Sustainability Analysis of Domestic Wastewater Treatment Technology Applied in Human Settlements in Swamp Areas

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Abstract— Providing wastewater treatment systems for human settlements in swamp areas is challenging. Those challenging factors are related to specific physical condition of the settlements, including specific type of house in settlement and specific environmental conditions, as well as specific non-physical condition. Related to those challenging factors, maintain the sustainability of an applied wastewater treatment technology in swamp settlemens is becoming a big concern and the development of existing wastewater treatment technologies to overcome the challenges in swamp settlements is necessary. Wastewater treatment technologies that have been applied in swamp settlements were analyzed based on sustainability criteria. Those technologies included tripikon-S, compact biofiltration system, dry and separated toilet with container, floating pods/ garden, and anaerobic baffled reactor. A hierarchical framework adapted from the Analytical Hierarchy Process (AHP) with sustainability criteria was used as an evaluation tool. The criteria were adapted from widely-used sustainability criteria for sanitation from references, with the elimination of socio-cultural and institution criteria. To weigh the criteria, the assumption of equal importance of each factor in the same stage of the hierarchical structure is used. Several issues were highlighted for existing wastewater treatment systems applied in human settlements in swamp areas, such as durability related to specific environmental conditions, problem in operational and maintenance, treatment efficiency, and cost-related issues. These highlighted issues form the consideration to decide the sustainability of each technology. As a result, the dry and separated toilet with container is considered as the most sustainable system (with score 0.832) and both floating pods/garden and tripikon-S system have the second highest scores (0.666). Based on that result, low-cost concept, that is also related to material selection and environmental, is concluded to be an important factor in achieving the sustainability technological developments of wastewater treatment for human settlements in swamp areas.

Index Terms— domestic wastewater, swamp area, sustainability criteria, wastewater treatment technology

1 Introduction

SWAMP, also known as a bog, fed, marsh, or wetland, is a flat area with soft soil where the soil is permanently filled with water. Most swamp areas are continuously or seasonally inundated [1, 2, 3]. This area can be formed as either a tidal swamp because of the tidal effect of being near coastal areas, estuaries and other areas that are affected by tidal waves, or as non-tidal inland swamps in flat areas near to lakes, rivers or other areas with no rainwater runoff. In some South East Asian countries, many swamp areas are used as residential area. The existence of human settlements in swamp areas was driven by historical, cultural, and economical reason [4, 3].

One of the major issues of human settlements in swamp areas is insufficient sanitation facilities. Open defecation and overhung toilets without treatment are generally found in swamp areas. The impacts of the discharge of domestic wastewater into rivers, lakes, estuaries and the sea is a matter of great concern in most developing countries [5]. The problem becomes bigger when the water bodies that directly receive wastewater are used for basic needs such as cooking, washing, bathing and cleaning teeth, or even drinking water. Several human settlements in swamp areas, especially in urban areas, are categorized as high density slums. With the frequent domestic activities of the people in those areas, the problem of water quality degradation and deposition of domestic wastewater in settlement areas is increasing.

Providing wastewater treatment systems for human settlements in swamp areas is challenging. Djonoputro et al. [3] categorised two main categories of challenges in applying wastewater treatment systems in swamp areas. The first category is related to physical conditions, consisting of 1) types of houses, 2) water waves, 3) floods, 4) seasonal water level variations, 5) unstable ground soils, 6) high groundwater levels, 7) erosion, 8) land subsidence, 9) corrosive air, 10) irregular shape of the settlement, 11) limited land availability, and 12) insufficient road access. The second category is refers to non-physical challenges that are mainly related to the peoples' characteristics, consisting of 1) general slum/squatter characteristics, such as high density, low economic states, illegal settlement, unorganized spreading of the settlement, and dirty environment conditions, 2) low hygiene knowledge among the communities, 3) immigrants domination that makes communities feel that they have little responsibility, 4) low priority area for the government to develop and monitor, 5) defecation habits that are difficult to change.

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Some non-physical factors were also mention by Katukiza et al. [6] as challenges affecting the application of sanitation facilities in urban slums. Those are mostly related to making people want to use and maintain the facilities. Related to those challenging factors, maintain the sustainability of applied wastewater treatment systems in swamp settlements is becoming a big concern and the development of existing wastewater treatment technology to overcome the challenges is necessary [4,7].

