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A Vertical Flow Constructed Wetland (VFCW) Design for Communal-Scale Domestic Wastewater Treatment: The Case of Environmental Service Dormitory in Jakarta Capital Special Region (DKI Jakarta) Province

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Abstract

The DKI Jakarta Provincial Government built Wastewater Treatment Plants (WWTP) around the city to treat its generated daily domestic wastewater. Engineering effort is needed to address the influential parameters and quality once the respective measurements are taken. This research proposes the addition of a vertical flow constructed wetland (CW) treatment to the existing WWTP to ensure that the resulting effluent meet domestic wastewater quality standards. This makeover uses both primary and secondary data. Both bathing and toilet wastewater was directly transported to the WWTP through the installed pipe lines, while the washing and rainwater runoff will enter the drainage systems to the Ciliwung River. The proposed CW creates wetlands in the field with fluctuate discharge and release quantity. Data analysis revealed that outflow effluent had a low C/N ratioThe results confirmed that the VFCW processing of the WWTP Unit 1, 2, and 3 have successfully met the Indonesian standards for domestic wastewater, especially the ammonium-nitrogen level and BOD values. However, the NH_4 *value does not fulfill national standard for domestic wastewater quality. Because WWTP Unit 4 has a significantly high ammonia concentration, it will be improved from four to five plants per square meter (ppm) to boost fertilizer absorption that is suitable to remove ammonia by 34–95%.*

Keywords: Domestic wastewater, planning, constructed wetland, WWTP

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INTRODUCTION

The demand for residential facility in DKI Jakarta Province grows steadily following its rapid urbanization that also promotes the investment in housing sector (Utami, 2017). However, the high demand for housing from the market has forced the housing developers become to focus on the speed of house construction to ensure that they will be ready for immediate use. As a result, wastewater management in Jakarta has been a long time issue and should be solved as soon as possible (Afifah et al., 2020; Fadhilah et al., 2020; Septiariva et al., 2022). Hence, there is a discernible water pollution tendency due to excessive use of water by the residents for their domestic activity (Hilmi et al., 2022; Sofiyah et al., 2021; I. W. K. Suryawan et al., 2021).

Yet, the attention to the treatment of domestic waste is slightly sidelined and develops several serious environmental and social problems. In fact, statistic data show that 99.24% of 13 rivers in DKI Jakarta are classified as heavily polluted (Yohannes et al., 2019). To deal with this condition, the DKI Jakarta Provincial Government has built Domestic Wastewater Treatment Plants (DWWTP) at various points in Jakarta to properly manage the generated domestic wastewater. Those include community-based WWTPs, to On-site WWTPs, which include toilets with septic tanks (Ristiawan et al., 2019; I. W. K. Suryawan et al., 2022).

Communal WWTP is a wastewater treatment facility to treat wastewater generated from domestic activities whose management is submitted and handled by the community through Community Self-Help Groups (KSM) or Management and Benefit Groups (KPP) (Renima, 2019). In addition, the program also provides physical facilities for sanitation processing to the community and involves the respective residents actively, starting from the planning, development, and operation to the counseling and mentoring stages.

Based on the flow direction, the CW is divided into 2 types, namely horizontal flow and vertical flow. In fact, the vertical flow CW can treat domestic waste better than the horizontal flow (Shukla et al., 2021; Thalla et al., 2019) due to its better air exchange rate (Zhu et al., 2013). With a better air circulation, an optimal nitrification and denitrification processes with the help of aerobic bacteria can be expected (Tsihrintzis, 2017). On the other hand, artificial CW with horizontal flow is prone to an aerobic conditions in the medium due to the limited air circulation process (Dotro et al., 2017). In addition, the vertical flow CW requires less surface area than the horizontal flow (Matamoros et al., 2007).

In general, vertical flow artificial CW can remove TSS, which is between 80%-90%, organic material 80%-90%, ammonia nitrogen up to 90%, and total coliforms more than 90% (Dotro et al., 2017). Therefore, the use of this vertical flow CW can be an alternative as an additional wastewater treatment after the existing WWTP in the DKI Jakarta DLH Dormitory. However, it is necessary to redesign the waste treatment unit to ensure that all effluent water parameters fulfill the regulations of PermenLHK no. 68/2016 concerning domestic wastewater quality standards (Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia, 2016).

