Use of engineered wetlands for onsite treatment of wastewater by the local communities: Experiences from Tanzania

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Abstract

Since its inception about 10 years ago, Constructed Wetlands (CWs) technology has been well received in Tanzania due to a wide range of functions. CWs are used to treat wastewater from municipal systems, pulp and paper industries, prisons, schools and colleges. Among the recipients of CWs are the Moshi Urban Water and Sewerage Authority (MUWSA) for polishing Waste Stabilization Ponds effluents, Kibo Paper Mills for treating industrial effluents, Shinyanga, Malya and Bariadi Prison and Kleruu Teachers College and Ruaha High School for Treatment of domestic wastewater. All these systems are Horizontal Sub-Surface Flow Constructed Wetlands. This paper reports on results of a survey of the six (6) mentioned operating CW systems, focusing on the existing situation and the observed operation and maintenance challenges and needs. The survey was carried by visiting the CWs and sampling for determination of BOD$_5$, COD, PO$_4^{2-}$, NO$_3$-N, and NH$_3$-N. Results from the survey and laboratory analyses in three of these CWs indicated lack of general and site-specific operation and maintenance guidelines, which seriously affect life of these systems, aesthetics and performance of pollutant removal. This is evidenced by failure of these systems to meet local and international permissible discharge limits to the receiving water bodies.

Keywords: constructed wetland, maintenance, operation, performance, wastewater

INTRODUCTION

Constructed Wetlands (CW) must be managed if they are to perform well (Beharell, 2004). Thus, CW require regular monitoring and maintenance to ensure it remains functional and in a 'healthy' condition. Development of Operation and Maintenance (O&M) guidelines should be consistent with the purposes and intended life of the wetland, which includes the requirements for safety, water management, cleanout of sediment, maintenance of structures, embankments, and vegetation, control measures for vectors and pests, and containment of potential pollutants during maintenance operations (Kuginis, 1998; Beharell et al., 1998; Beharell, 2004). In Tanzania, CW technology dates back to 1998 when the first research group was launched at the University of Dar es Salaam under DANIDA funding. The group conducted research on the feasibility of using Horizontal Sub-surface Flow Constructed Wetlands in Tanzania. 10 years of successful studies and awareness raising about what these systems can do in terms of pollution control resulted into massive acceptance by the local public. A number of projects on the use of CW systems for wastewater treatment were developed notably in Iringa, Moshi, Shinyanga, Dar es Salaam and Mwanza. However, the major challenge facing these systems is lack of guidelines on operation and maintenance so as to ensure optimum performance and long life span of these systems. Therefore this study reports on needs assessment for operation and maintenance of CW systems in Tanzania. Together with the performance data, this could pave way to developing operation and maintenance guidelines for maintaining consistently good performance and longer life span of this technology.
Site visit and questionnaire survey

A total of seven (7) Constructed Wetland sites were visited and assessed. These sites are located at Shinyanga Region (Shinyanga Prison and Bariadi Prison), Mwanza (Malya Prison), Iringa (Kleruu Teachers Training College and Ruaha Secondary School) and Moshi (MUWSA and Kibo Paper Mill). The field visits were conducted for data collection on baseline information regarding the current condition of CW systems through physical observation, conducting structured questionnaire survey and focused group discussions. Comprehensive surveys and interviews were conducted for the users of CW technology at each of the visited site to identify specific needs related to operation and maintenance. In addition to field observations, the questionnaires and interviews were designed in such a way to capture important site-specific issues such as wetland specifications, current operational problems, fencing, status of plant and vegetation health, existing weeds and unwanted plant control programs and existence of local operation procedures.

Wastewater Sampling and Analytical Methods

Wastewater samples were collected from three CW sites between January and December 2009 for determination of wastewater physico-chemical parameters. A total of twelve (12) samples were taken from Shinyanga Prison, 10 samples from MUWSA and nine (9) from Ruaha Secondary School. Wastewater samples from the three sites were analysed at close-by Government Water Laboratories in Mwanza and Iringa and also at the MUWSA Water Quality Laboratory. Temperature, pH and Electro Conductivity were measured in situ, and the determination of other physico-chemical parameters was in accordance with the Standard Methods for Examination of Water and Wastewater (APHA, 1998).

