Conference Paper

Wastewater Treatment Plant and Wetland Design Analysis (Case Study in Samosir, North Sumatera)

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Abstract

Lake Toba, North Sumatera is one of the national tourism areas in Indonesia that has water pollution problem due to the unsustainable development especially in the catchment area. To support Lake Toba Tourism Area and to educate the people about sustainable development, Ministry of Public Works and Housing, Republic of Indonesia built integrated tourist toilets equipped with wastewater treatment plant at Menara Pandang Tele Area, one of the most strategic tourism attraction located in the catchment area of Lake Toba. The wastewater treatment plan is not only to use biofilter but also *Kolam Sanita* (wetland) as secondary treatment. This study would like to see how the wastewater treatment plant at Menara Pandang Tele is designed and see what modification are made from the original design to make it well functioned. This study uses a quantitative method to calculate the volume of the wastewater treatment plant. Further calculation is also needed to determine the dimension of the technologies. The geographical character is the main aspect to be considered in this step. The results showed that to meet the quality standard of the wastewater, the biofilter technology is determined to use three processing stages starting with equalization, primary sedimentation, and secondary process which consist of anaerobic process and clarifier. The dimension modification must not be more than two meters in height. Kolam Sanita is needed to make sure the effluent quality will not harm the groundwater. The modification is required due to the various heights of the ground level and makes the design representative of aesthetic function.

Keywords: wastewater, wetland, Kolam Sanita, tourism area

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1. Introduction

As one of the national strategic tourism destination, the sustainable development of Toba Lake is essential. Based on the data from the Environmental Agency of North Sumatera Province, there has been an increase in domestic waste entering Lake Toba since 2006 [1]. Those pollutants come from the settlements located in the catchment area of Lake Toba. The wastewater enters the water body which mostly empties into

Lake Toba. It causes Lake Toba to become increasingly polluted. As reported, nowadays, many people who settled on the banks of Lake Toba have to travel long distances to get clean water on the hill, as happened in Huta Ginjang Lontung in Samosir [2]. But in reality, not only settlements are found in water catchment areas. The encroachment of water catchment areas is also carried out for tourism. The waste of the activity is also channeled to the water body and contributes to polluting Lake Toba.

The sustainability of Lake Toba the government through the Ministry of Public Works and Housing built the integrated tourist toilets in the Menara Pandang Tele Area which is one of the entrances to Samosir Island, a volcanic island located in the middle of Lake Toba. It also aims to educate people about the dangers of waste to the groundwater and introduce the developed technologies of the Research Institute for Housing and Human Settlements (RIHHS) of Ministry of Public Works and Housing as a solution to reduce the pollution problem in Lake Toba that has been going on for a long time. People have to know that any development should not sacrifice the basic needs of the people around, in this case, the basic need for clean water.

The integrated tourism toilets are using two technologies. Those are Biofilter and Kolam Sanita (wetland). The using of those technologies are usually for urban settlements, both individual and communal users. However, Menara Pandang Tele Area has geographic and geological characteristics that are different from the previous location of technology applications. Menara Pandang Tele is a tourism area and located on the hill. Thus, several modifications must be made so that technologies can function optimally in this location. This study aims to know how the wastewater treatment plant in Menara Pandang Tele is designed and see what modification are made from the original design to make it well functioned.

2. The Method

The method used is a quantitative method where calculations are performed to determine the volume of the technologies. The further calculation also performs to determine the dimension and time needed for the technology to produce effluents that are in accordance with environmental standards. The estimate may be the same as the ideal, but if there is any particular condition on the site, there must be an adjustment to the technologies. All the adjustment will be mentioned at the end of the section.

3. Menara Pandang Tele Tourism Area

Tourism development around Lake Toba makes the catchment area vulnerable. This is because the water catchment area, mostly in a high position, is the best place to enjoy the beautiful view of Lake Toba. Potential locations will certainly lead to the development of supporting facilities, such as toilets, stalls, etc. The wastewater from tourism facilities that are not well-managed then pollutes groundwater. Groundwater which is alternative clean water for the people below the hill will be affected by this situation, so it is important to build eco-friendly tourism facilities.