To create a strong foundation from which to develop wastewater treatment, the evaluation of existing wastewater treatment technologies should be done. In this paper, a hierarchical framework based on Analytical Hierarchy Process (AHP) with sustainability criteria is used to evaluate wastewater treatment technologies that have been applied in human settlements in swamp area. The AHP is a basic approach to decision making that cope with both rationale and intuition to select the best option from a number of alternatives evaluated with respect to several criteria [8]. AHP is designed to structuralise a scenario affected by multiple independent factors. A complex problem can be divided into several sub-problems that are organized according to hierarchical levels, where each level denotes a set of criteria or attributes related to each subproblem. The top level of the hierarchy denotes the goal of the problem and the intermediate levels denote the factors of the respective upper levels. Meanwhile, the bottom level contains the alternative or actions considered when achieving the goal [9].

2 Methodology

2.1 Selection of Wastewater Treatment Technology

The wastewater treatment technologies that are evaluated in this paper were limited to several technologies that have been applied in swamp settlements, both for stilt houses and floating houses. The information of those technological applications was collected from literature study, field observations, and interviews. The list of technologies that has been evaluated in this paper and its location are presented in Table 1.

TABLE 1
WASTEWATER TREATMENT TECHNOLOGY APPLIED IN SWAMP SETTLEMENT

Wastewater Treatment Technology	Application in Swamp Settlement
Tripikon-S	Application in swamp and river settlements in Pontianak-Kalimantan, Yogyakarta, Morodemak, and Palembang (as off-site system)
Biofiltration System	Application in river swamp settlements in Banjarmasin and Palembang, Indonesia
Dry and separated toilet with container	Application on floating houses in Tonle Sap Lake, Cambodia
Floating pods/gardens	Application on floating houses in Cambodia as primary treatment and in river swamp settlements in Banjarmasin, Indonesia as secondary treatment
Anaerobic Baffled Reactor	Application as communal treatment in Tihik-tihik and Selangan Communities-Kalimantan, Indonesia and Bintan Islands, Indonesia

2.2 Criteria Selection

Criteria developed in this paper was based on several sustainability indicators that are commonly used in domestic wastewater or the other sanitation fields. From many literatures, the main sustainability criteria comprise technological selection/ technical aspect, financial/ economical, environmental (including or not including health criteria), sociocultural, and institutional/organizational factors (Table 2).

TABLE 2
COMMON SUSTAINABILITY INDICATORS FOR SANITATION

Indicators	Explanation
Technological Selection/ Technical Aspect [10, 11, 12, 13, 14, 15, 16, 17, 18]	Related to several technical consideration, from construction, operational, and maintenance, also consideration of system endurance/ age. Some included consideration of environmental condition (such as tophography, soil, groundwater)
Financial/ Economical [10, 11, 12, 13, 14, 15,16, 17, 18, 19, 20]	Related to cost, mainly cost of contruction/ capital cost, operational and maintenance, and some give correlation to willingness to pay and ability/ capacity to pay.
Environmental [10, 11, 12, 13, 14, 15,16, 17, 18, 19, 20]	Related to pollution risk to the environment. Mostly include the treatment (removal) efficiency and or water stream quality/ carrying capacity. Some mention about several health indicators, and some also mention about sources that required from environmental, including raw materials, energy, and forestry also the reuse potential.
Socio-cultural [10, 11, 12, 13, 14, 15,16, 17, 18, 19]	Related to community/ people. Some common indicators are participation and acceptance and several criterias related to community background (such as educational, hygiene). Some literature also consider about conformity, convinience, usability.
Institutional/ Organizational [10, 11, 12, 13, 15,16, 17, 20]	Related to management structure, several correlated it to the government and other stakeholders capacity

In order to meet the purpose and the conditions of evaluation in this paper, socio-cultural and institutional/organizational criteria were eliminated. This is due to the consideration that the technology that is being evaluated were applied in different places with different cultures and institutions, while this evaluation purposes is for general application in common condition of swamp settlements. In terms of the weighing criteria, instead using paired comparison judgement with the fundamental scale as suggested in AHP procedure, in this paper, the assumption of equal importance of each factor in the same stage of the hierarchical structure is used. Table 3 presents the detail of each criteria and weights that are used and Figure 1 represents the hierarchical structure for the sustainability analysis in this paper.

