Development of an Open Channel That Also Functions as a Wetland to Reduce Domestic Wastewater

Pungut¹, S Widyastuti¹, E Suhartanto²

¹Environmental Engineering, PGRI Adi Buana University, Surabaya
²Water Resources Engineering Department, Faculty of Engineering, Universitas Brawijaya, Malang, 65145, Indonesia.

Abstract. Besides accommodating rainfall-runoff, the drainage channel of the Dukuh Menanggal area in Surabaya also accommodates domestic wastewater. The objective of developing the function is to degrade domestic wastewater pollution that flows into the drainage channel. The wetland is applied in the drainage channel with coarse sand media, Caladium (Caladium), and Water lettuce (Pistia stratiotes L) plant according to land size planning based on existing discharge, detention time, the porosity of the planting medium, and the root zone of the applied plants. The observed properties of domestic wastewater were Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and detergents. The result is that the treatment of domestic wastewater passes through the artificial wetland in the drainage channel. The constructed wetland can reduce the contamination content of domestic wastewater for the parameters of BOD, COD, and detergents with efficiency levels of 46%, 61.8%, and 69%, respectively.

keywords: artificial wetland, coarse sand, caladium, domestic wastewater, water lettuce

1. Introduction

Domestic wastewater consists of surfactants, nitrogen, and phosphates from washing and food residue. It is also a source of pollution because it is discharged from residential and commercial areas into drainage channels or rivers without any treatment [1]. Domestic waste has one component that can harm the environment, namely detergent or surfactant [2].

Water pollution from domestic liquid waste contributes to water pollution of 87%, while the rest comes from industrial liquid waste [3]. Domestic wastewater from the laundry business affects groundwater quality, especially chemical parameters such as phosphate and pH [4].

The use of detergents in high concentrations can cause more significant water pollution. Thus, it can endanger the life of aquatic biota, plants, and humans who consume the water. Surfactants in water can interfere with the entry of oxygen from the air into the water. Phosphorus and nitrogen compounds contained in surfactants can cause eutrophication in waters. In the form of growth inhibition, the following effect causes functional damage to various body organs of aquatic organisms.

Domestic wastewater is the rest of the washing process contains high levels of ammonium (NH₃), phosphate (PO₄), and detergent [5]. In addition, there are also various kinds of organisms in laundry wastewater, such as bacteria, fungi, and similar aquatic organisms [6]. The high nutrient content (N and P) in laundry wastewater causes eutrophication in receiving water bodies [7]. Therefore, an alternative domestic wastewater treatment technology is needed that can overcome these problems.
Wastewater treatment technology has improved. It is currently possible to treat wastewater very efficiently and cheaply [1][3]. There are many ways to treat domestic wastewater to be reused. Various processing methods must be safe from a health point of view and not harmful to the environment. Domestic wastewater collected in urban drainage channels allows opportunities to maximize recycling programs.

Waste treatment technology has developed and varies based on the type and design criteria. However, the main obstacles are investment and operational costs. Inexpensive wastewater treatment systems in terms of both design and operation are needed in developing countries. One of the inexpensive wastewater treatment technologies in terms of design and application but has a reasonably good pollutant removal capability is the use of aquatic plants to treat waste.

Aquatic plant systems have long been a process used in the context of waste recovery and recycling. The main objective of this system is focused on effluent stabilization and pollutant removal. The primary mechanism occurring in this system is physical sedimentation and microbial metabolic activity as in conventional activated sludge and trickling filters. Low cost and easy maintenance are the main attraction of using this aquatic plant system. Therefore, artificial swamps with aquatic plants are widely used as residential waste treatment. Using plants for waste treatment is called phytoremediation. The advantage of using phytoremediation is its ability to produce secondary wastes that are lower toxic, more environmentally friendly, more economical, and plants can be easily controlled for their growth [8].

Constructed wetland or artificial swamp system is a simple alternative technology. It has relatively low operational and maintenance costs to treat laundry wastewater [9][5][7][10][11]. Constructed wetland is designed and built by utilizing natural processes involving plants, soil, and microorganisms that interact for wastewater treatment. In principle, this system utilizes a symbiotic relationship between the activities of microorganisms attached to the roots of aquatic plants in decomposing pollutants, where plant roots produce oxygen to create aerobic conditions that support the decomposition. In the end, biogeochemical cycles and food chains occur, so this system is sustainable [12][13].