The Menara Pandang Tele Tourism Area is an area with those conditions. The Menara Pandang Tele Tourism Area is one of the strategic tourist attractions around Lake Toba that is located on the hill. This area is located on the main route that connects Silangit Airport with Samosir Island as shown in Figure 1. This area is the good stopover location before continuing the trip because it is around three hours from Silangit airport or one hour from Pangururan, the district town located on Samosir Island. The area around The Menara Pandang Tele Tourism Area is a water catchment area which is a source of clean water for the people of Pangururan City and its surroundings.

Figure 1: The Location of the Menara Pandang Tele Tourism Area.

There were toilets managed by local officers before the government decided to build integrated tourist toilets. The demand for toilets is very high because many people, tourists, and commuters, stop by to find a toilet. Meanwhile, the condition of the toilet was very simple with a sewage system that was directly channeled into the gorge at the back of toilets. The lack of knowledge and the “not in my backyard” mindset made the treatment for the waste even worse.

Based on geographical conditions, the Menara Pandang Tele area is located around 1800 meters above sea level [3]. The average rainfall per month in this area is high which is between 177 - 440 mm per month and humidity is about 85 percent. The average temperature in this region is 17°C - 29°C. The wind condition is something that needs to be considered because, in certain times such as the evening or night, the wind can blow very strong.

For geological conditions, the Menara Pandang Tele Tourism Area has a shallow hard rock structure. Geological test reports show that hard soil is obtained at a depth of 2.2 - 2.6 meters [4]. Therefore, the excavation work cannot be done too profoundly. The maximum excavation recommended is 1.8 meters.

Based on the projection made by the planner, the number of visitors to the Menara Pandang Tele Tourism Area is expected to reach 300 people per day in the next ten years [5]. The number of visitors is important for planning the dimensions of the waste treatment unit.

4. The Model

Biofilter technology and Kolam Sanita are adopted-technologies developed by RIHHS of Ministry of Public Works and Housing, Indonesia. This technology is widely applied in urban areas where the wastewater becomes a severe problem. The technologies were chosen because they are simple and do not require expensive maintenance costs so that local staff can carry out operations and maintenances easily. The technologies are also widely used by the UN to overcome sanitation problems in poor and developing countries. As stated by the UN Economic and Social Council that “not every problem has a high-technology solution” [6]. Simple and easy technology is the ones needed by newly developing locations where the operation and maintenance resource is not sufficient enough to make it sustainable as we meet in the Menara Pandang Tele Area

4.1. Biofilter technology

A biofilter is a recycling-based wastewater treatment technology that implements a fixed biofilter system where wetlands are made beneath the surface with vertical, horizontal, or combination flow. The biofilter system uses media that serves as a place for biomass growth and retains solids. Media selection must consider specific gravity, hardness, abrasion resistance, surface roughness, the coefficient of uniformity and availability in large quantities. Besides, the media must also have the convenience of backwash and release trapped solids [7]. In general, waste processing is divided into

1. The preliminary stage consisting of equalization and grit chamber;
2. The primary processing stage which includes primary deposition; and
3. The secondary processing consisting of anaerobic biofilter and clarifier

There are some steps to do to planning a wastewater treatment. Before deciding the number of the compartment, some steps must be followed as shown in Figure 2

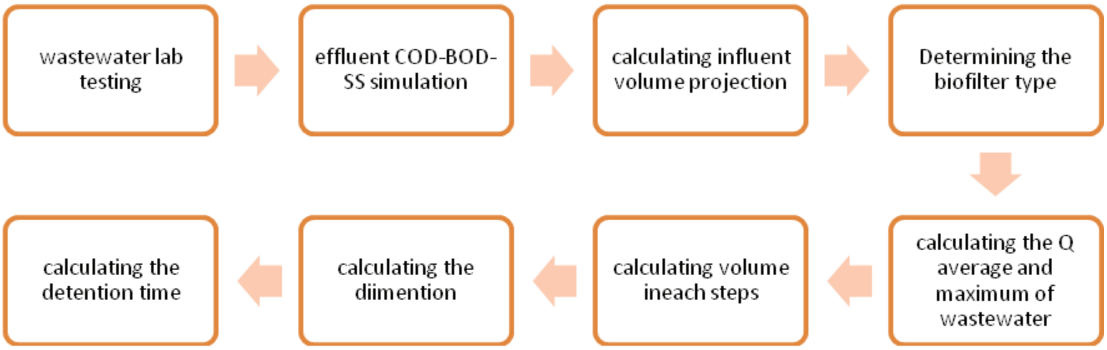

Figure 2: The Design Process of Biofilter.