3 Results and Discussion

3.1 Existing Wastewater Treatment Systems in Swamp Settlements

3.1.1 Tripikon-S System

The Tripikon-S (Three consentric pipe-septic) technology (Figure 2) was developed based on the consideration of the condition of stilt houses at the upper sections of river swamp areas. This technology is considered a low cost, easy to build, easy to finance, and easy to replicate wastewater treatment system.

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TABLE 3
SUSTAINABILITY CRITERIA FOR WASTEWATER TREATMENT TECHNOLOGY AND IMPORTANCE WEIGHT SCALE

Criteria	Explanation	Weight
Technological Selection		**0.333**
1. System endurance	Durability of wastewater treatment system in responding to the environmental conditions of the swamp area	0.167
2. Operational easiness	Easy to operate, do not required special attention, and do not required specific skills to operate	0.167
3. Maintenance easiness	Easy to maintain, can be maintained by the community	0.167
4. Construction easiness	Easy to construct, do not require professional skills, and is not more difficult than on land	0.167
5. Availability of sparepart	Easy to find materials and spare parts for solving problems or repairing damage	0.167
6. Adaptability	Can be adapted easily to other places	0.167
Financial		**0.333**
1. Investment cost	Cost that is required to construct the wastewater treatment system is considerably low	0.333
2. O&M cost	Costs that are required in operating and maintening the system are considerably low	0.333
3. Local development	The possibility of communities to pay the cost requirement (investment and O&M)	0.333
Environmental		**0.333**
1. Not polluting the water body	Less potential to spread pollutants in water body due to low removal efficiency and leakage	0.333
2.Efficiency of raw materials	Raw materials are efficiently used in terms of system construction and operation and maintenance, minimising waste production.	0.333
3.Minimization of wastewater	Amount of wastewater is minimized by reducing water use or by using a liquid-solid separation system	0.333

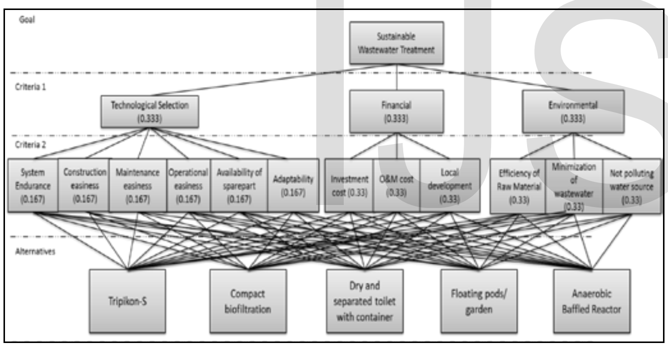

Fig. 1. Hierarchy Structure in Reviewing Sustainable Wastewater Treatment Technology

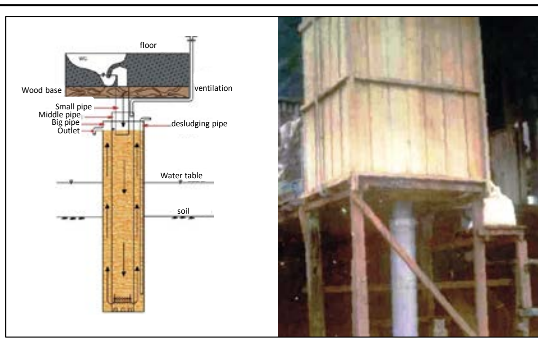

Fig. 2. Tripikon-S System

The Tripikon-S system uses vertical flow in a septic container using PVC pipes with three different sizes and build concentrically around each other as the place where the anaerobic treatment process takes place. Tripikon-S process is adapting septic tank system with three days of detention time.

