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Vertical Subsurface Flow (VSSF) constructed wetland for domestic wastewater treatment

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Abstract. Vertical Subsurface Flow Constructed Wetland (VSSF) is appraised to become an alternative solution for treating domestic wastewater effectively and efficiently. The system which imitates the natural wetland concept is able to reduce organic material and nutrients in wastewater; therefore, it will be more feasible to be discharged to the environment. This study aimed to compare which species is more recommended to be applied for reducing organic material and nutrients in domestic wastewater. This experimental study applied four treatments, i.e 1) control (unplanted), 2) single species *Iris pseudacorus*, 3) single species *Echinodorus palaefolius*, and 4) combination (*Iris pseudacorus* and *Echinodorus palaefolius*) with three days of retention time. The application of those plants aims for holding the role in increasing wastewater quality and adding aesthetic impression at once. The plants were planted on VSSF media, in relatively same of weight and size to compare their effectiveness in decreasing organic and inorganic load. The parameters measured pervade TDS, pH, BOD₅, COD, Nitrate, and Phosphate. The plants' condition was also observed during and after the system worked. The result showed that the best average value of effectiveness for each of parameters: COD by combination treatment (50.76%), BOD₅ by single *I. pseudacorus* (30.15%), Nitrate by single *E. palaefolius* (58.06%), Phosphate by single *E. palaefolius* (99.5%), and TDS by *E.palaefolius* (3.25%). The result showed that there was a significant difference of Nitrate and Phosphate reduction between control and three other treatments, while pH parameter showed non-significant change among them. In term of performance, *I.pseudacorus* seemed showed a preferable achievement.

1. Introduction

As a developing country, Indonesia is inevitably encountered by the rate of population growth, especially in moderate to big city. Based on "The Indonesian Central Bureau of Statistics" [2], the population growth rate of Indonesia achieved 1.49% per year, with total population of 237,641,326 inhabitants in 2010. This trend definitely drives the increase of domestic activity and will be parallel to greater productivity of domestic wastewater which ends up to high rate of its volume. [31] stated that the domestic activity was the prime contributor pollutant in Indonesia. As usually happen in most of the settlements, the wastewater is directly discharged to water body without any treatment. It is clearly revealed by [33], this practice occurred since many cities in developing countries still have obstacle in constructing and managing sewage treatment facilities. Domestic wastewater which is not treated right will evoke many impacts that threaten ecological function. Eutrophication is the example of ecological damage caused by nutrient content of wastewater [5]



[28]. Eutrophication constitutes the phenomenon of blooming algae raised by nutrient enrichment of a water body coming from the input of organic material or by nitrate and phosphate. It can also deliver to the increase of aquatic plant's growth and reduce light intensity to the water body [12].

Problems such as high cost (construction, operation, maintenance) and aesthetics take important concern in finding out the right treatment. Besides, a tendency of a certain system might not be applicable to some developing countries due to high rate of energy and mechanization [24]. The aspects such as cost-effective and aesthetics presumably deliver to an inevitable consideration in innovating treatment which is applicable for community, anywhere and anytime. As those reasons, the effective and efficient wastewater treatment is considerably required.

One of the efforts to find out the alternative treatment is by using CW (Constructed Wetland). CW is system which is designed to imitate natural process such as wetland vegetation, soils, and the associated microbes for treating wastewaters [30]. CW constitutes low cost and low maintenance technology, has a big prospective to be applied in developing countries [13], fits for either small communities or as a final stage treatment in large municipal system [20], and allows to be applied in various wastewater types [19]. CW is also effectively proven in removing pollutants in municipal wastewater [11] [14]. According to US Environmental Protection Agency [27], CW is an artificial natural wetland involving diverse kind of natural process to treat wastewater, which has planted usually by aquatic vegetation. Plants are holding important role to conduct purification in CW [8]. The objective of the study is for comparing which species is more recommended to be applied for reducing organic material and nutrients.