Before calculating, it is important to simulate the effluent according to the standards issued by the government. The following (Table 1) are the design criteria at each stage:

The planning of the biofilter tank must also be carried out in order for no idle capacity to be used for the work system. The calculation process for each stage is adjusted to the large volume entered and generally accepted.

$$Q\ average\ needed = Eq\ Pop\ x\ Q_{water\ needed} \quad (1)$$

4.1.1. Preliminary treatment

The equalization basin is functioned to homogenize the flow and load contained in wastewater, therefore the amount of effluent capacity released from this tub. While the grit chamber uses to separate the grit particles carried in the wastewater, so as not to interfere with the process and operation of the next unit. In addition, the separation of grit particles can also reduce the processing load for subsequent processing units.

$$Volume = 18\%\ x\ Q_{max\ of\ wastewater} \quad (2)$$

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TABLE 1: Biofilter Design Criteria.

Preliminary stage	Equalization Basin	
	Chamber volume	18 % of maximum capacity of wastewater
	Grit Chamber	
	BOD Removal	0-5 %
	COD Removal	0-5 %
	SS Removal	0 -10 %
	Detention time	45 – 90 s
	Horizontal velocity	0.25 – 0.40 m/s
Primary processing	**Primary Deposition**	
	BOD Removal	30-40%
	COD Removal	30-40%
	SS Removal	50-65%
	P Removal	10-20%
	Org-N Removal	10-20%
	N Removal	0
	Detention time	1.4 – 2.5 hours
Secondary processing	**Anaerobic Biofilter**	
	HRT (Hydraulic Retention Time)	4-72 hours
	Loading of bacterial growing media	0.4-4.7 kgCOD/m^3.hari
	Up flow velocity	$\leq$2 m/hr
	Clarifier	
	Surface loading	10.2-50 m^3/m^2.day
	Hydraulic Loading	0.5-0.8 m/hour

$$Checking\ volume = (p \times l \times t) - 1 \tag{3}$$

$$Detention\ time = checking\ volume / Q_{max\ of\ wastewater} \times 24\ hours \tag{4}$$

4.1.2. Primary treatment

The principle in the first sedimentation basin is to separate suspended solids in wastewater by gravity. This can be done by adjusting the speed of settling. The first two depositional targets in wastewater treatment are clarification and thickening of mud. The removal efficiency of discrete particles with the same size, shape, density and specific gravity does not depend on the depth of the body, but on the surface area of the body and detention time.

$$Total\ volume = Q_{peak} \times HRT / 24\ hours \tag{5}$$

$$Detention\ time = volume \times 24\ hours / Q_{peak} \tag{6}$$

4.1.3. Secondary treatment

Anaerobic Biofilter processes non-deposited materials and dissolved solids by contacting with a microorganism surplus. These microorganisms will decompose dissolved organic matter and dispersed organic material in the waste. A filter is a medium in which bacteria can stick and waste can flow through, as long as the flow of organic matter is broken down by various bacteria

$$\textit{Total volume} = \textit{HRT x Q / 24 x void ratio} \tag{7}$$

While the clarifier serves to separate the activated sludge from activated sludge from MLSS. Sludge containing active bacteria will be recirculated to activated sludge and the sludge containing dead or inactive bacteria is channeled into sludge treatment. This step (sludge treatment) is the last step to produce a stable effluent with a low BOD concentration and low suspended solids (SS)

$$\textit{Surface area} = Q_{peak} \textit{ / surface loading} \tag{8}$$

$$\textit{Total volume} = \textit{surface area x height of the compartement} \tag{9}$$

After the calculation is completed, the dimension calculation can begin. Dimensions can be calculated by the formula

$$\begin{aligned} \textit{Total length } &= \textit{L divider x3 + L deposition basin} \\ &\quad \textit{+ L anaerobic basin x2 + L clarifier basin} \end{aligned} \tag{10}$$

Dimensions affect the length of time needed for the entire process to run. The duration of the process is calculated by the following formula:

$$\begin{aligned} \textit{Total detention time } &= \textit{HRT settling basin + HRT anaerobic basin + HRT Clarifier} \\ &\quad \textit{+ (2x divider width + basin width} \\ &\quad + \textit{effective}_{height}/24 \text{ x } Q_{maxofcleanneeded}) \end{aligned} \tag{11}$$

4.2. Kolam Sanita technology

Kolam Sanita is a naming used by Housing Institute for the development of wetlands. *Kolam Sanita* is usually used for secondary waste treatment after septic tanks or biofilter.