This study aims to propose a vertical flow CW design as an additional treatment for the DKI Jakarta Environmental Service Dormitory Communal Domestic WWTP as a technical recommendation to ensure the achievement of domestic wastewater quality standards.

METHOD

Data Collection

This redesign utilized available technical and operational data sources, namely primary data and secondary data. The data required are as follows:

1. The amount of clean water usage is obtained through secondary data from literature studies. The consumption and customers of drinking water in big cities and metropolitans for simple households are 150 liters/person/day (Messakh et al., 2018; Rinaudo, 2015; Suheri et al., 2020; Zevi et al., 2022). Meanwhile, the average wastewater discharge produced is 80% of the water use. These data are used to reference the dimensions of the CW required.
2. The quality of domestic wastewater in the DKI Jakarta DLH Dormitory environment is obtained through laboratory analysis with parameters measured following the Regulation of the Minister of Environment and Forestry Number 68 of 2016 concerning domestic wastewater quality standards (Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia, 2016). Water samples were taken three times during peak hours of water use in the morning, afternoon, and evening on the same day.
3. The condition of the land designated for the CW and the design location was obtained through land measurements using the google maps application and location contour data obtained through earthexplorer.usgs.gov.

Calculation and Planning

Planning was subjected to the DKI Jakarta Environmental Agency Dormitory with the detailed location can be seen in Figure 1. The planning framework is made in the form of a visual description of the planning stages to facilitate planners in planning and reducing risks that can occur during planning. CW offers easy and affordable technology in planning and operating household wastewater treatment systems. This paper will discuss the type of CW, the types of plants used in CW planning, planning media, CW form, and CW performance. Discharge in a CW depends on many things, such as incoming discharge, evaporation by plants, runoff, groundwater in and out, and so on (Acreman & Holden, 2013). For example, evapotranspiration will reduce the water stored in the system, while runoff will add water to the swamp system. The presence of an impermeable layer can also suppress the value of groundwater infiltration. So, the total discharge from the artificial CW is:

$$Qo = Qi + Qp - (ET \times A) \quad (1)$$

where:

Qo= discharge of wastewater from wetlands, m^3/day
Qi = wastewater inflow, m^3/day
Qr = Runoff Discharge, m^3/day
ET = evapotranspiration, m^3/day
A = Surface area of wetland

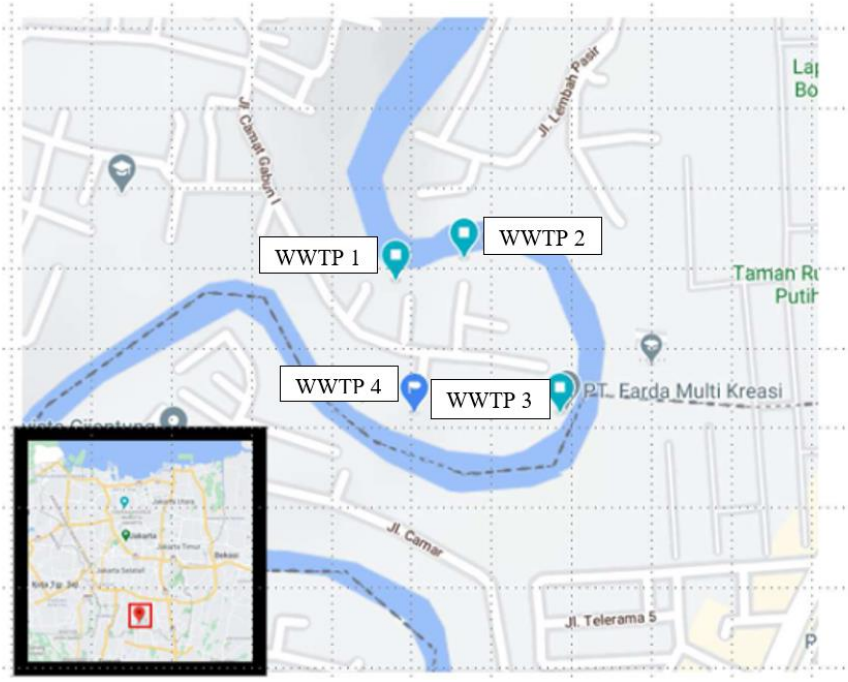

Figure 1. Study Locations in CW Planning (Google Map, 2021)