A subsurface system (SSF) constructed wetland can be used because, in this system, water does not stagnate above the planting media but flows under the media. Hence, it has various advantages. One of the advantages is that plants that can adapt are more varied to be used as gardens with good aesthetics [14].

The Sub Surface Flow-Wetlands system has the working principle of a waste treatment system by utilizing symbiosis between aquatic plants and microorganisms in the media around the plant's root system (Rhizosphere) [15].

The best treatment using the combination method of ABR and wetland was able to reduce the concentration of domestic sewage pollution with a treatment efficiency value of pH 6.47, BOD of 57.1%, TSS 72.4%, COD 58.7%, and Fat with 97.1% efficiency [16]. The efficiency value shows that the best percentage reduction in pollutant concentration occurs at a processing residence time of 48 hours or two days [16].

Various types of plants can grow in the SSF constructed wetland system. Previous studies reported that for wastewater treatment can use water lettuce (Pistia stratiotes L.), water jasmine (Echinodorus palaefolius), genjer (Limnocharis flava L.), water hyacinth (Eichhornia crassipes), kana (Thypha angustifolia), umbrella grass (Cyperus Alternifolius), and lotus (Nyphea firecrest) [9][5][7][10][11][17]. Taro stems were able to reduce phosphate levels by 5.43 mg/L and lower pH from 9.54 to 6.61 [18].

Water caladium (Caladium) and water lettuce (Pistia stratiotes L.) can be used as alternatives to aquatic plants planted in the SSF constructed wetland for domestic wastewater treatment. This plant is relatively adaptable to the humidity of the growing media, which is relatively high. In addition, the two plants are also relatively easy to find and breed. This plant is an ornamental plant that has good aesthetic value. Both water caladium (Caladium) and water lettuce (Pistia stratiotes L.) are plant species susceptible to pollutants.
Phytoremediation mechanisms that occur in water lettuce (Pistia stratiotes L) plants are phytoextraction and rhizofiltration. Phytoextraction is the process of plants pulling contaminants from the media. Thus, they accumulate around plant roots and are translocated to other plant organs. The phytoremediation mechanism in the water crab (Pistia Stratiotes L) is also in the form of rhizofiltration, which is the adsorption or deposition of contaminants to stick to the roots. The grasshopper plant absorbs through the roots and is then distributed to all plant parts [8].

The aims of this research are: 1) to study the reduction of BOD, COD, and detergent levels in domestic waste using SSF constructed wetland, 2) to examine the ability of caladium (Caladium) and water lettuce (Pistia stratiotes L.) to reduce levels of BOD, COD, and detergent.

2. Materials and Method

2.1. The study location

The study location is the Dukuh Menanggal Sub-District, Gayungan District, Surabaya City, East Java Province. Surabaya City has an area of 52,087 Ha. Geographically, it is located between 7°9′ to 7°21′ South Latitude and 112°36′ to 112°57′ East Longitude. In contrast, elevation about 3-6 meters above seawater level and some in the south are hilly with a height of 25-50 meters above sea level.

![Figure 1. Dukuh Menanggal Sub-District, Gayungan District, Surabaya City, East Java Province](image)

2.2. Time and Data Collection

This research was conducted from January to February 2019 and collected data set:

a. Chemical Oxygen Demand with 4 data amount of 24 hours treatment.
b. Biological Oxygen Demand with 4 data amount of 24 hours treatment.
c. Detergents with 4 data amount of 24 hours treatment.
2.2.1 **BOD (Biological Oxygen Demand)**
BOD is based on empirical analysis that attempts to approach globally the microbiological processes that occur in water. The BOD value is the number of oxygen bacteria require to decompose (oxidize) almost all dissolved organic substances and a portion of suspended organic substances in water [19].

2.2.2 **COD (Chemical Oxygen Demand)**
COD is the amount of oxygen required to oxidize organic substances found in wastewater using the oxidation agent of potassium dichromate as the source of oxygen. The COD value measures water pollution by organic substances that can naturally be oxidized through biological processes and may cause the decrease of dissolved oxygen in water [19].

2.2.3 **Detergents**
Generally, the term “detergents” is applied to materials and/or products that provide the following functions (a) Promote removal of material from a surface, e.g., soil from a fabric, food from a dish, or soap scum from a hard surface; and (b) Disperse and stabilize materials in a bulk matrix, e.g., suspension of oil droplets in a mobile phase like water [20][21].