[19] mentioned that, according to the flow, CW was categorized into two i.e. surface and subsurface CW. Subsurface type is divided into horizontal and vertical flow. Vertical Subsurface Constructed Wetland permits the continuous or intermittent loading with upstream or downstream characteristic [21]. The subsurface type of wetland is considered to have several advantages over the surface type. If the water surface is maintained below the media surface there is little risk of odors, exposure, or insect vectors [26]. Besides, the wastewater was directly connected with the plant's *rhizosphere*, which plays important roles in degrading organic materials and reducing nutrients. Contaminant removal is supported by root system of plants and media (soil and stone), compiling bio-film which maintains the degradation [28].

The plants are used since those two are commonly found in Indonesia as ornamental plants. In consideration, they will bring up the fineness in application. *Iris pseudacorus* (also called "Yellow flag iris") is a perennial herb in the Iris family. *I. pseudacorus* considered as a tough one, since it withstands high levels of soluble organics, reduces the organic load by 25% over one year, and may survive in unfavorable conditions [7]. It also tolerates the low levels of oxygen [25]. [32] observed that *I. pseudacorus* had high nutrient absorption and storage capacity for treating wastewater and concluded as a preferred species for CW in northern China. *E. palaefolius* is also well known or its capability in reducing nutrients of domestic wastewater through some studies in Indonesia. According to Prayitno [16], the efficiency of *E. palaefolius* pervaded 68.75% for COD and 61.79% for BOD in tannery wastewater. *E. palaefolius* could reduce 446.890 mg/L, 172.1748 ppm, and 38.748 mg/L of COD, phosphate, BOD₅ respectively, in laundry wastewater [15].

2. Methods

2.1 Site description of inlet source

The inlet contained domestic wastewater which was collected from primary treatment of Municipality Treatment Plant (MTP) / IPAL Sewon, Bantul. This MTP is located in Sewon District, Bantul, Yogyakarta, positioning at 7°51'39.2"S as latitude and 110°20'06.4"E as longitude. It carries out waste management with centralized system namely the existence of pipes which drain wastewater coming from water disposal/waste households that in the region of Sleman, Bantul, and the city Yogyakarta to Sewon [17].

2.2 The implementation of study

The study was conducted in the Laboratory of Ecology of Duta Wacana Christian University (DWCU) for three months from March to May 2015.

2.3 Media and plant selection

The reactors' media consisted of soil and gravels obtaining from around DWCU's yard. *I. pseudacorus* plants were also taken from DWCU's yard, while *E.palaefolius* plants were obtained from plant market in Bantul, Yogyakarta. The plants were selected in relatively same of weight and size, concerning their good condition. Plant age was negligible. No additional fertilizer was applied before and during the system worked.

2.4 Experimental design

Four different treatments (reactors) i.e. 1) control (unplanted); 2) single species *Iris pseudacorus*; 3) single species *Echinodorus palaefolius*; and 4) combination (*Iris pseudacorus* and *Echinodorus palaefolius*) flowed continuously from 300 L inlet basin. Each of reactors had the dimensions of 33 cm (L) x 24 cm (W) x 40 cm (D). Every treatment was made of two replications. The system was run for 3 days retention time. The flow rate was controlled every day to retain the flow stability. Gravels by diameter ± 1 cm, ± 4 cm, and ± 8 cm were arranged below the soil from up to bottom, respectively. The scheme of experimental design (reactor) is showed in Figure 2. Every reactor was filled with tap water up to 30 cm depth for the first three days, and then flowed by domestic wastewater gradually until the water tap was all replaced by wastewater.

2.5 Analyses of inlet and outlet sample

Dissolved Oxygen (DO) and Chemical Oxygen Demand (COD) were measured at the beginning to observe the readiness of the reactor until reaching the stable value. The performance of media and plants were also monitored when the initial wastewater started to flow. Measurements of Total Dissolved Solid (TDS), pH, and Biological Oxygen Demand (BOD) were conducted in Laboratory of Ecology of Duta Wacana Christian University. The TDS measurement was using TDS meter, while the pH measurement was using pH meter. BOD₅ measurement was using "Micro Winkler" method. Measurements such as Phosphate, (COD), and Nitrate were conducted in Yogyakarta Health Laboratory Service.