The Tripikon-S system has been applied and piloted in many places, including the river swamp area of Pontianak and Banjarmasin (data from Civil Engineering Traditional Technology Laboratory, Gajah Mada University and interviews), the riverbank area in Yogyakarta [21], coastal area in Morodemak [22], and swamp area in Palembang (data from observations and interviews). Several information about the removal capacity of Tripikon-S has been reported. The field application of Tripikon-S in Pontianak achieved 95% of organic removal as $KMnO_4$, and in Banjarmasin achieved 83% of organic removal as $KMnO_4$. Both cases had an influent of 1000mg/L organic concentration as $KMnO_4$ and reached optimal conditions after 3-4 months of usage. Saraswati et al. [22] reported that Tripikon-S could remove 40% of organics as BOD5 and 44.5% of organics as $KMnO_4$ after five years of use (without maintenance) with an initial concentration 334.7 mg/L BOD5 and 3,177 mg/L $KMnO_4$. Beside field applications, laboratory studies on Tripikon-S have also been done. In Selintung et al. [23], the outdoor Tripikon-S system, designed for six persons with three days detention time, was analyzed for ten days. It achieved 20.86% organic matter removal as $KMnO_4$, 35.03 % BOD5 removal, and 23.92 % COD removal (influent concentration: organic matter as $KMnO_4$ = 179 mg/L; BOD5 = 362 mg/L, COD = 533 mg/L). Putri et al. [24] did the optimization of the Tripikon-S system, using artificial domestic wastewater, removal works efficiently in 1-2 days, and by using a continuous procedure, 58% COD removal can be achieved (initial COD = 1,500 mg/L) with a 48 hour hydraulic retention time (HRT) and 50% COD removal achieved (initial COD = 2,000 mg/L) with 48 HRT. In order to reach higher removal efficiencies, several developments of Tripikon-S system have been established. Saraswati et al. [22] combined the Tripikon-S system with a gravel filter and Putri et al. [24] designed Tripikon-S with additional bioball in the large pipe and with an additional venturi-shaped chamber. Both designs gave promising increases in organic removal efficiency.

The problems in applying the Tripikon-S system are mainly related to its durability and maintenance. Five Tripikon-S systems were applied in the Morodemak region in 2003 [22]. Two were built in a wet area (river swamp) with the system directly attached below the toilet facilities, three others was built in land/dry areas, with a separated system connected by a pipeline and using concrete to replace the biggest pipe. Out of the two wet types of Tripikon-S, one of them completely could not be used since major big damage was caused by a boat crash. Another one was still being used by the people even though it had some leakage problems at the bottom. Out of the three land-type Tripikon-S system, one was still being used by the people without any problems, another one could still be used, but was not being used because the toilet had been replaced, and another one could not operate since elevation changes affected the flow of the wastewater.

3.1.2 Compact Biofiltration System

The compact biofiltration system that was mentioned in this paper is a fabricated fiber tank with several compartments that facilitate different treatment process, including the suspended and attached microorganism process. The biofiltration system makes it possibile to facilitate both the anaerobic and aerobic process in one system [25]. This treatment system was claimed to be a complete treatment system that made the requirement of an additional infiltration area negligible. Since the system is fabricated and produced as a compact product, repair works and spare parts can only be provided by a specific company. The biofiltration system cannot be considered a cheap wastewater treatment system, but can be considered as easy to build system.

Sumidjan [25] applied the biofiltration system with floating wetland/garden as a additional treatment step (called BIOSANTER) in the river swamp settlement of Banjarmasin (Figure 3). The biofilter tank was placed directly above the swamp soil, connected to a hanging toilet by a PVC pipe. The tank was damaged after several months, presumably due to the impact that was received due to the tank moving from the effect of the tidal wave. In order to solve the problem, special materials (heavy duty) were used, but this affects the cost of the system. The problem of applying a fiberglass biofiltration system was also found in Palembang [26]. The biofiltration tank was found floating freely due to the effect of the tidal wave, loose from its pipe connection. The issue of the pipe connection and joint being affected by the movement of the tank was also considered in Djonoputro et al. [3].