2.3 **Caladium and Pistia stratiotes L. Plants**
*Caladium* plants comprise a genus of plants (in the taro family, *Araceae*). In everyday usage, the name also refers to several other plants related to but not included as *Caladium*, such as taro (*Colocasia*). *Caladium* plants rarely form corms that enlarge. These plants originated in the forests of Brazil, but they are now distributed to various parts of the world [22].

*Pistia stratiotes L.* has a pantropical and subtropical distribution. *Pistia stratiotes* are widespread throughout Africa, where the plant was first recorded in South Africa in 1865 from KwaZulu-Natal. In North Africa, *P. stratiotes L.* was first recorded on a small multipurpose impoundment near the town of Fez in Morocco in 2012. In Asia, *P. stratiotes L.* has a wide distribution and is recorded as invasive (CABI, 2016). The plant was recorded in the Philippines as early as 1925, floating in abundance in shallow waters [23].

2.4 **Research Procedure**
a. Parameters measured were to determine the level of pollution are BOD COD and detergent content in mg/l unit.
b. The wetland system used in this research was a subsurface wetland system with the subsurface flow.
c. The artificial wetland used in this study was a wetteright ditch.
d. The planting medium used was coarse sand with a grain diameter of 2.0 – 5.0 mm.
e. Aquatic plants used in this case were water plants of caladium (*Caladium*) and water lettuce (*Pistia stratiotes L.*) because these two plants could live well in wet environments and receive sunlight. In addition, we also obtained two benefits from the use of this type of plant, namely aesthetic value and waste treatment.
f. The wastewater used was from bathroom, kitchen, and laundry sewerage outlets that flow in drainage ditches.
g. Raw water samples were taken on day 0 or the beginning of the wetland that was declared ready for operation and then taken every three days for 15 days. Samples of standard liquid waste were taken when the liquid waste would be put into the wetland. Wetland product samples were taken from the wetland outlet every three days for 15 days. Samples were taken three days after day 0, which was the beginning that stated the wetland was ready to operate. Samples were taken in the amount of 600 ml with the principle of taking to avoid aeration.

2.5 **Steps of Treatment**
a. Acclimatization of plants was conducted with the aim that plants can adapt to the new growing media. Acclimatization was carried out for two weeks. It was expected to be able to adapt to the new growing
media. Acclimatization is presented by pouring water for five days and then gradually replaced with wastewater until the implementation of sampling.
b. The research was conducted in a wetland constructed wetland with an SSF (Subsurface Flow System) system because, in its application, this system required a smaller area of land than the FWS (Free Water Surface) system for the same wastewater input conditions. In addition, wastewater was under the surface of the media so that there was no puddle and could reduce odor and mosquito disturbances.
c. The type of flow used was horizontal flow because it was expected to provide solid and bacteria reduction due to better filtration ability considering the longer time of wastewater flowing through the media.
d. During the research, the setting of the influent discharge was carried out every day by measuring the unit volume per unit time using a measuring cup with a discharge of 25 L/day. The wastewater used pure wastewater that was not diluted. Wetland was made with a slope of 1% to obtain horizontal flow. Sampling and parameter measurements were carried out for 15 days with a sampling interval of 3 days
e. Laboratory Testing of BOD, COD, Detergent Contents
Testing for BOD, COD, Detergent contents in domestic wastewater was conducted in the laboratory, covering these samples:
1) Raw wastewater before being put through treatment.
2) Wastewater after being put through treatment in the wetland.

Figure 2. Research Flowchart
3. Results and Discussion

3.1. Results
The results of the initial characteristics of domestic wastewater are presented in Table 1. Based on the analysis results, it can be seen that the value of BOD, COD, and Detergent levels in domestic wastewater exceeded the quality standard based on East Java Governor Regulation Number 72 of 2013.

Table 1. Laboratory Test Results for BOD, COD, and Detergent Contents in Campus II Domestic Wastewater in (mg/l).

| Sample | BOD$_s$ | COD | Detergent |
|--------|---------|-----|-----------|
| 1      | 585.60  | 288.50 | 16.80     |
| 2      | 556.50  | 277.80 | 13.89     |
| 3      | 538.50  | 266.20 | 13.56     |
| 4      | 510.86  | 245.50 | 12.58     |
| 5      | 490.06  | 250.30 | 12.00     |
| Mean   | 536.30  | 265.66 | 13.77     |

While the data on the content of BOD, COD, and Detergent in Campus II domestic wastewater (mg/l) after processing in the wetlands can be seen in Table 2.
Table 2. Laboratory Test Results for BOD, COD, and Detergent Contents in Campus II domestic wastewater in (mg/l) post-treatment in wetlands.