2.6 Data and Statistical Analyses

Each of treatments produces six data for each of parameters to calculate the average of removal percentage of organic material and nutrients. The removal percentage was calculated by formula:

$$\text{Removal Percentage} = \frac{\text{Inlet Concentration} - \text{Outlet Concentration}}{\text{Inlet Concentration}} \times 100\% \quad (1)$$

One-Way ANOVA was used for verifying significant difference related to the average of removal percentage for both physical and chemical parameters at 5% level of significance using SPSS Statistics 17.0.

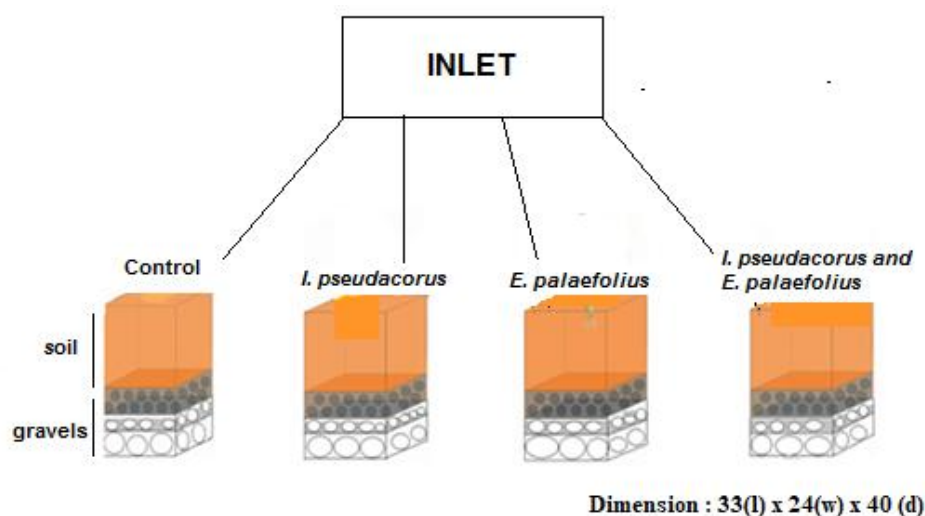


Figure 1. Scheme of experimental design (reactor).

3. Result and Discussion

3.1 Reduction of BOD and COD parameter

In general, result showed none of the significant difference among four treatments in BOD₅ and COD parameter. It implied that each of treatments more or less had the same capability in reducing BOD₅ and COD parameter value. However, combination treatment was appraised having the best performance for reducing COD value (50.76 %). It is assumed that the diversity of microorganism in *rhizosphere* area was high since the mixture of both plants. Averages of effectiveness among the treatments are shown in Table 1.

Table 1. The averages of removal percentage/effectiveness (%) among treatments. The values which were followed by same letter indicate non-significant difference, while those followed by different letter indicate significant difference.

Parameter	Treatments			
	Control	<i>I.pseudacorus</i>	<i>E.palaeifolius</i>	Combination
COD	32.73 ^a	18.91 ^a	27.8 ^a	50.76 ^a
BOD ₅	-5.05 ^a	30.15 ^a	-40.15 ^a	6.25 ^a
Nitrate	38.88 ^a	51.36 ^b	58.06 ^b	46.13 ^b
Phosphate	23.2 ^a	87 ^b	99.5 ^b	95.3 ^b
TDS	-21.25 ^a	-41.21 ^a	3.25 ^a	-45.8 ^a
pH	3.56 ^a	1.78 ^a	0.96 ^a	0.88 ^a
Average value: 6.9 Average value: 7.2 Average value: 7.2 Average value: 7.4				