RESULTS AND DISCUSSION

Description of Visited CW systems

*Kleruu Teachers Training College (TTC) CW.* The CW system is located within the Kleruu TTC campus, and has been operational since 2003. The college owns a Horizontal Subsurface Flow Constructed Wetland (HSSFCW), consisting of baffled system with 4 cells and a total area of 625m² planted with *Phragmites mauritianus*, although several other species have emerged due to overland flows, phasing out the originally planted species. The system was designed with the capacity to treat wastewater of 800 people. Before the realization of the Constructed Wetland, the Kleruu TTC used a Mechanical Aeration Chamber. The function of the mechanical aeration chamber was to remove organic loading and suspended solids from wastewater prior to entering the oxidation pond downstream. However, the mechanical aeration system is not functioning due to failure by the college to meet running costs especially electricity. CW was installed to replace the pond in the understanding that the mechanical aeration system was replaced by septic tank. The college however, failed to secure funds to complete the project. Thus, the CW system practically receives untreated domestic wastewater, causing clogging and overland flow as a result of high nutrient, suspended solids and organic loading. CW effluent is discharged via a chamber to an open channel which is also used for irrigation of vegetable gardens.
Ruaha Secondary School CW. Ruaha Secondary School has a HSSFCW system consisting of two cells of 20 m×10m planted with *Phragmites mauritianus*. One cell was constructed in 2004 and the other built one year after. The system receives wastewater of domestic nature from student dormitories, offices and kitchen, pre-treated in a septic tank before entering the wetland. Each cell was designed to treat wastewater to 600 people, bringing the total capacity treatment of wastewater of 1200 people equivalent. The treated effluent is used for irrigation of elephant grass, which is a source of fodder for cattle owned by Ruaha Secondary School.

Moshi Urban Water Supply and Sewerage Authority (MUWSA) CW. Moshi municipality has a HSSFCW system consisting of one cell of 57m × 27m and depth of 0.6 planted with *Phragmites mauritianus*. The wetland was designed to polish domestic and industrial sewage from Waste Stabilization Ponds. The wetland is connected to the second maturation pond in a ponds system having 6 cells. The overall system consists of HSSFCW, Fish Pond (FP), and Paddy Farm (PF). This integrated system was designed and constructed in 2004 which treats effluent from the primary facultative pond. The flow rate to the HSSFCW is 400m³/day. The effluent from the HSSFCW is reused for irrigation in the pilot paddy farm and aquaculture farming (fish pond).

Kibo Paper CW, Moshi Municipality. Kibo paper mill located in the outskirts of Moshi Municipality, close to Kranga river which originates from Mount Kilimanjaro catchment area. The CW system consists of a Baffled system for treatment of sewage from paper milling industry. The Kibo paper HSSFCW consists of baffled system with three cells of 128m × 42 m planted within *Phragmites mauritianus* with the total covered area of 5376m². The designed flow rate was 81L/sec with the operational flow rate of 80L/sec. Wastewater influent to the CW has a very strong organic load in form of suspended solids that are discharged from industrial processes, which is a major reason for clogging and overland flow in the system. The treated wastewater from this system is discharged to a nearby river and also used for irrigation of soy and vegetable farms in the vicinity of the area.

Shinyanga Prison CW. Shinyanga prison has a HSSFCW system consisting of one cell of 50m×15mx0.6m planted with both *Phragmites mauritianus* and *Typha latifolia*. The wetland cell was constructed in 2001 and designed for the purpose of treating sewage from the prison. The average flow rate to the system is 50m³/d.

