Constructed Wetlands: Sustainable Solution to Managing Domestic Wastewater in the Rural Areas of Sarawak

Yee Yong Tan1, Fu Ee Tang1, Carrie Lee Ing Ho1

1Department of Civil and Construction Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, Miri 98009, Sarawak, Malaysia

E-mail: tan.yee.yong@curtin.edu.my

Abstract. Constructed wetland (CW) could be an attractive alternative for wastewater treatment in Sarawak, particularly in rural areas with low population densities, due to its advantage of being cost- and energy-effective, as well as its simplicity in operation and maintenance. CW has been widely used as a decentralized wastewater treatment system in developed and developing countries to treat various types of wastewater, including domestic sewage, surface runoff, agricultural wastewater, and sewage sludge. However, CW is still a relatively new wastewater treatment method in Sarawak, where only two CW systems are available in the entire state. This paper presents a review of existing CW systems treating domestic sewage and a pilot-scale study of subsurface flow CW system treating septage in Sarawak. In addition, the cost-effectiveness, environmental impact, public perception, and legislative requirement of CW systems are discussed in the context of wastewater management policies in Sarawak. This study gains important insight into the feasibility of CW systems as a long term solution to wastewater management in the rural areas of Sarawak.

1. Introduction
As the largest state of Malaysia, the total population and level of urbanisation in Sarawak as of 2010 are 2.47 million and 53.8%, respectively [1]. The relatively low level of urbanisation implied that the development of rural areas is still an important agenda of Sarawak State Government. The longhouses and other rural settlements in Sarawak are traditionally situated near rivers as their livelihood is highly dependent on these waterways [2]. Therefore, the protection of aquatic environments in these communities from potential pollution is important. In Sarawak, the direct discharge of raw domestic wastewater is one of the main cause of water pollution [2]. Such type of wastewater typically contains significant amounts of suspended solids, readily biodegradable organic matters, nutrients, and pathogens. In general, domestic wastewater constitutes greywater and blackwater, in which greywater is the wastewater generated from households through showering and washing activities, and blackwater is the mixture of faeces, urine and flushwater discharged from toilets. It should be noted that blackwater only constitutes a small portion of the total domestic water, but it contains the majority of the organic matter, nutrient, and total pathogen [2].

Sewerage service is an important part of public sanitation, which protects public health by reducing the risk of disease outbreaks due to pollution by domestic wastewater. In Malaysia, the major challenges of the development of a sewerage system are population density, piped water and energy supply, and funding for operation and maintenance [3]. The average population density in Sarawak is only twenty-
two (22) people per square kilometre as of 2016 and it could be much lower in the rural areas [4]. Thus, an onsite or decentralized system is a more cost-effective solution for wastewater management. Similar to sewerage services, the coverage of treated water supply in the rural areas of Sarawak is low, which was only 39% as of 2017 [5]. As a consequence, there is a lack of service in the rural areas to support a conventional wastewater treatment system due to its high water and energy demand for operation and maintenance. As for funding, Reference [3] highlighted that the public is less willing to pay for sewerage services in Malaysia compared to clean water supply. Reference [6] also highlighted that stormwater management was considered as a more urgent issue than wastewater treatment in Sarawak. Furthermore, in Sarawak, there is an absence of private wastewater operators such as Indah Water Konsortium Sdn. Bhd, which operates and maintains sewerage services in Peninsular Malaysia. As a result, there is no long-term commitment to sustain sewerage services in the rural areas of Sarawak, in which most planning, construction, operation and maintenance of sewerage systems are currently funded by the government.

In the rural settlements of Sarawak, the greywater is usually discharged to storm drains, where it directly flows to the rivers or waterways without any treatment due to the low level of contaminants [7]. On the other hand, on-site domestic treatment such as septic tank is widely used to provide preliminary treatment for blackwater. As of 2016, there were 456,678 individual septic tanks (ISTs) in Sarawak, serving more than 2.2 million people or 89% of the population in both urban and rural areas [8]. IST is a simple and low-cost method to primarily treat blackwater by means of sedimentation and anaerobic process [9]. The effluent of IST is mixed with greywater and is discharged to the waterways without further treatment. The performance of IST is subject to the quantity of solids that accumulate in the tank over the time, where it has to be desludged regularly to maintain its treatment efficiency. The mixture of sludge and blackwater removed from the septic tank is known as septage, which is a high strength waste that has to be adequately managed and disposed [10]. However, the regular desludging of septic tank is deficient in the rural areas of Sarawak due to limited access to desludging trucks and a lack of treatment facility. Therefore, IST is not a sustainable solution for wastewater management in the rural areas.