[19] explained that BOD₅ and COD removal is supported by the mutuality interaction between microbial and physical mechanism by involving the dissolved oxygen. BOD₅ removal involves sedimentation and microbial degradation conducted by aerobic bacteria attached to plant roots, while COD removal prefers to sedimentation and filtration rather than biological process. The single *E.palaeifolius* seemed to show unfavorable work for these parameters. The authors assumed for some reasons. Along the system run, this plant grew so nice. Many leaf buds appeared and some mature leaves developed wider. However, some of their base stalks were frequently withered, and then they got rotten inside the soil gradually. This condition is assumed contributing organic load and increasing the COD value. The negative value of efficiency was also found in *I.pseudacorus* presumably met the same condition, even though the rotten parts of *I. pseudacorus* plants were not frequently found as *E.palaeifolius*. The control is less favorable rather than combination since there was no additional oxygen supply from *rhizosphere*, as it was

unplanted. Nevertheless, the existing aerobic microorganisms that live in soil apparently could still utilize the available oxygen inside the soil to degrade the organic matter. It was often found that soil animal such as earthworm existed in control treatment, thus giving good aeration due to their tracks. It assumed that the control showed a better result than two single planted treatments. This also signified that those plants presumably were better in reducing nitrate and phosphate which are inorganic, rather than the organic ones.

A study [14] stated that microorganisms can multiply themselves and conduct the degradation of organics since the media such as sand contributes a good environmental condition. Therefore, even though the control is unplanted, the COD value is subsided. [23] stated that soil microorganism such as aerobic bacteria, fungi, and *actinomycetes* are commonly found in *rhizosphere* than in non-*rhizosphere* area.

3.2 Reduction of Nitrate (NO_3)

By comparing all the treatments, there was a significant difference result in reducing nitrate. The control had significant result than three others. According to Table 1, the control showed increment of nitrate concentration namely -38.88% removal for the average. This is assumed that NO_3 was formed due to nitrification. Nitrification can be conducted by some existing *heterotroph* bacteria such as *Nitrobacter*, *Nitrospina*, and *Nitrospira*, converting NO_2 to NO_3 in a system [9]. Through this significant difference between unplanted and planted treatment, it could be concluded that plants played big role in uptaking NO_3 . The highest average nitrate removal (58.06%) conducted by single *E.palaeifolius*. As authors stated in previous explanation of how they grew along the system ran (leaf buds appeared, mature leaves developed wider, the base stalks were frequently decayed) became the reason why the nitrate was well removed. The plants do not only uptake the nitrate as nutrient, but also serve the carbon and energy to provide denitrification which was originated from decaying biomass or root release [1]. It is assumed that *E.palaeifolius* held those two roles by uptaking the nitrate to establish their growth (indicated by their new buds and wider leaves), and serving the base matter of denitrification namely carbon and energy (from decaying base stalks) to reduce nitrate. [18] conveyed that denitrification results nitrogen gas (N_2), nitrous oxide (N_2O), or nitric oxide (NO) through the facultative bacteria. Some of them namely *Proteus*, *Aerobacter*, *Flavobacterium*, were only able to reduce NO_3 to NO_2 .

Single *I.pseudacorus* was also achieved a good work in reducing NO_3 (51.36%). The processes might similar, nevertheless, since they have different root size and shape, they may have different soil microenvironment due to the diversity of the microorganism. [1] stated that plants support NO_3 removal but the effect is various depend on their species. The combination treatment did well in reducing NO_3 , even though single treatments were better. The microbial diversity in this treatment might be the highest, since the combination of those two plants. However, the authors assumed that in combination treatment, the NO_3 was concentrated to be used for plants' growth, rather than converted. This was observed by the performance of the plants in this treatment. During the system worked, those two species grew so well when they are combined, especially *I.pseudacorus*, signed by the leaves that grew higher, and the flowers were formed. Camacho et al [4] in their study observed that *I.pseudacorus* experienced good growth and had 47.8% efficiency in reducing NO_3 in domestic wastewater.

3.3 Reduction of Phosphate

Phosphate is one of the prominent parameters in domestic wastewater since detergent is widely used in every domestic activity, especially for washing clothes and dishes. The form of phosphate was measured as orthophosphate in wastewater [5]. Excessive phosphate in wastewater may raise eutrophication and leads to the blooming algae [12].