The practical value of evaporation for terrestrial ecosystems can be determined through the Thornwaite equation.

$$Eti = 16 (10Ti/I)\ a \quad (2)$$

where:
ETi=evapotranspiration potential for month I (mm/day)
Ti = average monthly temperature (°C)
I = local heat index

$$a = (0.675 \times I^3 – 77.1 \times I^2 + 17.9210 \times I + 492{,}390)\ 10^{-6} \quad (3)$$

Then the discharge from evapotranspiration for is:

$$Q_{ev} = \text{Evapotranspiration rate} \times \text{area} \quad (4)$$

HRT is the average time the water is in a CW, as the (U.S. Environmental Protection Agency, 2002; US EPA, 2000) reported. The value is obtained from the volume of water that can be accommodated by the wetland divided by the average discharge.

$$HRT = Vw\ \varepsilon /Q \quad (5)$$

where:
HRT = hydraulic retention time
V_w = Wetland Volume (m^3)
ε = Wetland porosity (0.875) (US EPA, 2000)
Q = Flow rate

HLR is the flow rate divided by the surface area of the wetland and represents the water depth at a certain time interval. Based on the guidelines from the (U.S. Environmental Protection Agency, 2002), the value of the HLR can be determined by the following equation:

$$q = Qi/Aw \quad (6)$$

where:
q = Hydraulic loading rate (HLR) (m/day)
Q_i = Incoming wastewater (m^3/day)
Aw = CW area (m^2)

The BOD value that comes out of this upstream CW system can be determined using the equation from (United States Environmental Protection Agency, 1998) as follows:

$$C_e/C_o = \exp^{(-Kt \times t)} \quad (7)$$

For the calculation of the level of processing efficiency from artificial CW, paying attention to the incoming and outgoing discharges is necessary. This is because the hydrology of the swamp makes this difference in value. So the level of removal efficiency quoted from (Dotro et al., 2017) is:

$$E = (Q_o \times C_o) – (Q_e \times Ce)/(Q_e \times C_e) \quad (8)$$

where:
E = Removal efficiency
Q_o = Influent Discharge (m^3/day)
C_o = Influent Concentration (mg/l)
Qe = Effluent Discharge (m^3/day)
C_e = Effluent Concentration (mg/l)

RESULTS AND DISCUSSION

The Jakarta Environmental Agency (DLH) dormitory is a residence for DKI Jakarta DLH employees and families. The hostel is located on Jalan Camat Gabun I, Jagarkarsa Village, Lenteng Agung District, DKI Jakarta and has 245 families spread over 7 RT. In this area, there are four communal WWTPs with anaerobic-aerobic biofilter processing technology placed in 4 RTs, namely (1) RT 1 serves 26 families; (2) RT 3 serves 31 families; (3) RT 4 serves 35 families; and (4) RT 6 serves 42 families.

In this area, wastewater from bathing and latrine activities enters directly to the WWTP through a pipeline network. Meanwhile, water from washing activities and rain runoff will enter different drainage channels. In this study, this wastewater will be transferred into the receiving water body, namely the Ciliwung River. With this separation between washing water and domestic wastewater strategy, the antibacterial content of soap and detergent that potentially affect biofilm growth in each WWTP will be negligible (Ariani et al., 2015; Nillian et al., 2016).

The ratio between the CW's length and width of the CW of 2:1 recommended (Crites, 1994), the CW's length and width of the CW for WWTP 1 are 6.718 meters and 3.35 meters. Therefore, the dimensions of the CW are 6 meters long and 3 meters wide to facilitate the construction of wetlands. Dimensions for all vertical flow blinds are shown in Table 2. The detailed drawing for the CW planning in detail can be seen in Figure 1.