In general, a constructed wetland is divided into several types based on the direction of flow: the vertical flow type, horizontal flow type, and hybrid flow type [8]. In some references, there is also a type of surface flow where there is water stagnating on the surface and the type of subsurface flow where the flow is underground [9].

While the development by Housing Institute is more in the subsurface flow type wetland with vertical, horizontal, or hybrid flow types. According to Sarbidi, the vertical type Kolam Sanita can do 80-95 percent nitrification, horizontal type Taman Sanita is more on denitrification, and hybrid type denitrification up to 75-80 percent [10]. Figure 3 is the stages needed in designing the Taman Sanita

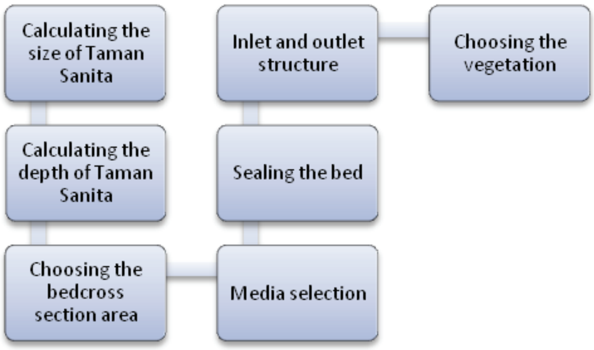

Figure 3: The Design Process of Taman Sanita.

For the planning stage, it is important to ensure the number of influents so that the size of the Kolam Sanita garden can be determined. In addition, the important thing is also to know the local climate conditions, so that consideration of the type of flow can be made. Formulas that can be used to determine the dimensions of Kolam Sanita based on the volume entered are as follows:

$$A = Q_d(inCi - InCe) / K_{BOD} \tag{12}$$

Where A = surface area of Kolam Sanita (m^2); Qd = average flow (m^3/day); Ci = BOD concentration of inffluent (mg/l); Ce = BOD concentration of effluents (mg/l); KBOD = constant velocity (m/day)

Whereas to determine the partition area that is commonly used for horizontal type so that the flow does not return to the previous stage, this formula can be used

$$A_c = Q_s / K_f(dH/ds) \tag{13}$$

For A_c = divider area (m^2); Q_s= average flow (m^3/s); K_f = hydraulic conductivity (m/s) $1x10^{-3} - 3x10^{-3}$; dH/ds = lower cross section slope (m/m)

For other stages, considerations are tailored to the location of the application. Like the consideration of the gravel used, the plants planted. For plants, what must also be considered is the type of flow used in Kolam Sanita.

5. Empirical Calculation

Before performing further calculations it is important to know the concentration of wastewater that will enter the biofilter. Based on tests conducted in the field, the concentration of wastewater entering biofilter is BOD = 350 mg / l, COD = 700 mg / l, SS = 120 mg / l, and NH3 = 84 mg / l. Besides, the important thing is the projection of the number of visitors. As stated in [5], the projected number of visitors is 300 people. If it is assumed that the water requirement per person is 0.03 lt / day, then the water requirement per day is 9 m^3.

5.1. Biofilter technology

The mass balance calculation is used to determine the level of pollutant removal that occurs in each unit. Calculations can be seen from the scheme below (Figure 4). The quality of pollutants in the effluent must meet the quality standards so that it is feasible to be discharged into the water body. The Mass Balance flowchart below is a mass balance on each unit's effluent which can be calculated based on percent removal.