Fig. 3. Application of the Compact Biofiltration System [25]

3.1.3 Dry and Separated Toilet with Container

The dry and separated toilet (Figure 4) is one of the sanitation options for urban slums [6] and from the perspective of the difficult environmental conditions for construction such as in swamp areas, it can be one of the best solutions. Navarro [4] mentioned that for houses built on areas with high groundwater levels and those submerged in water, the most ideal means is to collect the human waste and transport it to another site for treatment or disposal. However, the wastehandling requirement of this system makes this technology difficult to adapt by many communities. Putri [27] also mentioned that people rejected the use of dry toilets in the swamp settlements of Palembang city and Banyuasin regency. It can be concluded that the biggest consideration of the application of dry and separated toilet with container is related to peoples' acceptance, both the acceptance to use the dry toilet system and to contribute in wastehandling such as replacing and collecting the waste container.

Fig. 4. Dry and Separated Toilet with Container and Waste Collection Station [28]

Brown [28] and Sayre et al. [29] applied the dry and separated toilet system (Urine Diversion Dehydrating/ Dry Toilet – UDDT) as a Community-based project which included capacity development and empowerment of people in the floating communities of Tonle Sap Lake, Cambodia. The community was involved in designing the toilet from the beginning. They also contributed to the trial phase. It led to people accepting and agreeing to operate and maintain the toilet system, including replacing the bucket and collecting used bucket at a waste collection station. This UDDT application is considered a low-cost wastewater treatment system since it utilized components that could easily be found, such as buckets and jerrycans. Other consideration include that its by-product could be used as fertilizer, as long as the stabilization process is complete, so that the products do not contain any harmful/pathogenic microorganisms.

3.1.4 Floating Pods/ Gardens

Floating pods/ gardens (Figure 5) refer to the modification of wetland system as a wastewater treatment technology. Chakraborty et al. [30] developed a floating pod system for the Tonle Sap Floating Communities in Cambodia by using widely-available tarpauline with water bottles sewn into the edges. A single pod has 235 L of capacity while a douple pod has 470 L of capacity. Water hyacinths (Eichhornia crassipes) are used to carry out the treatment. A rope connects the system to the house. Two floating pods were implemented by simply added tap water and water hyacinths, then putting sewage (35 L/ day) in one of the floating pods and feces (500 g/day) into the other. The system can reduce coliform bacteria from 65,000 cfu/100 ml as the influent concentration, to 10,000 cfu/100 ml as the effluent concentration. Several issues that appeared in the implementation of floating pods by Chakraborty et al [30] were the smell, animals such as mice that disturbed the treatment area, durability or tarpauline especially at the edges related to sun exposure, and stability/flexibility issues.

Brown [28] and Sumidjan [25] have also implemented a floating garden, but the design was quite different to Chakraborty et al. [30]. Sumidjan [25] added a floating garden by using a PVC pipe as floating material and nets, using coconut fiber as the growth media of the plantation, and did not use any specific type of plants. The floating garden received effluent water from biofiltration via a PVC pipe with capillary hole to help grow the plant. In this work, the floating garden was used mainly to value add to the whole treatment plant, mainly to its aesthetic value and to help people understand that the treated wastewater could be a functional resource. Similar to Brown [28], a floating garden was an added value to the people as it was also designed to use the stabilized wastewater from the UDDT after several months of stabilization process in the storage.

Fig. 5. Floating Pods/ Gardens [25, 30]

3.1.5 Anaerobic Baffled Reactor (ABR)

The ABR (Figure 6) is considered an improved septic tank because of the series of baffles under which the wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment [31]. Organic removal as BOD may be reduced by up to 90%, a lot higher compared to a conventional septic tank (around 50-60% removal). Sludge will accumulate, especially in the first treatment chamber, meaning that desludging is required every 2 to 3 years. Infiltration is still required as secondary treatment for the ABR effluent.

Fig. 6. ABR Followed by Filtration in Tihik-tihik and Selangan Coastal Communities

The ABR system can be applied as individual or communal wastewater treatment, but is mostly used as communal wastewater treatment. One of the considerations is cost, since the cost could be considerably lowered if it is implemented to serve higher numbers of people. The system was widely used, including in several swamp areas in the Sumatera and Kalimantan area of Indonesia. Djonoputro et al. [7] described the difficulties in constructing the ABR system and other large concrete tanks in a swamp and flooded environment. Beside these difficulties, the cost (ABR is classified as moderate cost) can be significantly higher compared to construction on land. The additional cost is related to the additional structures required, such as pile for foundation, also related to drying effort and other additional engineering work during installation. Putri et al. [26] also mentioned another issue related to the concrete ABR tank in Palembang area, which are the cracking of the tank and/or the movement of the treatment system related to the soil condition in swamp that can change the flow of wastewater changed.