Table 1. Inlet Wastewater Quality for Each WWTP

Parameters	WWTP 1	WWTP 2	WWTP 3	WWTP 4
pH	7.44	7.55	7.76	7.5
BOD	43.67	10.78	27.75	29.143
COD	155.73	48	78.93	56
TSS	22.416	21.5	22.66	24.66

Table 2. Dimension For Each WWTP

Dimension	**WWTP 1**	**WWTP 2**	**WWTP 3**	**WWTP 4**
Width (m)	3.5	4	4	4
Length (m)	7	7	8	9

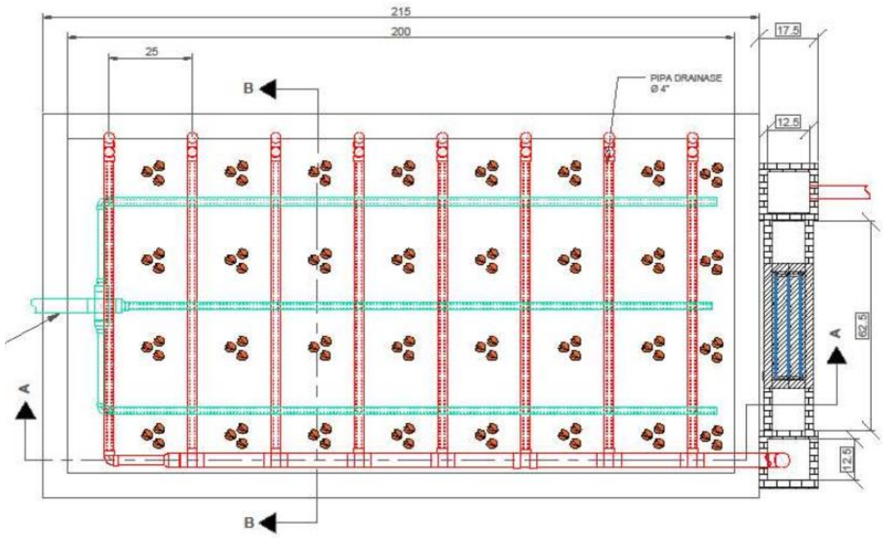

Figure 2. Layout Detail of CW Planning

Upon a thorough data processing, it was found that the existing outlet wastewater had a low C/N ratio of less than 8 (Hanafiah et al., 2019). WWTP 1 is worth 6; WWTP 2 is 3.65; WWTP 3 worth 2.49; and WWTP 4 is only 1.19. Obviously, these conditions can affect the planned VFCW performance because a low C/N ratio can interfere with the nitrification and denitrification processes (Zhou et al., 2017, 2018). Nutrient availability is very important for microorganism growth in wastewater (Afifah et al., 2020; Mutiara et al., 2023; Prajati et al., 2021; I. Suryawan et al., 2021). To overcome this problem, it is necessary to add a carbon source to increase the carbon content in the treated wastewater, and a better nitrification and denitrification processes can be expected.

Table 3. CW Depth Dimensions

Layer	Substrate Thickness	Unit
Sand (d1)	10	cm
Charcoal (d2)	15	cm
Fine gravel (d3)	15	cm
Medium gravel (d4)	25	cm
Boken stone (d5)	15	cm
Total	80	cm