| Sample | BOD  | COD  | Detergent |
|--------|------|------|-----------|
| 1      | 404.30 | 147.50 | 7.60 |
| 2      | 315.50 | 110.25 | 4.56 |
| 3      | 288.90 | 96.50  | 3.38 |
| 4      | 244.50 | 88.60  | 3.24 |
| 5      | 205.70 | 70.00  | 2.98 |
| Mean   | 291.78 | 291.78 | 4.35 |

a. Data Analysis
Data analysis and discussion were carried out on the data obtained from the results of parameter measurements. There was the content of BOD and COD. From the data, it can be calculated the magnitude of the reduction in BOD and COD content in each wetland with the formula below:

\[
\text{BOD Reduction Percentage} = \frac{B_0 - B_i}{B_0} \times 100\%
\]

In which:
- \( B_0 \) = Influent BOD concentration
- \( B_i \) = Enfluent BOD concentration

\[
\text{COD Reduction Percentage} = \frac{C_0 - C_i}{C_0} \times 100\%
\]

In which:
- \( C_0 \) = Influent COD concentration
- \( C_i \) = Enfluent COD concentration

\[
\text{Detergent Reduction Percentage} = \frac{D_0 - D_i}{D_0} \times 100\%
\]

In which:
- \( D_0 \) = Influent Detergent concentration
- \( D_i \) = Enfluent Detergent concentration

b. Parameter Reduction of BOD
The analysis result of BOD levels using a constructed wetland, Caladium (Caladium), and water lettuce (Pistia stratiotes L) plants are presented in Table 3. The efficiency of BOD reduction was 46%. This artificial wetland system is an imitation of the water purification process that occurs in swamps, where aquatic plants (Hydrophita) that live in the swamp play an important role in restoring water quality [16]. The activity of microorganisms and plants was through oxidation by aerobic bacteria growing around the plant rhizosphere, and heterotrophic bacteria in wastewater play a role in the reduction in BOD concentration. BOD removal can be carried out through complex chemical and biological processes between soil and rock material media, plants, and microorganisms. Plants obtain organic matter as nutrients through the process of decomposition of organic matter by plant root tissue. Organic matter is a nutrient in the form of carbon, nitrogen, and energy [24].

The activity of microorganisms and plants in providing oxygen occurred through the process of photosynthesis. The roots of aquatic plants below the water's surface were off oxygen and formed an oxygen-rich rhizosphere zone. Oxygen was supplied to the roots through stem diffusion in the leaf pores. The release of oxygen by the roots of aquatic plants caused the water and soil around the root hairs to have higher dissolved oxygen than water and soil that were not overgrown with aquatic plants. It allowed decomposing organisms such as aerobic bacteria to live in an anaerobic wetland environment [14][25][26].
Table 3. Reduction Percentage of BOD$_5$ (mg/l)

| Sample | Inlet | Outlet | Reduction | % Efficiency |
|--------|------|--------|-----------|-------------|
| 1      | 585.60 | 404.30 | 181.30    | 31          |
| 2      | 556.50 | 315.50 | 241.00    | 43          |
| 3      | 538.50 | 288.90 | 249.60    | 46          |
| 4      | 510.86 | 244.50 | 266.36    | 52          |
| 5      | 490.06 | 205.70 | 284.36    | 58          |
| Mean   | 536.30 | 291.78 | 244.52    | 46          |

c. Reduction Parameter of COD
The reduction in COD parameters can be seen in Table 4. The efficiency of reducing COD levels reached 61.8%. In the constructed wetlands method, the reduction in COD was due to the cooperation between plants and microorganisms found around plant roots, which were usually called rhizosphere microorganisms. Oxygen derived from photosynthesis carried out by plants is used by microorganisms to decompose organic matter. In contrast, the results from the decomposition of organic matter were absorbed by plants. The cycle of decomposition of organic matter and absorption of nutrients rotates. Through this symbiotic cycle, it would have an impact on reducing pollution in wastewater.