A concept of ecological sanitation (EcoSan) has been introduced to sustainably manage blackwater from a government boarding school with 1,900 students in the rural areas of Sarawak [2]. The EcoSan modified the ordinary flush toilets to canal-flush toilets, which reduced the volume of flush water up to 80%. An oil & grease trap was installed to trap the oil & grease and food waste from the greywater before it was discharged to the storm drain. The retained oil & grease and food waste were discharged to a digester chamber, where they mixed with the blackwater from the canal-flush toilets and underwent anaerobic digestion to produce biogas. The fermented waste was then discharged into a sand bed for dewatering. The nutrient-rich solids trapped by the sand bed was used as the fertilizer. The EcoSan is an ideal technology for domestic wastewater management in the rural areas, but there are still several drawbacks. The economic impact of such a system is poor when implemented in isolated dwellings or small communities since the quantity of blackwater and food waste collected is insufficient to produce significant amounts of biogas and fertilizer. Secondly, the existing construction and social and cultural habits have to be changed in order to adopt the EcoSan. For example, the ordinary flush toilet have to be renovated to canal-flush toilets, as well as the used toilet paper have to be disposed separately from the flush water to prolong the system’s lifetime.

 Constructed wetland (CW) could be an attractive alternative to the conventional wastewater treatment to solve the problem of managing wastewater in Sarawak, in particular for rural areas with low population density, as it is simple to operate and maintain and it is cost- and energy effective [6]. CW is an artificial system to replicate the treatment ability in natural wetlands. CW has been widely used as centralized, decentralized, and onsite wastewater treatment systems in developed and developing countries to treat various types of wastewater, including domestic wastewater, stormwater runoff, and agricultural wastewater [11]. Furthermore, CW also demonstrated good capability in septage dewatering and treatment [12]. Its simple design also eases the construction, operation, and maintenance of the CW. In addition, the water and energy consumption of CW during operation and maintenance are much lower.
compared to a conventional wastewater treatment plant. CW may also act as an educational and recreational park, simultaneously enhancing the wildlife habitat [13]. The major drawback of CW is the large requirement of land area. Although CW has been recommended by the Department of Irrigation and Drainage Sarawak as a low-cost and energy-efficient disposal alternative for treated wastewater in smaller communities with available land, such a system is still rarely applied in Sarawak, where only few CW systems are available in the entire state at the time of writing.

This paper briefly reviews the existing CW systems and a pilot-scale study of CW in Sarawak. This paper further examines the feasibility of CW for wastewater management in the rural areas of Sarawak by looking at the environmental impact, cost-effectiveness, public perception, and legislative requirement towards implementation of the technology in these areas. The barriers to implementing the use of CW as a wastewater treatment option in Sarawak is also discussed. The approach to promote the implementation of CW system in the rural areas of Sarawak is then proposed.

2. Review and Discussion

2.1. Existing CW System

There are two types of CW: free-water surface flow (FWS) and subsurface flow (SSF). A FWS system is a flooded basin where the plants are floating above in or rooting in the base of basin. FWS system is generally used as a secondary or tertiary treatment to “polish” the stormwater or treated wastewater that has low level of contaminants and odour. SSF system consist of a wetland bed that acts as a filter for solids retention, a substrate media for the bacteria growth, and a base for plant growth. SSF system can be further categorized into horizontal flow (HF) and vertical flow (VF) system based on the water flow direction. Such a system is feasible to serve as a primary treatment for blackwater, greywater, or even septage. The design of CW has high flexibility to adapt various types of wastewater. In both FWS and SSF system, the role of plants is to uptake the nutrients from the wastewater and release oxygen into the wetland bed. The basin or wetland bed provides a substrate media for microorganism to remove contaminants such as organic matter, nutrients, and pathogen via biological and chemical process, as well as to physically remove solids through settlement and filtration. Sand and gravel are the common materials used to construct the wetland bed, which are usually available in the rural areas of Sarawak.