3.2 Sustainability Analysis

From the review of existing wastewater treatment technologies that have been described in the previous sub-chapter, the information that is collected is further used to assess the degree of accomplishment for each sustainability criteria A summary of the sustainability analysis of wastewater treatment technologies is represented in Table 4.

From the sustainabilty analysis, the highest score was achieved by dry and separated toilet with container (0.832), while both floating pods/garden and tripikon-S system received the second highest scores (0.666). These three technologies has some similiarity in their concept and considerations in technology establishment. Those similar concepts are low-cost, use of widely-available material, and the technology concept was originally developed with the purpose of dealing with swamp/flooded environmental conditions.

TABLE 4
SUMMARY SUSTAINABILITY ANALYSIS OF WASTEWATER TREATMENT TECHNOLOGY

	Tripikon-S	Compact Biofiltration	Dry separated toilet with containment	Floating pods/ garden	ABR
Technological Selection					
1. System Endurance	X	X	√	√	√
2. Operational Easiness	√	√	X	X	√
3. Maintenance Easiness	X	X	X	X	X
4. Construction Easiness	√	√	√	√	X
5. Availability of Sparepart	√	X	√	√	√
6. Adaptability	√	√	X	√	√
Financial					
1. Investment cost	√	X	√	√	X
2. O&M cost	√	√	√	√	√
3. Local Development	√	X	√	√	X
Environmental					
1. Efficiency of raw material	√	X	√	√	X
2. Minimization of wastewater	X	X	√	X	X
3. Not polluting water source	X	√	√	X	√
Score	0.666	0.389	0.832	0.666	0.444

The other two treatment technologies, which are ABR and the biofilter are the treatment technologies that were originally designed to fulfill standard human settlement conditions, mostly for land area. In order to fulfill swamp area conditions, these technologies must use additional constructional tools or structures. The consideration of low-cost and widely-available material is partly fulfilled but additional costs are required for implementation in swamp area. While the biofiltration system, since it is pre-fabricated, is not considered a low-cost technology.

Low-cost was also mentioned in Navarro [4] as a key factor in applying wastewater treatment in a coastal area. In some aspects the situation is similar to swamps. It was stated that low-cost could be achieved by analyzing the environment conditions, community structures, and available services such as water supply, collection of waste water and solid waste. In the larger feasibility framework, Navarro [4] explained that a wastewater technology is feasible to be applied in coastal areas when it is feasible in areas with adverse ground conditions, specifically, impermeable and unstable soils with high ground water tables; high density areas; requires minimum water; and does not require large equipment for waste collection and transportation.

From the result, accompanied by the comparison with feasibility criteria by Navarro [4], this analysis highlights some essential factors that can increase the sustainability potential in developing wastewater treatment technologies for applications in human settlements in swamp areas. The key consideration is to provide a low-cost technology, while achieve overcoming the constraints of specific environmental conditions and the availability of resources (especially related to building materials). Socio-cultural and institutional factors also should not be forgotten in order to select and develop technologies for the specific human settlement conditions in swamp area.

6 Conclusions

Several issues were highlighted regarding existing wastewater treatment technologies applied in human settlements in swamp areas, such as durability related to specific environmental condition, requirements and fulfilment of operation and maintenance, treatment efficiency, and cost-related issues. Those highlighted issues comprise the considerations to decide the sustainability criteria that each technology should accomplish.

Dry and separated toilet with container are considered the most sustainable system (with a score of 0.832) and both floating pods/garden and tripikon-S systems have the second highest scores (0.666). Based on the result, low-cost concept that was also related to material selection and environmental characteristic is concluded to be a factor in achieveing sustainability of technological development of wastewater treatment for human settlements in swamp areas.

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