Dissemination of the sustainable wastewater technology of constructed wetlands in Tanzania
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Factors for Success and Failures of Constructed Wetlands in the Sanitation Service Chains

Team Members:
Dr. Richard J. Kimwaga
Dr. William J.S. Mwegoha
Dr. Anes Mahenge
Dr. Agnes M. Nyomora
Mr. Leonard G. Lugali

VLIR UOS South Initiatives 2011-2013
Promoter: Thomas More Kempen University College
Local Partner: University of Dar Es Salaam, WSP and CW Research Group

Dissemination of the Sustainable Wastewater Technology of Constructed Wetland in Tanzania (VLIR Research Project)

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Dr. Richard J. Kimwaga
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CONTENTS

ABBREVIATIONS AND ACRONYMS

CW	Constructed Wetland
AMD	Acid Mine Drainage
ARI	Accounting Rate of Interest
BOD	Biological Oxygen Demand
CBA	Cost Benefit Analysis
CBO	Community Based Organization
COD	Chemical Oxygen Demand
FC	Faecal Coliform
FP	Fish Pond
FSS	Free Water Surface
HSSFCW	Horizontal Subsurface Flow Constructed Wetland
IRR	Internal Rate of Return
IRUWASA	Iringa Urban Water Supply and Sewerage Authority
MORUWASA	Morogoro Urban Water Supply and Sewerage Authority
MUWSA	Moshi Urban Water Supply and Sewerage Authority
ND	Not Determined
NGO	Non Governmental Organization
NH_3	Ammonia
NH_3-N	Ammonia Nitrogen
NO_3	Nitrate
NPV	Net Present Value
NR	Not Recorded
NYP	Not Yet Planted,
O&M	Operation and Maintenance
O-N	Organic Nitrogen
ORS	Oral Rehydration Salts
PF	Paddy Farm
PV	Permanganate Value
RSS	Ruaha Secondary School
SBR	Sludge Blanket Reactor
SSF	Sub Surface Flow
SSFCW	Subsurface Flow Constructed Wetland
TSS	Total Suspended Solids
TTC	Kleruu Teachers Training College
UDSM	University of Dar es Salaam
WSP	Waste Stabilization Ponds

LIST OF FIGURES AND PLATES

LIST OF TABLES

1. BACKGROUND INFORMATION

1.1 General Introduction

There is no even a single city or town in Tanzania with adequate sewage treatment facilities (Mohammed, 2002). In normal circumstances urban centres would be served by wastewater treatment plants and regulated septic disposal facilities, while peri urban areas would experience un-regulated dumping and waste burial. In Tanzania however, a very small portion of the urban centres are served with adequate wastewater facility. Coverage by sewerage services in major cities such as Dar es Salaam, Arusha and Mwanza is less than 15%, an exception is Moshi with 40% coverage (Zephania Mihayo and Cyrus Njiru (2005)). About 60-70% of the urban population (Mato, 2002), in Tanzania, currently lives in unplanned peri-urban areas, relying mostly on pit latrines and septic tank soak away systems for sanitation. Major problems with pit latrines and septic tanks in Tanzania are leakages caused by poor construction, flooding of low lying areas, and lack of maintenance. Soak away pits fill up due to poor infiltration when built in clay soil areas. Possibility of conventional systems polluting drinking water sources is great due to building the systems in close proximity to shallow water wells and rivers. In urban areas there is generally lack of adequate wastewater treatment resulting from rapid population growth, lack of funds to implement centralized wastewater treatment and lack of commitment among policy makers to adequately deal with the problem.

To tackle these problems good solutions for improving sanitation systems in Tanzania have to be identified. A sustainable low cost solution for hygienic sanitation identified is implementing constructed wetland systems. The use of constructed wetlands (CW) for domestic wastewater treatment in Tanzania has gained much popularity over the last ten years since the early pioneering works by Kimwaga et al. (2004) and Senzia et al. (2003).