There are two existing CW system in Kuching city, the capital of Sarawak. The first CW system started operation in 2010, which treated the domestic wastewater from 191 units of houses or 600 population equivalent (PE) at Taman Boulder Built Kuching [15]. The project cost of this system was RM 2 million. There are two wetland cells in this wastewater treatment plant. The first cell is a horizontal SSF system that receive the primary effluent from an Imhoff tank with screen chamber. Then, the treated wastewater from the first cell is discharged to a FWS system that serves as a tertiary treatment. The record showed that the effluent quality from this wastewater treatment plant complied with Standard A of the Environmental Quality Act (Sewage and Industrial Effluents) 1979. FWS system was also used in the Kuching Centralised Sewage Treatment Plant as tertiary treatment before the effluent is discharged to Sarawak River [16]. In addition to these plants, a SSF CW was also applied in a pilot project of Urban EcoSan in Hui Sing Garden, Kuching, to treat greywater discharged from nine households [16]. A horizontal SSF CW was constructed as a secondary treatment after oil and grease traps and biofilters. Reference [17] indicated that significant removals of organic matter, nutrients, suspended solids, and faecal coliform were observed in the effluent from the SSF CW. These case studies has revealed that CW has been considered as a viable solution for secondary and tertiary wastewater treatment in Sarawak.

SSF CW system has been proven as a feasible system to dewater and mineralize septage [18]. A pilot-scale, two-stage vertical flow SSF CW system has been constructed in Curtin University Malaysia, Miri, to treat septage collected from households [12, 19]. The wetland beds in the first stage were constructed using gravel and planted with common reed, which aimed to dewater raw septage by separating solids and liquid using physical filtration. As for the second stage treatment, sand, gravel, and palm kernel shell were used in the wetland beds to prolong the hydraulic retention time of influent,
and thus the dissolved organic matter and nutrients could be adequately treated. This pilot-scale system demonstrated a promising dewatering efficiency, and the effluent showed a substantial removal of organic matter and nutrients [12, 19]. The technical aspects of this pilot-scale SSF CW system, including the optimized loading rate, resting period, and hydraulic behaviour, have been comprehensively reported [12, 19, 20, 21]. However, the mineralisation of sludge deposit and the associated clogging issue in this SSF CW is still under study.

Through an interview, Drainage and Irrigation Department Sarawak has raised several potential issues to implementing CW in Sarawak. One of the main issue is that large amount of gross solids such as domestic, industrial, and construction wastes are found in the wastewater, which would lead to clogging issues. In addition, the design loading rate for the CW is also typically low compared to the rate of discharge of wastewater. Poor operation and maintenance practice may also lead to clogging issues in the CW.

In summary, all existing CW systems serve as secondary or tertiary treatment after the conventional wastewater treatment method, including the activated sludge system, Imhoff tank, and biofilters. The examination of CW system at Taman Boulder Built and Hui Sing Garden in Kuching showed that CW is an appropriate alternative of wastewater treatment for small communities, but its viability to treat blackwater directly remains questionable since CW has not yet been implemented as the primary treatment for domestic wastewater in Sarawak. On the other hand, CW might be a practical solution for septage disposal in the rural areas of Sarawak. The characteristic and composition of the domestic wastewater and septage from the local source are important design parameters for the CW.

2.2. Cost-effectiveness and Environmental Impact

CW system is a wastewater treatment that is relatively cheap in capital, operation, and maintenance cost. It is mainly attributed to its simple configuration and low energy and chemical consumption. However, due to its large land requirement, the cost of implementing a CW system in an area with limited land is uncertain. Therefore, a life-cycle cost analysis (LCCA) might be used to measure the cost-effectiveness and treatment capacity of a CW system over a given time period.

To conduct the LCCA, it is essential to identify the cost breakdown of a CW system. In general, the capital cost for such a system can be categorized into wetland bed and control system. The construction of wetland bed requires land, earthwork, liner, substrate media, vegetation, and ventilation pipes. Then, the control system comprises storage tanks, pumps, water control structures, monitoring equipment, inspection chambers, piping, electrical instrumentation, and facility appurtenances. As for the operation and maintenance cost, the major expenses are on the staff (plant control, monitoring and inspection, maintain/repair structure and equipment, regulatory duties, etc.), electricity, materials and equipment parts for maintenance, and engineering consulting/contracting.

