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Ways to Improve Water Quality in Diponegoro Reservoir at Krengseng Watershed, Semarang

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ABSTRACT

This paper explains how to maintain and to improve water quality in Diponegoro Reservoir. Krengseng watershed is located in Banyumanik sub-district and Tembalang sub-district which is part of Diponegoro University campus area. The influent water to the reservoir mostly comes from urbanize areas. Therefore, the quality of reservoir's inflow should meet with domestic wastewater quality standards. Domestic wastewater sewerage systems and treatment plants are required in Krengseng watershed area in order to improve the reservoir's water quality. Water sample were taken from the Krengseng River at 17 locations during the end of dry season. It shows that the concentration of COD, nitrogen and phosphate exceeded the water discharge criteria. Parameter such as COD, DO, pH, temperature, nitrogen, and phosphate were determined. Therefore, a wastewater treatment plant should be designed. The treatment plants are basically using septic tank as primary treatment and anaerobic filter as secondary treatment. EPA SWMM 5.0 was utilized to analyze and design the sewer system. A small bore sewer was used as the main idea for the sewer system. Specifications of piping system must comply with the following criteria such as minimum pipe slope more than 0.006, flow rate between 0.6-3 m/s, and water flow quantity in pipe between 0.2-0.8 of pipe diameter. Total costs for this design are planned about Rp 133.819.636.500, 00 with construction duration for a year and ten months.

Keywords: Water Quality, Wastewater, Sewerage System.

1. INTRODUCTION

Diponegoro dam is located in Krengseng River and the dam is still under construction. The main purpose of the reservoir is for education. The reservoir also can be used to reduce the peak of Krengseng River flood and as a source of water for local domestic water treatment plant. The catchment area of the reservoir is part of Tembalang and Banyumanik sub-district, which is used as residential area, business and industrial areas. During the dry season, most of the reservoir inflow comes from domestic wastewater. It is important to improve and to maintain the quality of water influent using domestic wastewater treatment systems. According to The Agency for Regional Development and Central Bureau of

Statistics City of Semarang, the population growth rate of Semarang is quite high. Based on the City of Semarang population data in 2012, Tembalang sub-district population growth rate is around 3.69% and Banyumanik sub-district population growth rate is around 1.09%. Moreover, all faculties of Diponegoro University had moved to new campus at Tembalang sub-District. This will cause the number of houses and business area in Tembalang sub-District and Banyumanik sub-District increasing. As the increasing population, the quantity of domestic wastewater will also increase.

Nowadays, the drainage system in Tembalang and Banyumanik sub-districts are still a combined system and all of the water flows into Krengseng River. It makes the quality of influent water-to-water body not compliant with the wastewater standards of the Environmental State Minister Regulation No.112 Year 2003. Therefore, a domestic wastewater treatment system should be planned in order to obtain wastewater quality that suitable with wastewater standard.

2. METHOD OF STUDY

Investigating the existing water quality of Krengseng River and designing wastewater networks are two activities in this study for improving the future water quality reservoir. According to topographical conditions and flow directions, the Krengseng river watershed consists of 17 sub-catchments (see figure 1). These seventeen outlets of sub-catchment were determined as sampling location for the river water.

Sampling of river water was conducted during dry season. The river discharge, flow velocity, pH, and DO were measured. In addition, parameters such as COD, Ammonium, Nitrate, Nitrite and Phospate were measured from water samples in laboratorium (Sudarno et al, 2013).

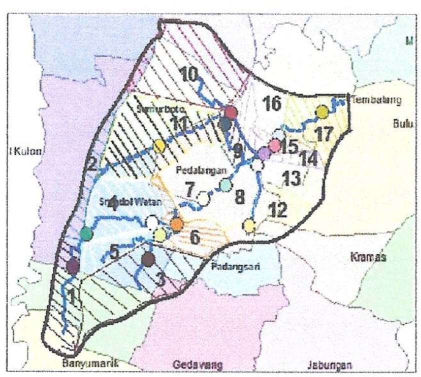

Figure 1. Krengseng River Sub-Watershed
Reference: Sudarno et al, 2013.

On site physical condition and topographical maps, population, infrastructure facilities, and socioeconomic condition of catchment area are required for designing the wastewater system. These data will be used for analyzing the most suitable domestic wastewater system such as pipe diameter, pipe slope, flow rate in pipe, and dimension of the wastewater treatment plant. According to the topographical condition of the catchment area and in order to minimizing operational costs, the wastewater system was implemented using a gravitational system. EPA SWMM 5.0 hydraulic software was utilized for analyzing the hydraulic dynamics of the open channel pipe networks such as; flow rate, pipe slope and flow quantity in pipe network.