Malya Prison CW. The Malya Prison CW system consists of one HSSFCW cell planted with *Phragmites mauritianus*, designed to treat wastewater from the septic tanks serving the Malya prison community. The size of the system is 55m × 20m wide with the area of 1100m² designed and constructed for treating domestic sewage. The average flow rate to the system is 50m³/d. The system also experience clogging and overland flow (flow channeling). Several native plant species which were not originally planted have emerged, making diverse plant community.

Bariadi Prison CW. The Bariadi Prison CW consists of two HSSFCW cells packed with gravel and no vegetation. One cell was designed to treat sewage from septic tanks of the prison community. The size of the system is 45m x 20m with the total area of 900m². The system has the flow rate of 50m³/d.

Common CW Problems

Results indicate that 86% of the surveyed CWs experience various forms of operational problems. The major problem experienced in most of these systems is a combination of blockage and flooding/overland flow (Figure 1). Other operational problems include seepage through the walls or leakage, storm water runoff especially during and after rainfall events and, cracks.
Main causes of blockage of the system range from solid wastes introduced accidentally, solid wastes introduced intentionally to solids deposition and biological growth. For situations where there is both blockage and over flooding of the systems, major causes have been identified to be lack of drainage system (50%) and hydraulic overloading (33%). The frequency of occurrence of blockage and overland flow/over flooding varies from one system to another, ranging from once per week to once per year depending on site-specific conditions.

**Plant Maintenance.** Six out of seven CW systems surveyed are planted with *Phragmites mauritiana*. Bariadi Prison wetland was not planted at the time of visit, due to lack of specific instructions for planting. Plant health condition at Kleruu TTC wetland was poor at the time of visit. The poor health condition of Kleruu plants may be attributed to the fact that the wetland receives untreated sewage that contains high organic loading content and high amount of suspended solids. All surveyed CWs systems that are planted have age of more than three years.

Three out of seven CWs have their own locally developed plant maintenance program. The maintenance program is developed from within. As stated earlier, Bariadi Prison and at Kibo Paper Mill CW systems had no plant maintenance program whatsoever. Owners of MUWSA and Shinyanga Prison CWs only prune some of the trunks. Pruning is done as needs arise (normally once per two or three months) by cutting unwanted plant trunks. At Malya Prison, they perform watering in periods of no flows and periodic replacement of unhealthy plants. Watering is done once per week and periodic replacement of unwanted plants is done once per month. At Ruaha Secondary School, harvesting of plants, uprooting of unwanted weeds and pruning of some trunks is practiced. Harvesting of plants is done once per year and is done by cutting the plants at 10-30 cm above the surface of substrate. The harvested plants, litter and debris are removed from wetland bed and burned.

Uprooting of unwanted weeds is done at the time when the plants are short to ensure accessibility. Pruning is done especially to stop the plant trunks from covering the inlet and outlet zones of the wetland. This is mostly done once per month. At Kleruu TTC, plant harvesting at the time of removing the substrates for cleaning, after every nine months of operation, Weeding of unwanted plants is done as need arise. About 57% of harvested plants are disposed onsite. Five out of seven CW owners requested to be provided with a standard plant maintenance guideline. At present, the cost for plant maintenance ranges from TZS 45 to 90 USD per operation. About 75% of maintenance funds are raised by CWs owners.

**Fencing constructed wetland premises.** Results show that out of 7 surveyed CWs, 3 systems have been fenced. While fenced systems (Ruaha, Kleruu and Kibo Paper) are situated at more risk areas where people and livestock can easily intrude the systems, non fenced CW systems belong to a more...
controlled and monitored authority like Prisons and the MUWSA. For the fenced systems, the materials used are wire mesh and barbed wires supported by concrete and wooden poles, and in general, they were found in a good condition at the time of visit, with minor damages that occur less frequently. Nevertheless, 71.4% of respondents acknowledge the importance of fencing CW system in order to minimize encroachment from livestock and humans. The rest didn't acknowledge the importance of fencing the CW on the basis of cost implications borne upon fencing. However, all respondents had no idea of the costs for building and maintaining a fence for the CW systems.