A brief LCCA for a CW system was carried out by the authors in the year 2013. The system was designed to treat septage up to 100,000 PE. The design comprised eight primary wetland beds and eight secondary wetland beds. The area of the wetland bed was estimated at 3.2 m² per PE with an aspect ratio of 10:6, in which each wetland bed has a dimension of 15.4 m x 25.7m. The wetland beds were designed to be constructed by coarse gravel and sand and were vegetated with Phragmites Australis. This LCCA also included the distribution and drainage pipes, pumps, and concrete tanks under the capital cost. Due to its low energy and chemical consumption, the major expenses on operation is on the removal of residual sludge deposit and administration. Based on this analysis, the overall life cycle cost for a CW system up to 50 years was three times lower compared to a conventional treatment plant. The capital cost was highly dependent on the design of the system. On the other hand, the operational and maintenance cost for CW system was much lower compared to conventional sludge treatment plant with same capacity.

In general, life cycle assessment (LCA) can be used to measure the environmental impact of the wastewater treatment system. Reference [22] indicated that the CW is an appropriate decentralized wastewater treatment system for rural communities as it is low in energy consumption and solids emission. Reference [23] also reported that the environmental footprint of CW system in small
communities was much lower compared to conventional activated sludge system since it is a nature-based technology with low electricity and chemical consumption. Furthermore, CW is an attractive system when the availability of land is not an issue. Reference [24] highlighted that the environmental impact of CW is typically caused during the construction phase and was highly dependent on the materials used in the system. Reference [25] further emphasized that the use of artificial materials such as reinforced concrete or polyethylene cover might increase the environmental footprint of the system.

2.3. Public Perception

Reference [26] carried out a social survey to study the attitudes and behaviour of the local community towards the pilot project of EcoSan in Hui Sing Garden, Kuching. This pilot project received positive feedback by the residents since the landscape of wetland created zero nuisance as a local wastewater treatment system. The residents showed strong willingness to support such a system to be implemented in a larger scale. This survey also revealed that the interest and awareness of water pollution was typically poor among the residents. In addition, the role of the government was also emphasized through the survey in terms of policy establishment and facility implementation to solve the issue of wastewater treatment.

Reference [6] reported that the acceptance of CW as a stormwater and wastewater treatment method by the stakeholders of the construction industry in Sarawak, including engineering consultants, contractors, and local authorities, was relatively low. The survey showed that only 36% of the respondents considered CW as a practical solution for stormwater and wastewater treatment in Sarawak, and only 23% of the respondents were willing to pay for a CW system. It was mainly due to poor understanding about its cost-effectiveness and absence of a standard guideline for the design, construction, and operation of CW in a tropical region. On the other hand, 68% of the respondents believed that CW was constructible and 59% assumed that no delay will be caused from its construction. This study also pointed out that funding, enforcement, and lack of knowledge were the major barriers to implement CW system in Sarawak. These barriers were directly or indirectly linked to the policies and practices of the state government and local authority.

A study that investigated the sustainability of three existing CW systems in Thailand through interviews and questionnaire surveys [27] is also referred to here. The interview revealed that low operation and maintenance cost was the main consideration for the implementation of the CW as a wastewater treatment system, in particular to avoid the dependency on user payment for its operation and maintenance. The results also indicated that attitudes, knowledge, awareness, and support of the local community were crucial to sustain the CWs in Thailand. Furthermore, the availability of local expertise, clear institutional framework, and public awareness significantly affected the sustainability of the CW system. In addition, the visible impact of the CW system on the environment played a key role in attracting financial support from the government.

There is a lack of up-to-date study regarding the public perception of CW system in Sarawak, where the existing surveys were done more than a decade ago. The existing study have revealed that the awareness and knowledge of water pollution issues are crucial to the implementation of CW system in Sarawak. Moreover, poor understanding about the CW system also prevents greater commitment in using this technology.