In this study, the phosphate generally could be removed by all treatments. Nevertheless, the result showed that there was significant difference between control and three other treatments in reducing phosphate. Therefore, using single and combination for both plants in reducing phosphate were not giving

big difference in this study. Single *E.palaefolius* revealed the most effective was by 99.5% phosphate reduction. It indicates that this species is very potential to uptake the containing phosphate. [6] stated phosphate removal relies on plant uptake; hence, observing of accumulation on plant's tissue is important. It delivers to an assumption that planted system took bigger role compared to unplanted. A study [22] observed that root is the key of up taking nutrients due to symbiotic microorganism exists in the roots. The following uptake was conducted by stem and leaf respectively.

Besides plant uptake, the phosphate removal can also occur through ion exchange and adsorption from substrate material [10]. [3] stated that combination of materials such as sand or gravel can enhance P-sorption in subsurface constructed wetland.

3.4 Reduction of TDS

The negative value of TDS removal efficiency was revealed by most of treatments, except single *E.palaefolius*, although the value was so small. There was no any significant difference among them in reducing TDS. It was presumed that after the bio-films were growing in the media especially gravels in large amount, some of the bio-films fell out and got dissolved, and therefore it could enhance TDS value through the outlet. Total Dissolved Solids (TDS) is defined as solid which dissolved in water, comprising inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and some small amounts of organic matter [12]. A study conducted by Almeida et al [1] found out the slight increment in TDS in effluent compared to influent and effluent of each trial, however, no significant difference was found. This study indicated that these results were generated by the absence of retention of salts into the vertical flow constructed wetland.

3.5 pH parameter

The capability of maintaining pH was almost the same for each of treatments. It indicated that those four treatments generated pH stability. Wastewater pH is such a prominent aspect promoting the anaerobic organic degradation [18]. pH of wetland should be above 6 in order to support the denitrification process, delivering to N atmospheric [29].

3.6 Condition of plants

During one month of observation, *I.pseudacorus* showed more tenacious than *E.palaefolius*. It had shown by their endurance in tolerating wastewater, proved by their appearance. They were rarely withered during the system ran, only a few of their base stalks rotted occasionally. The leaves grew taller and the flowers bloomed. In combination with *E. palaefolius*, *I.pseudacorus* is disposed to be more stable than *E.palaefolius*. While *E.palaefolius* was excellent in the rapid rate of shoot and flower growth. The mature leaves were also wider fast. These conditions were compatible with the good capability of this species in absorbing nutrients, as this species showed the best result for reducing some parameters. Figure 2 shows the condition of plants.



Figure 2. Treatment from left to right: control, single *Ipseudacorus*, single *E.palaefolius*, and combination treatment.

4. Conclusion

Vertical Subsurface Flow (VSSF) constructed wetland denoted effective and efficient system of removing nutrient load from domestic wastewater. Chemical, physical, and biological mechanisms are occurred within the constructed wetland for reducing nutrient load. The role of media (sand, gravel), plant, and microorganism within the system support the good environmental condition in enhancing wastewater quality. This study found out that *I. pseudacorus* as vegetation was better in maintaining endurance and tolerance towards wastewater. Nevertheless, *E.palaefolius* was appraised more efficient in reducing some parameters such as Nitrate, Phosphate, and TDS. However, since there were no any significant differences in each of parameters between *Ipseudacorus* and *E.palaefolius*, the authors concluded that *Ipseudacorus* species was more recommended than *E.palaefolius* since *Ipseudacorus* showed better endurance. There was no significant difference between single species and combination treatment in upgrading the quality of wastewater. However, there were significant differences for reducing Nitrate and Phosphate parameter between control (unplanted) and planted system. In this study, those two plants tend to be better in removing inorganic matter, rather than the organic one. VSSF constructed wetland has great potential to be applied in concerning about domestic wastewater. It can also be used as means of education to recognize people about low cost and low maintenance wastewater treatment technology.

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