3. RESULTS AND DISCUSSION

3.1. Water Quality

Water quality of sampling point is summarized in Table 1. Parameters, expecially COD, NH_3, NO_2^- and Phosphate exceed the recomendation value, that might cause a loss in exosystem fuctnion and increase risk of downstream eutrophication. A control over COD and nutrient loads into river which are asociated mainly with human activity, should be taken.

Table 1 Water Characteristic

Sampling Location	TSS (mg/l)	COD (mg/l)	NH_3 (mg/l)	NO_2^- - N (mg/l)	NO_3^- - N (mg/l)	Phosphate (mg/l)
T1	30	45*	4,23*	0,01	0,02	0,27*
T2	68	45*	3,65*	1,61*	4,05	0,19
T3	26	33*	4,99*	0,01	0,16	0,16
T4	70	70*	7,29*	0,01	0,28	0,17
T5	26	30*	3,39*	1,75*	0,26	0,16
T6	300	47*	3,86*	0,90*	0,10	0,19
T7	114	30*	3,16*	0,61*	0,06	0,27*
T8	62	285*	2,98*	1,12*	0,12	0,25*
T9	60	113*	1,40*	0,45*	0,41	0,51*
T10	90	77*	53,08*	0,54*	0,52	0,27*
T11	20	113*	3,78*	0,44*	0,22	0,30*
T12	180	30*	4,43*	0,61*	0,33	0,31*
T13	112	65*	4,59*	0,50*	0,30	0,25*
T14	180	53*	4,20*	0,64*	0,15	0,31*
T15	62	40*	4,50*	1,20*	4,40	0,29*
T16	62	28*	4,49*	0,38*	0,01	0,25*
T17	120	23	4,25*	10,11*	0,25	0,30*

* exceeds the river water quality standard according to Government Regulation No. 82 Year 2001

Reference : Sudarno et al, 2013.

3.2. Service Area

In order to plan wastewater treatment system, service area should be determined. The wastewater treatment was located at a lower elevation than local residence, so that the system could avoid the utilization of pumps. Also, the wastewater location must be close to the river so that the wastewater influent can easily flow into river. Here are the steps:

- The service area for the wastewater treatment system in the Krengseng River catchment area was divided into several zones or sub-service areas. According to topographical condition of the Krengseng River catchment area was divided into 24 zones or sub-service areas, the sub-service area cannot be determined according to administrative areas. The locations of each sub-service area are shown in figure 2.

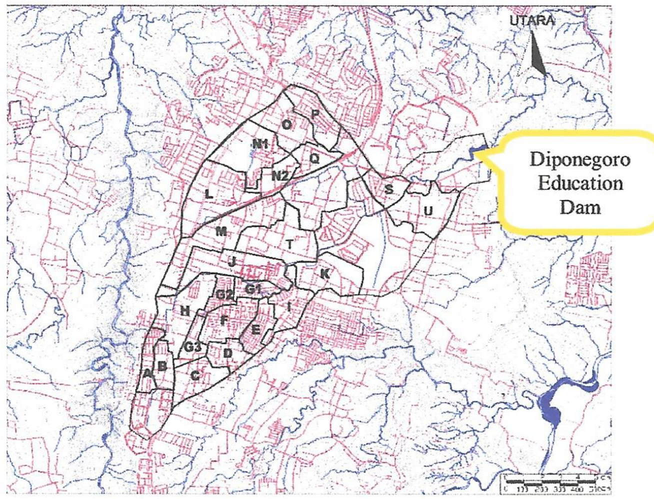

Figure 2. Service Area
Reference: Grace and Rahmat, 2013.

- The pipes of the sewerage system should be placed along the roadside and equipped with a manhole for every pipe junction. A manhole should also be placed every 50 m for the purpose of sewerage maintenance of a straight-line pipe.

3.3. Wastewater Sewerage and Treatment Plant Design

Banyumanik and Tembalang sub-districts are still served with combined drainage system that will cause degradation in the water quality of the Krengseng River. For that reason, the wastewater network system must be separated with a drainage system. Based on recent study of domestic wastewater management in Banyumanik and Tembalang sub-districts, 99% of houses have been equipped with septic tank (Rahman, 2012). Therefore, a small-bore sewer system was chosen as a domestic wastewater sewerage system which is most of the influent water into the domestic wastewater sewerage system only contains minimum sediment (Grace and Rahmat, 2013).