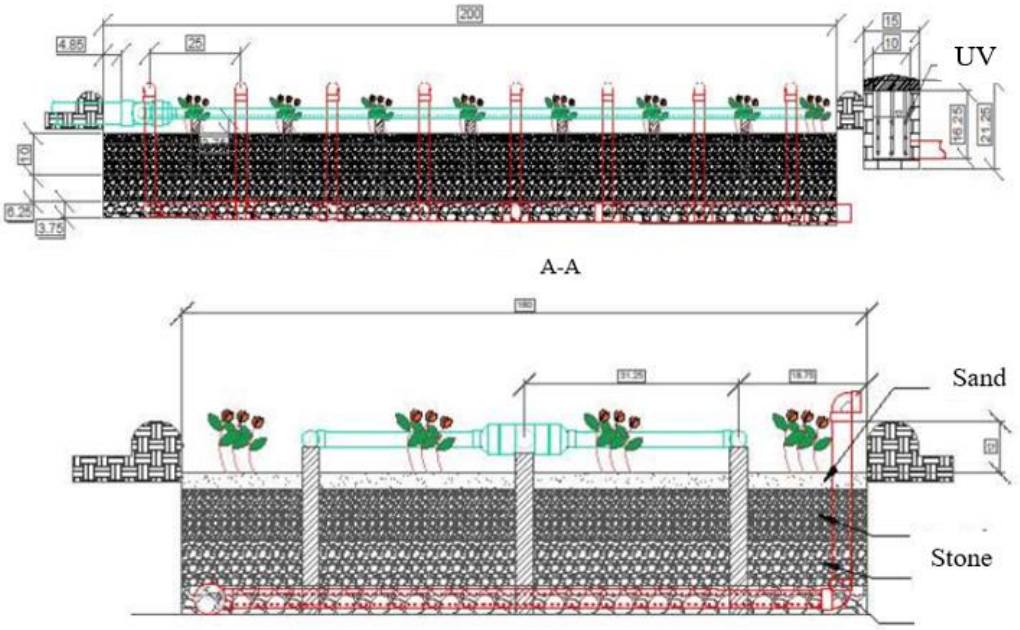

Figure 3. Deep Detail of CW Planning

In a study conducted by (Zhou et al., 2017) and (Zhou et al., 2018), mixing charcoal and fine gravel with a ratio of 1:1 was able to increase the efficiency of COD removal respectively. ,44% and 48.02% to 77.315% and 67.2%, respectively.

Meanwhile, the allowable levels for NH_{4+}-N were 29.98% and 39.26%, respectively. Based on research on mixing charcoal in fine gravel from research (Zhou et al., 2017, 2018), as well as variations in the thickness of the American type VFCW substrate layer from the research of (Tsihrintzis, 2017), the media layer used presented in Table 3.

The greywater discharge used in this study was obtained from 80% of the total use of clean water (Adicita et al., 2020; Hasnaningrum et al., 2021; Khansa et al., 2021; Safrodin et al., 2017). Therefore, the resulting greywater debit can be calculated by assuming the amount of clean water usage based on simple household water use of 150 liters/person/day (Table 4).

Table 4. Quantity of Water Discharge to Each WWTP

	WWTP 1	WWTP 2	WWTP 3	WWTP 4
RT Name (Service Area)	1	3	4	6
Number of Family Heads	26	31	35	42
Total population	104	124	140	168
Greywater	15.0	17.9	20.2	24.2

In applying artificial CW in the field, the discharge wastewater that enters the wetland is not the same as the discharge that exits the wetland. Therefore, the amount of wastewater can be reduced or increased depending on the existing conditions. This certainly needs to be considered so that the presence of water in the swamp system can be controlled. The rain discharge is based on the calculation of the rain return period (PUH). According to the Ministry of PUPR (2015), for rain catchment areas in metropolitan areas, a 2-year PUH is used. Research (Khansa et al., 2020) shows that the average rain discharge for two years of PUH is 73.47 mm/day, and hence, the runoff water discharge for artificial CW can be obtained. The calculation results are presented in Table 5.

Table 5. Quantity of Water Discharge to Each WWTP

	WWTP 1	WWTP 2	WWTP 3	WWTP 4	Unit
Luas	24.5	28	32	36	(m^2)
$Q_{Evapotranspiration}$	0.804	0.919	1.050	1.182	(m^3/day)
Q_{rain}	0.699	0.799	0.914	1.028	(m^3/day)
Q_{out}	15.081	17.976	20.297	24.346	(m^3/day)
HRT_{ave}	1.137	1.090	1.104	1.035	(day)
HRT_{ave}	27.293	26.169	26.487	24.842	(hour)
HRT_{rain}	1.359	1.426	1.445	1.351	(day)
HRT_{rain}	32.604	34.233	34.669	32.421	(hour)
HLR_{ave}	0.611	0.638	0.63	0.672	(m/day)
HLR_{rain}	0.644	0.671	0.663	0.705	(m/day)