2.4. Legislative Requirement

The implementation of CW system in Sarawak has to fulfil legislative requirements. Desktop studies and interviews have been carried out with government agencies, including the local government, Land and Survey Department, and the Department of Environment, to identify the potential hindrances with respect to legislation.

According to Environmental Quality (Sewage) Regulations 2009, the act and regulations for the wastewater treatment service is based on the quality of wastewater discharged from any premises into any inland waters or Malaysian waters. For the new source of wastewater discharge or release, a notification shall be submitted to Department of Environment, which includes the description of the
wastewater source, information on wastewater treatment system, and discharge information. The construction of a wastewater treatment system requires permission from the relevant authority, in which the plan and specification of the system should be submitted. In addition, the operation and maintenance of a wastewater treatment system requires license from the authority. However, neither the Federal Government nor the Sarawak State Government has proper standards or guidelines for the operation and maintenance of a CW system, which more or less hindered the implementation of CW system in Sarawak.

Based on the Local Authorities Ordinance 1996, local authority is granted the right to establish, amend, or revoke by-laws to ensure the good order of health, safety, quality of life, and well-being of the residents in the local authority area. This right is applied to any waste treatment or processing plant. At the time of reporting, the only by-laws that is relevant to domestic wastewater management is the Local Authorities (Compulsory Desludging of Septic Tanks) By-laws 1993, which indicates that the private septic tanks in the local authority area should be properly deslugged and serviced after a certain period. Since CW system is not a common wastewater treatment system in Malaysia, the local government does not have any specific regulations or by-laws for such a system.

Due to the large land area requirement, the application of land use for the CW system is always a challenge. In Sarawak, the application of land development is through the Land and Survey Department. For the private developer, the applicants have to register with the State Planning Authority to propose the planning of land development. According to the Land and Survey Department, the CW system is considered as an industrial premise. The application of land development for a wastewater treatment plant must be submitted together with the engineering drawings of the system with all the key plans and detailing. All the engineering drawings must be acknowledged by a professional engineer. After the land development plan has been approved, the applicant would need to pay the planning approval fees and submit the subdivision and engineering plans to the Land and Survey Department. In addition, an authorized land surveyor needs to be appointed for the land development.

The application of land development for a project initiated by the Federal or the Sarawak State Government is relatively simple. The details of the project, including the purpose of development, information of applicant, sources of funding, site description, etc., needs to be submitted to the Land and Survey Department. If the applicant agrees with the site designated by the Land and Survey Department, a site acceptance form has to be submitted. The land survey for the government project is carried out by the Land and Survey Department. Then, the engineering drawings and building plans are prepared by the Public Works Department. State Planning Authority holds the right for the project approval.

In summary, the effluent quality from the CW system must comply with the standard as established in Environmental Quality (Sewage) Regulation 2009, and the license of the operation and maintenance has to be granted by the local authorities. Therefore, the absence of a standard or guideline for the CW system might hinder the approval of the project. The large land area requirement of CW is always a challenge, and the feasibility of the CW system in treating either domestic wastewater or septage has to be convincing to the State Planning Authority prior to the application for the land use.

3. Conclusion

The advantages of CW system can be summarized as being low in capital cost, operation cost, energy usage, and chemical consumption, as well as simple in construction, operation, and maintenance. Accordingly, CW is a feasible decentralized system to manage domestic wastewater in the rural areas of Sarawak, either to treat domestic wastewater directly or to treat the septage desludged from septic tanks. However, CW is still not a common wastewater treatment system in Sarawak. There is an insufficient number of existing system to demonstrate the treatment capacity of CW. The government and private sector are also not motivated to adopt such a system due to lack of engineering guidelines on design and construction of the CW. Furthermore, lack of technical knowledge and large land area requirement also hinders the implementation of CW in Sarawak. The following approaches are recommended to promote the implementation of CW in the rural areas of Sarawak:
To develop a standard guideline for the design, construction, operation, and maintenance of CW system in Sarawak;
To develop comprehensive life cycle assessments or life cycle cost analyses to determine the cost-effectiveness and the environmental footprint of CW in Sarawak;
To include CW system as an option for domestic wastewater treatment in the act and regulation;
To promote CW to the local authorities, developers, and industries as a system that creates a visible improvement on the water quality through a public showcase.

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