Table 4. Reduction Percentage of COD (mg/l)

| Sample | Inlet | Outlet | Reduction | % Efficiency |
|--------|------|--------|-----------|-------------|
| 1      | 288.50 | 147.50 | 141.00    | 49          |
| 2      | 277.80 | 110.25 | 167.55    | 60          |
| 3      | 266.20 | 96.50  | 169.70    | 64          |
| 4      | 245.50 | 88.60  | 156.90    | 64          |
| 5      | 250.30 | 70.00  | 180.30    | 72          |
| Mean   | 265.66 | 102.57 | 163.09    | 61.8        |

d. Parameter Reduction of Detergent
The analysis results of a detergent level using constructed wetlands, using Caladium and Pistia stratiotes L. are presented in Table 5.

Table 5. Detergent Reduction Percentage (mg/l)

| Sample | Inlet | Outlet | Reduction | % Efficiency |
|--------|------|--------|-----------|-------------|
| 1      | 16.80 | 7.60   | 9.20      | 54          |
| 2      | 13.89 | 4.56   | 9.33      | 67          |
| 3      | 13.56 | 3.38   | 10.18     | 75          |
| 4      | 12.58 | 3.24   | 9.34      | 74          |
| 5      | 12.00 | 2.98   | 9.02      | 75          |
| Mean   | 13.77 | 4.35   | 9.41      | 69          |

3.2. Discussion
Although the detention time for each treatment had been made the same length of 24 hours, the results of processing by the wetland regarding the parameters of BOD, COD, and detergent showed different results. This may be due to the following:
1) Pollution in the initial (raw) wastewater as the input showed fluctuations depending on the actual pollution quality of the existing created wastewater from the campus's cafeteria kitchens, bathrooms, and washing drains. Higher content of pollutants in the initial wastewater will require a greater detention time than a lower content of pollutants.
2) The actual temperature of the wetland cannot be ensured to be the same because the wetland as an open construction is very much affected by weather conditions, whether sunny, cloudy, or rainy, which leads to the temperature in the wetland ditch being hot, warm, or cold. This temperature factor, according to wetland theory, very much influences the results. The ideal temperature of the wetland is between 20 and 30 degrees Celsius.

3) Occurrences of rain were not the same for each treatment. The rainwater that filled the drainage ditch of the campus meant a dilution of the processed wastewater. The effect may be positive yet unpredictable toward the reduction of pollutant content in the wastewater.

Several factors could not be conditioned in this research. Nevertheless, they play an essential role in resulting inaccurate research data. The following are these factors:

1) Optimal Detention Time
In this research, there was no variation in the detention time for wastewater processing to determine the optimal detention time.

2) Temperature
In this research, the temperature of the wetland could not be controlled, considering that the experiment was conducted in the rainy season, and thus the conditions of one treatment are likely to be very different from the conditions of another treatment due to heat, rain, or other influences from the weather.

3) Rainwater Dilution
Whether rain occurred and the amount of rain that occurred very much affected the process and results of the experiment. However, this factor was not observed in this research. However, the drainage ditch is utilized as the wetland is in an open area.

4) Highest Pollutant Content of Raw Wastewater
This experiment utilized all existing input without a maximum permitted limit for pollutants. The raw wastewater came in its original state from the sources of origin without first being equalized in quality through a pre-treatment process.

The reduction in BOD, COD, and detergent content proves that physical, chemical, and biological processes occur due to interactions between plants, substrates, and microorganisms. It occurs because water lettuce and caladium wood can reduce the COD concentration by the absorption of organic matter by these plants. In the root area, aerobic and anaerobic degradation of organic matter occurs as long as the liquid waste passes through the plant's rhizosphere. Organic matter will be decomposed due to microbial activity, and nitrogen will be identified if sufficient organic matter is available, the media and plants will absorb that.

These processes occur because plants play an important role and have several functions, including as a medium for growing microorganisms and providing oxygen needs for roots and root areas by photosynthesis. It is used for biological planting for microorganisms in the root zone. Plants can pump air through the root system. In addition, they are also an important component in the nutrient transformation process that takes place physically and chemically to support the deposition of suspended particles. The death in the roots is accompanied by the release of organic matter that supports the denitrification process and the filtration process of solid materials [15].

4. Conclusions
The conclusions are summarized below:

1. The drainage channels in the area of Dukuh Menanggal in Surabaya in the form of an open ditch could be utilized as a wetland construction that can process the pollution content of wastewater.

2. The efficiency values of reducing domestic wastewater's BOD, COD, and detergent levels using SSF (Subsurface Flow System) constructed wetlands are 46%, 61.8%, and 69%, respectively.

3. Caladium and Pistia stratiotes L. synergize to reduce BOD, COD, and detergent parameters in domestic wastewater.
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