Processing of domestic wastewater with VFCW showed that the entire BOD value of the effluent produced was lower than 30 mg/L, which indicates that VFCW processing can meet the parameters of quality standards. In addition, the elimination rate was also excellent, which is an average of 91%. Generally, the average performance of BOD removal is 85% using VFCW, so the amount of BOD processed in the DKI Jakarta Environmental Agency Dormitory exceeds the current average. The use of substrate media comprising a mixture of charcoal can remove COD up to 77.315% (Zhou et al., 2017). So that in this study, the removal of COD achieved 77.315%. Charcoal mixed substrate media removed ammonium-nitrogen ($NH4_{+}$-N) up to 29.98% (Zhou et al., 2017). As a result, the ammonia removal produced was 29.98%. The ammonium-nitrogen value can be found by comparing the value of the molar mass with NH_3. Also, according to research (Li et al., 2011), the earthworm *Eisenia foetida* can help reduce the value of $NH4^+$ by up to 5%.

Table 7. Quantity of Water Discharge to Each WWTP

Parameters	WWTP 1	WWTP 2	WWTP 3	WWTP 4	Unit
Final BOD Concentration	3.456	0.948	2.367	2.896	mg/L
Mass Loading Rate Final BOD	0.052	0.017	0.048	0.071	kg/day
Efficiency	92%	91%	91%	90%	%
Final COD concentration	23.36	7.2	11.84	8.4	mg/L
Mass Loading Rate Final COD	0.352	0.129	0.24	0.205	kg/day
Efficiency	85%	85%	85%	85%	%
Final TSS concentration	2.387	2.290	2.414	2.628	mg/L
Final Mass Loading Rate TSS	0.036	0.041	0.049	0.064	kg/day
Efficiency	89%	89%	89%	89%	%
Initial NH_3 concentration	25.917	13.158	31.708	47.083	mg/L
Initial NH_4 concentration	27.441	13.932	33.574	49.853	mg/L
NH_4 concentration after medium	16.739	8.499	20.480	30.410	mg/L
NH_4 concentration after the plant	8.929	4.533	10.924	16.221	mg/L
NH_4 concentration after worms	8.482	4.307	10.378	15.410	mg/L
Final NH_3 concentration	8.011	4.067	9.801	14.553	mg/L
Mass Loading Rate NH_4 after media	0.238	0.144	0.393	0.699	kg/day
Mass Loading Rate NH_4 after crop	0.127	0.077	0.209	0.373	kg/day
Mass Loading Rate NH_4 after the worm	0.121	0.073	0.199	0.354	kg/day
Provision Efficiency	69%	69%	69%	69%	%

After processing with VFCW, some of the values of the resulting effluent were lower than 10 mg/l. Therefore, WWTP locations 1, 2, and 3 have met the quality standard. However, because the ammonia concentration from Domestic Communal WWTP 4 was very high, the NH_4 value has not met the quality standard of PermenLHK No. 68/2016 concerning Domestic Wastewater Quality Standards. To overcome this problem, installation of more plants to WWTP 4 will be provided from 4 plants/m^2 to 5 plants/m^2, so that it is expected that plant nutrient absorption will be better (Table 7). The range of ammonia removal with VFCW is between 34% -95%, which shows that the amount of ammonia processed in the dormitory environment of the DKI Jakarta Environmental Agency is still included in the existing average allowance (Stefanakis et al., 2014).

CONCLUSION

A WWTP's artificial wetland measures 6.718 meters long and 3.35 meters wide. In-depth data processing revealed that the discharge effluent had a low C/N ratio. As expected, the WWTP 1, 2, and 3 have met the quality standards for effluent wastewater. However, due to the high ammonia level of the domestic wastewater, the final ammonium level has not met PermenLHK No. 68/2016 Domestic Wastewater Quality Standards. WWTP 4 requires addition of at least one plant per square meter to boost nutrient absorption. The BOD elimination rate was 91% indicating excellent performance of VFCW processing. The effluent's BOD was lower than 30 mg/L after VFCW processing suggesting the usefulness of VFCW processing for domestic wastewater treatment.

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