A domestic wastewater system with gravitation flow was planned for this domestic wastewater system. Septic tank was selected as the primary treatment of the system and an anaerobic filter as the secondary treatment. An anaerobic filter system was chosen for maximizing the quality of outflow water, because it will decrease BOD until 70-90%. Also this system is compatible for treating domestic and industrial wastewater with low TSS (Grace and Rahmat, 2013).

3.4. Pipe Design

An open channel flow assumption was used to calculated the pipe dimensions, with flow discharge in pipe between $0.2\ m^3/s<D<0.8\ m^3/s$, flow velocity between 0.6-3 m/s, and minimum pipe slope was 0.006 or 0.6%. PVC for wastewater or PVC class D was used for the domestic wastewater network with pipe diameters from 48 mm until 267 mm and the total length was 69.905,26 m

3.3.1. Wastewater Treatment Plant Design

In this design, septic tank was used as primary treatment and anaerobic filter as secondary treatment with a wastewater influent BOD values of 250 mg/l. This value was based on assumption from literature which stated that normally BOD_5 values for domestic wastewater are from 100-250 mg/l and COD values are from 200-600 mg/l. The wastewater treatment plant dimensions design was calculated from the domestic wastewater discharge which used the average domestic wastewater discharge. Here are the steps for analyzing dimensions of the wastewater treatment plant:

a. Septic Tank

- Calculation of COD effluent from septic tank.

COD removal is estimated based on the effect of sediment settlement and settling time or HRT. In this case HRT was assumed to equal to 2 hours. Figure 3 is a graph that shows the relationship between domestic wastewater settling time and COD removal rate.

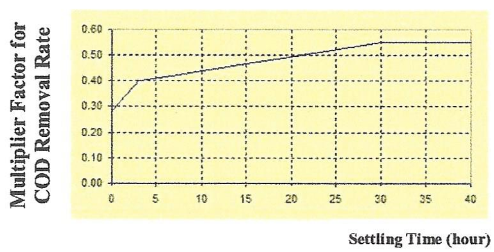

Figure 3. Domestic Wastewater Settling Time with COD Removal Graphic
Reference: Development of Settlement Environmental Health Directorate, 2013.

Equation (1) and Equation (2) are equations for estimating COD removal rate from septic tank.

$$\text{COD removal} = \frac{\text{SS Ratio /COD}}{0.6} \times \text{multiplier factor} \qquad (1)$$

The multiplier factor can be determined from figure 3.

$$\text{COD effluent (\%)} = \frac{100\% - \%\text{COD removal}}{\text{COD}} \qquad (2)$$

- Calculation of BOD removal

Correlation between BOD removal and COD removal is not linear. Therefore for the domestic wastewater correlation between the percentage of COD removal and BOD removal used multiplier factor shown in figure 4.

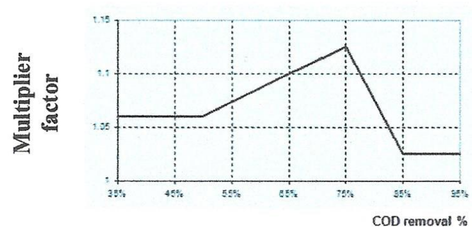

Figure 4. Correlation between COD Removal Percentage and Multiplier Factor for BOD Removal
Reference: Development of Settlement Environmental Health Directorate, 2013.

In order to calculate BOD removal rate from septic tank, Equation (3) and Equation (4) is needed.

$$\text{BOD removal} = \text{multiplier factor} \times \text{COD removal} \tag{3}$$

The multiplier factor can be determined from figure 4 and COD removal can be determined from equation (1).

$$\text{BOD effluent} = (100\% - \%\text{BOD removal}) \times \text{BOD} \tag{4}$$

- Calculation of septic tank volume

Each gram of BOD removal will produce 0.005 liter of sludge. Figure 5 shows the relationship between the sludge shrinkage and storage time.

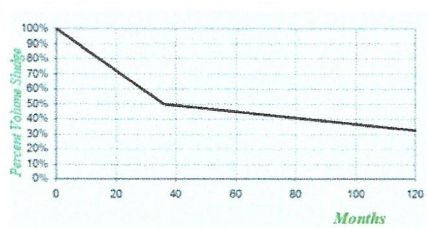

Figure 5. Correlation between Sludge Shrinkage and Storage Time
Reference: Development of Settlement Environmental Health Directorate, 2013.

