, 69 – 75%, and 80 – 84%, respectively. The media planted with *Thypha latifolia* had better performance in removing BOD₅, TSS, NH₄-N concentrations compared to pure sand media. However, regarding the PO₄-P removal, there was no significant difference between pure sand media and planted media.

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