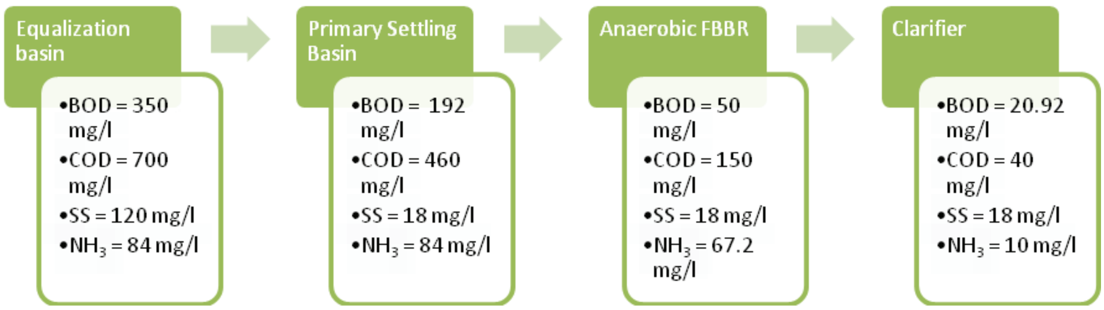

Figure 4: The Mass Balance Calculation Scheme.

Based on the simulation results, the effluent concentration from the last stage of biofilter has met the standards set by the government. The comparation of the effluent standard mentioned in Table 2 as follow

Table 2: Comparation of The Effluent Condition.

No	Parameter	Unit	Effluent Concentration Standard	Effluent Concentration Simulation Result
1	BOD	mg/l	30	20.92
2	COD	mg/l	100	40
3	TSS	mg/l	30	18
4	NH_3	mg/l	10	10

Based of the amount of water needs and water usage, the JSC-20 (A product code that widely used with the volume of wastewater below 20 m3) type is the best choice. The types are tailored to the types available at the vendor. That type of biofilter has the specification as follow: capacity = 9.6 m^3/day; factor peak (fp) = 1.8; factor maximum (fm) = 1.1; quantity of wastewater = 80% of water usage (capacity). The biofilter type data means that the maximum capacity of the tank is 9.6 m^3/day which is calculated on average, the wastewater produced per day is 7.68 m^3/day.

After the type of biofilter has been determined, the calculation is carried out in accordance with the formula (1) - (11). The calculation is not much different from the model where the results shown in Table 3:

Table 3: The Calculation Result of Biofilter Design.

Preliminary stage	**Equalization Basin**	
	volume	1.4 m^3/day
	Width	2 m
	Height	1.8 m
	Length	0.4 m
	Checking volume	0.4 m^3
	Detention time	1.13 hours
Primary processing	**Deposition Basin**	
	Sludge volume	1.13 m^3
	Total tank volume	3.46 m^3
	Detention time	2-4 hours
	Compartment 1 dimension	1.6 m x 1.5 m x 1.44 m (H x W x L)
	Compartment 2 dimension	1.4 m x 1.5 m x 1 m (H x W x L)
Secondary processing	**Fixed Bed Biofilm (anaerobic)**	
	Number of chamber	2
	Total volume	2.84 m^3
	Height	1.55 m
	Width	1.5 m
	Length	0.61 m
	Detention time	2.4 hours
	Buffle Basin	
	Surface peak area	0.82 m^2
	Final Clarifier	
	Width	1.5 m
	Length	0.61 m
	Height	1.6 m
	Detention time	4.61 hours

Then, the crucial thing is the determination of dimensions. As previously mentioned in [4], Menara Pandang Tele Area is an area with shallow hard-rock depth, so that the biofilter dimensions with high depth cannot be carried out. As we see in table 3, the maximum depth given is 1.8 meters so as to get the volume in accordance with the calculation, the length, and width of the compartment increases. The length of the automatic compartment will extend the retention time so that if calculated then, the retention time on the biofilter in the Menara Pandang Tele Area is 18.6 hours or rounded to 19 hours