Equation (5) is an equation for estimating the required volume for septic tank.

$$\text{Required Volume} = (\text{Sludge Volume} + V) + 10\%\,(\text{Sludge Volume} + V) \tag{5}$$

Where :

Sludge Volume = time of storage (month) x 30 x average domestic wastewater discharge x lt/gr BOD *removal* x (BOD *influent* – BOD *effluent*)/1000 x volume every one gram

V = HRT x *flow rate/hour*

b. Anaerobic Filter

- Calculation of COD removal

Temperature is an important factor and it will affect the pollutant decomposition in anaerobic system. Normally, Indonesian average temperature is above 25°C. The correlation between temperature and temperature factor for COD removal is illustrated in figure 6.

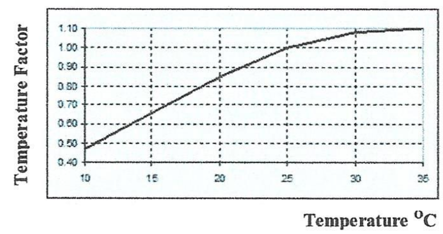

Figure 6. Correlation Between Temperature Factor in COD Removal and Temperature
Reference: Development of Settlement Environmental Health Directorate, 2013.

Anaerobic decomposition process is affected by the initial COD content (wastewater strength) which shown in figure 7.

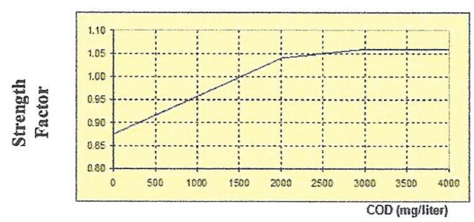

Figure 7. Correlation Between COD Removal Strength Factor and COD Value
Reference: Development of Settlement Environmental Health Directorate, 2013.

Media filter area also affected the capability of anaerobic filter to decompose pollutants. The correlation between COD removal factor and media filter area (specific surface area) is shown in figure 8.

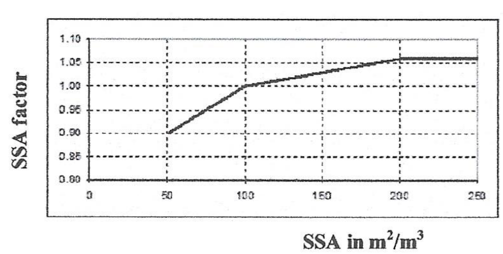

Figure 8. Correlation between COD Removal Factor and Media Filter Area
Reference: Development of Settlement Environmental Health Directorate, 2013.

As well as septic tank, the HRT also effects the COD removal. Figure 9 demonstrate the correlation between HRT and COD removal.

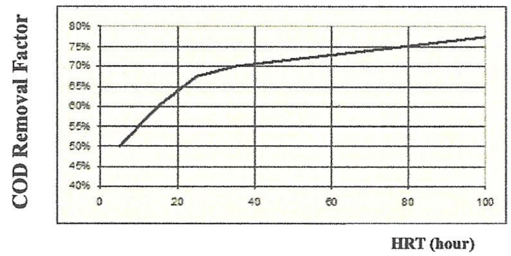

Figure 9. Correlation between COD Removal Factor and HRT
Reference: Development of Settlement Environmental Health Directorate, 2013.

The more chambers used in anaerobic filters it will produce 4% more efficient per chamber, although the effective volume in chambers were unchanged. To calculate COD removal, Equation (6) is needed.

$COD_{removal}$ = f.temperature x f.strength x f.SSA x f.HRT x (1+(total *chamber* x efficiency per *chamber*)) (6)

Where f. temperature is a COD removal factor due to the temperature which is shown in figure 6, f. strength is a COD removal factor because of the initial COD content shown in figure 7, f.SSA is a COD removal factor due to the specific surface area of the media filter which is shown in figure 8 and f. HRT is a COD removal factor due to the settling time in chamber which is shown in figure 9.

If the result > 0.9, 0.9 will be used as an upper ceiling for the BOD removal in anaerobic filter system. If the result < 0.9, then that resulted number will be used. Final COD effluent can be calculated with Equation (7) and Equation (8)

Final COD effluent after being processed = (100% - %COD removal) x COD influent (7)

$$COD = (Initial\ COD - Final\ COD)\ /\ Initial\ COD \quad (8)$$

- Calculation of BOD removal

It has the same calculation concept with BOD removal in septic tank.

- Calculation of anaerobic filter volume as secondary treatment

Anaerobic filter dimension is determined based on the required volume of the anaerobic filter was calculated by Equation (9)

Volume = HRT in *anaerobic filter* x average wastewater discharge/ 24 hours (9)

Table 2 illustrates the final wastewater treatment plant dimension design per zone or sub-service area and the wastewater treatment plant design shown in figure 10. Polypropylene and gravel was used as a media filter.