Weeds and Unwanted Plant Control. Out of seven CW systems surveyed, five systems experience operation problems related to weeds. The study also established that almost all operators of CWs do not have a structured and defined weeds control program rather they address the problem when it arises to a certain level. Weeds are removed from CW systems by manual uprooting. Sometimes, especially when the system is totally clogged (a case of Kleruu Teachers Training College), weeds are removed during the process of removing substrate materials. Removed weeds are dumped around the CW system and left to dry before open fire burning. The actual or indicative cost for removing weeds from CW systems is still unknown among CW owners and operators.

Operational Procedures. Out of seven systems surveyed on the water flow and levels, five were periodically inspected and two out of seven systems were less often inspected. For those systems assessed, sampling for water quality determination is done frequently in one system. In the other two systems, sampling is done less often. Sampling is not done at all in three CW systems. Daily checking up of debris and development of short circuits/dead zones are effectively carried out in all CW systems surveyed. This ensures longer life span and effective operation of the systems. Findings indicate that cleaning and maintenance of inlet and outlet structure, valves and monitoring devices are done in five out of seven systems. Maintenance and cleaning is done less often only for two systems. In the period of unusual flow due to a weather event, six out of seven CW systems are usually inspected. The number of operators is adequate in six out of seven CW sites. The assessment also revealed that facilities and equipment are adequate in two CW sites and inadequate at three sites. CW users at two sites had no idea on the necessary facilities and equipment for maintenance of CW systems. Results indicate further that out of seven respondents, on education, skills and training, three indicated that there is inadequate education, skills and training on CW among owners and operators of CW. The responses evaluation on motivation to operators shows that one out of seven responses indicated that the motivation is inadequate and three out of seven did not respond to the query.

Physico-chemical parameters. Results in Table 1 show the physico chemical and performance removal parameters for the three CWs surveyed. Discharge levels for BOD, COD, orthophosphate and ammonia were above the recommended Tanzanian Standards (Water Utilization Act No. 10 Tanzania, 1981) discharge limits to receiving water bodies. Despite, the Shinyanga Prison, MUWSA and Ruaha Secondary School CW wetlands respectively were able to achieve medium to moderately high removal efficiency for BOD (66.2%, 47.76% and 79.5%); COD (61.6%, 36.54% and 79.6%). High TSS removal efficiency was achieved at Shinyanga Prison (75.78%) although the actual concentration of TSS in the effluent was of inferior quality compared with the effluents from MUWSA and Ruaha Secondary School, whose influent TS S concentrations were also lower.

Nutrient removal efficiency was generally low in all CWs studied, although the actual effluent concentration of NO3-N was low enough to meet the recommended discharge standards for Tanzania; ranging from 1.12,11.3 and 11.44 mg/L for Shinyanga, Ruaha and MUWSA, respectively. The concentrations of phosphate in the effluents ranged from low (6.73 mg/L for Shinyanga Prison), medium (18 mg/L for Ruaha Secondary School CW) to high (39.9 mg/L for MUWSA). High nutrient content in the MUWSA CW is the reason for successful reuse of CW effluents for rice paddling by the farmers around the wastewater treatment facility. As regard to NH3-N, effluent removal efficiencies were 34.7% for Shinyanga Prison, 57.31% for Ruaha Secondary School and 60% in MUWSA CWs. However, the highest concentration in the effluent was 33 mg/L from Ruaha Secondary School CW.


The challenges that have been found for CW systems in operation is the general lack of specific operation and maintenance (O&M) plans/guidelines. Despite the lack of O&M plans and guidelines among the CWs owners, the performance data in three CWs show some substantial reduction of organic and nutrient loads, albeit failing to meet the desired discharge limits to the receiving environment. Appropriate guidelines could only help in improving the performance of these systems and ensure longer life span. Results from this study have helped in developing an Operation and Maintenance Manual that has specific instructions to meet the needs of CW owners and operators in East Africa. The level of detail of the O&M, has taken into consideration the site-specific aspects such as size and complexity of the CW systems visited and studied.

### REFERENCES


Water Utilization Act No. 10 Tanzania, 1981.