5.2. Kolam Sanita technology

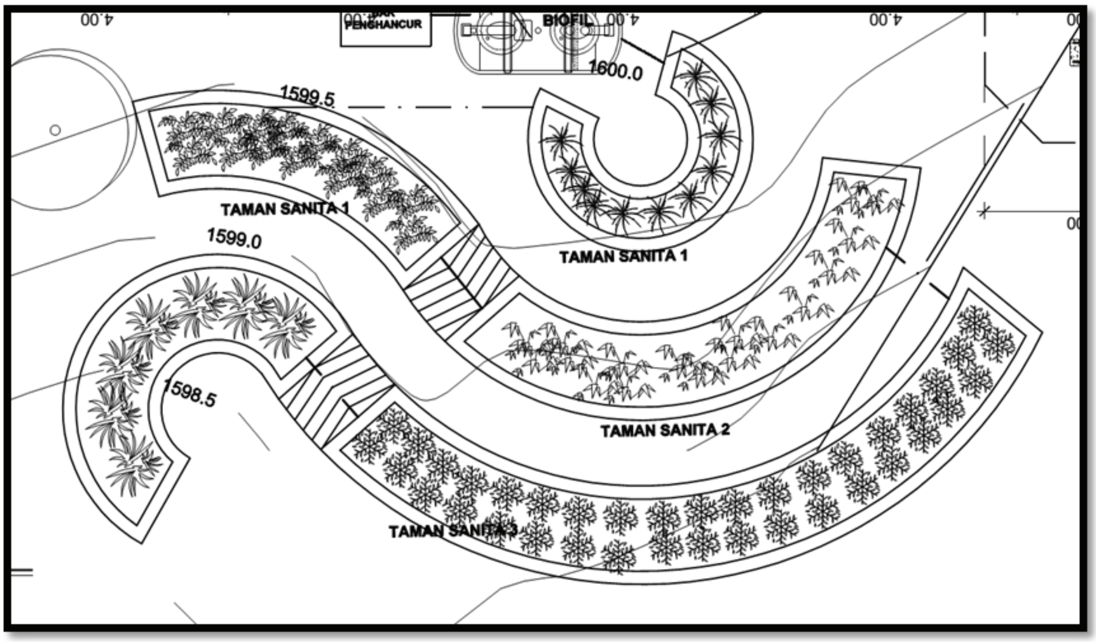

Figure 5: *Kolam Sanita* Design in Menara Pandang Tele Area.

As mentioned earlier in Figure 5, there are several steps taken to make *Kolam Sanita* operate. The first stage is in the form of calculating the dimensions of the Kolam Sanita. This calculation is based on the projection of the number of visitors that have been made previously. Based on the projected number of visitors [5], the total volume that goes into *Kolam Sanita* is 25 m3 / day. To meet this volume, the total length required is 24 meters, taking into account the maximum depth is 1.5 meters and 1 meter wide. *Kolam Sanita* in Menara Pandang Tele Area is divided into three stages of the process with a slope of 9 percent because of the contours around the location that do not allow *Kolam Sanita* to be made in one process. Therefore, this condition is then used to support the aesthetics of the area which is one of the tourist facilities. This also makes people think that the sanitation process not always as disgusting as they think.

Other aspects are the selection of plants and filter media where both aspects are selected based on availability at the site. Local plants will certainly be able to adapt to the local environment. The availability of filtration media determines the type of Kolam Sanita that was built where the Kolam Sanita in the Menara Pandang Tele Area uses the hybrid type which the stage one uses the vertical type and then the next two stages use the horizontal type. Zig zag insulation is another useful consideration for extending detention time so that the resulting effluent has a lower organic content

Inadequate resources in maintenance and high humidity at the site consider making Kolam Sanita with subsurface flow type so that the surface remains dry to avoid the development of insect habitat such as mosquitoes.

6. Conclusion

Based on the results of the design analysis carried out by referring to the previous implementation by Housing Institute, it can be concluded that the geological conditions have a significant influence on the application of sanitation technology in the Menara Pandang Tele Area. There is no difference in the method of calculation between biofilter and Kolam Sanita in the Menara Pandang Tele Area and the original ones. However, more adjustments to geological conditions where hard-rock is found at shallow depths. This condition affects the dimensions and the detention time of technology both biofilter technology and Kolam Sanita. Even so, the function of sanitation technology is still as proper as before as effluent standards prove that in accordance with the standards set by the government. The results showed that the biofilter technology was chosen using three processing stages starting equalization, primary sedimentation, and secondary process which consist of anaerobic process and clarifier There is dimension modification due to the geographical condition, yet still has sufficient volume up to the number of visitors estimation. Kolam Sanita is needed as a secondary treatment to make sure the effluent quality will not harm the groundwater. The modification is made to the kolam sanita because of the various heights of the ground level. The technology uses the three processing stages with the subsurface flow and hybrid type. The total length is 24 meters with height variations due to location contours.

Besides that, because of its function as tourist support, the presence of the *Kolam Sanita* is also considered as an aesthetic function as well as to educate public that waste management does not always have to look disgusting.

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