Table 2. Wastewater Treatment Plant Dimension

Zone	Unit	Dimension (m)		
		Length	Width	Height
A	ST	8.5	5.5	3
	AF	2.5	7	3
B	ST	7	4.5	3
	AF	2.5	5	3

Zone	Unit	Dimension (m)		
		Length	Width	Height
C	ST	6	5	3
	AF	2.5	6	3
D	ST	7	5	3
	AF	2.5	6	3

Zone	Unit	Dimension (m)		
		Length	Width	Height
E	ST	11	7	3
	AF	2.5	9	3
F	ST	13.5	7	3.5
	AF	3	9	3.5
G(1)	ST	8.5	5	3
	AF	2.5	7	3
G(2)	ST	9.5	6.5	3
	AF	2.5	7	3
G(3)	ST	4	3	3
	AF	2.5	4	3
H	ST	7.5	4	3
	AF	2.5	4	3
I	ST	8.5	5.5	3
	AF	2.5	6	3
J	ST	8	3.5	3
	AF	2.5	4	3
K	ST	5.5	4	3
	AF	2.5	7	3
L	ST	10.5	5	3
	AF	2.5	7	3
M	ST	10	5.5	3
	AF	2.5	6	3
N(1)	ST	9	4	3
	AF	2.5	5	3
N(2)	ST	4.5	4	3
	AF	2.5	5	3
O	ST	10	5.5	3
	AF	2.5	6	3
P	ST	7.5	4.5	3
	AF	2.5	6	3
Q	ST	4	4	3
	AF	2.5	5	3
R	ST	6	4	3
	AF	2.5	5	3
S	ST	13	7	3
	AF	2.5	8	3
T	ST	5	4.5	3
	AF	2.5	6	3
U	ST	12.5	8	3
	AF	2.5	9	3

Explanation: ST = Septic Tank
AF = Anaerobic Filter
Reference: Grace and Rahmat, 2013.

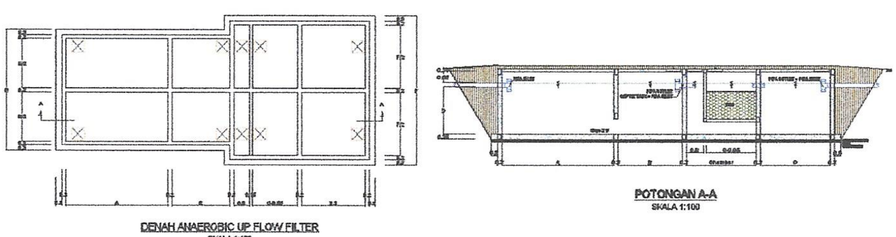

Figure 10. Typical of Wastewater Treatment Plant
Reference: Grace and Rahmat, 2013.

3.5. Cost Estimation

The estimate total cost of the project including tax for the construction of domestic wastewater treatment system was Rp 133.819.636.500,-. The total cost comes from the following components;

- Preparatory work, Rp 906.284.978,-
- Pipe work, Rp 37.347.365.704,-
- Manhole work, Rp 8.130.608.577,-
- Wastewater treatment plant work, Rp 66.252.177.514,-
- Other such as road reinstallation work, Rp 9.017.778.024,-

CONCLUSION

The river water quality investigation showed that the water temperature, pH and Nitrate from the Krengseng river water can fulfill water quality level II. However, TSS, Phosphate, Nitrite, COD and DO from the Krengseng river are over allowable water quality level II. Therefore, eutrophication is a possible problem which may occur at the Diponegoro education reservoir (Sudarno et al, 2013).

Therefore, domestic waste water systems for the Krengseng river was needed to solve the eutrophication problem and maintain reservoir water quality at the Diponegoro education reservoir. The total pipes length of domestic wastewater sewerage system was 69.905,26 m. The wastewater sewerage system utilized the small-bore concept, septic tank and anaerobic filter with Cascade Filterpak YTH1140–Polypropylene and gravel as filter media in anaerobic filter system. The total cost of the domestic waste water system was Rp 133.819.636.500,- .

A mathematical model should be developed for improving and monitoring of the reservoir water quality, since the main purpose of the reservoir is for education. However, it is necessary to conduct further research in order to find an accurate BOD value and BOD removal rate. This will result in a domestic wastewater treatment plant which is more efficient and project cost will be reduced. Moreover, a further population survey for more details regarding the on-site population is necessary. This will make the average wastewater discharge value closer with the real on-site conditions.

It should be introduced and socialized to the inhabitants or residence of the Krengseng watershed area because of the public participation is an important key for operating and maintaining the domestic sewerage system.

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