1.2 Constructed Wetlands

Constructed wetlands (CW) are natural systems in which wastewater is treated with plants and bacteria using natural processes such as filtering, sedimentation, natural die-off of pathogens, biodegradation, radiation of sunlight etc. to treat the wastewater in a controlled environment (Reed et al., 1995; Gray, 1999). There are different types of wetlands, in Free Water Surface (FWS) constructed wetlands, the plants float on the water while in Sub Surface Flow (SSF) constructed wetlands the plants are growing in a substrate, for instance sand or gravel. In these systems the wastewater level is kept below the surface. The advantage of keeping the water below the surface is that breeding of malaria mosquitoes is prevented; therefore the SSF system is favourable in Tanzania. When treating urban or mixed domestic wastewater, constructed wetlands are always preceded by primary treatment, in for instance a septic tank or waste stabilization ponds (WSP), as otherwise the loading with organic solids is too high and will cause clogging and malfunctioning of the system. The main advantage of constructed wetlands is that these systems are relatively easy to construct and to operate and maintain, furthermore, little input in terms of energy and no chemicals are needed. This means that also costs, both investment and recurrent, are generally low. In addition constructed wetlands can produce some biomass, in some cases also fish. Social acceptance of the wetland is generally good, as wetlands can be integrated in the natural landscape easily and when well designed there will not be any nuisance by smell or insects. Disadvantage may be the relatively large land area required compared to more intensive wastewater treatment plants. However, in many cases, such as implementation of constructed wetlands at schools and hospitals in Tanzania, land area is not a restricting factor.

This article analyses the economics (costs and benefits) of Constructed Wetlands. The analysis is based on the identifying the financial cost and benefits categories with the view of providing and insight of the cost benefit analysis (CBA). Moreover the article is meant to provide cost model for constructed such when one knows some aspects of CW design and construction, then one can easily estimate the costs of the CW.

2. EVOLUTION OF CONSTRUCTED WETLANDS TECHNOLOGY IN TANZANIA

The evolution of Constructed Wetlands technology dates back as far as 1995 when the University of Dar Es Salaam, College of Engineering and Technology Tanzania and two Danish Universities, namely the Royal Danish School of Pharmacy (Currently known as The Pharmaceutical University of Denmark) and The University of Copenhagen, The Technical University of Denmark developed a collaborative research project focusing on Waste Stabilizations Ponds (WSP). The emphasis for WSP research was placed on revealing the processing taking place with the WSP system through the use of ecological modeling approach so as as to improve the design approach for WSP as the earlier design approach didn't take into consideration the processes taking place within the system.

Since September 1998, the project started research on "Constructed Wetlands (CW)" in addition to WSP with the view of polishing/upgrading the WSP effluents. The research project started with pilot scale which was meant to establish design guidelines and criteria and other related information including construction and operation for use of CW in Tanzania. The research on CW focused on using ecological modeling using STELLA software. The areas that were research on included the following:

(i) Modeling of Nitrogen Transformation and Removal in CW
(ii) Modeling of coupled Dynamic Roughing Filters and CW
(iii) Selection of Suitable Soil Media for CW in Tanzania
(iv) Selection of Suitable Indigenous Macrophytes for CW in Tanzania
(v) Modeling of BOD removal in CW

As an output to the research project, the following were achieved:

- Better understanding of the processes taking place in WSP and CW has been documented

- A holistic ecological model for the design of WSPs and a model for nutrient removal have been formulated, validated, calibrated and verified

Based on the success of the research project, the results from the pilot studies were then transformed into practical application where a number of full scale projects both nationally and internationally have been implemented.

Despite the fact that CW technology has been in the country over the last two decades, there has been no any documentations in terms of factors for success and failures of the technology and therefore this report has captured the experiences of applicability of CW in Tanzania with the view of providing the factors that are important for success of CW technology. A number of factors need to be considered for the success of CW technology. These factors are broadly categorized as Technical factors, socio-economic factors Costs considerations of CW Benefits Aspects of CW Financing Mechanisms Public Health and Environmental Factors and Institutional Arrangement.

3. IMPLEMENTED PROJECTS FOR CONSTRUCTED WETLANDS IN TANZANIA

3.1 Introduction

The “Waste Stabilization Pond & Constructed Wetland Research Project” of the University of Dar es Salaam (UDSM) has successfully introduced constructed wetland technology for wastewater treatment mainly to institutions such as schools, prisons and colleges since 2002. A total of 10 units of variable sizes have been built to treat domestic wastewater. These systems have been built in Iringa (at schools for 1,200 p.e. (population equivalent) and 1,000 p.e.), Shinyanga prison (2,500 p.e.), Malya prison (3,500 p.e), Bariadi prison (2,000 p.e.), Moshi Municipality (45,000 p.e.), Kibaha (2,500 p.e.) and Dar es Salaam (2 households).

These units were introduced because of serious wastewater treatment and disposal problems that the institutions were facing. The CW's were meant to provide decentralised wastewater treatment to these institutions to meet Tanzanian effluent standards. The problems faced by are typical of many such institutions in Tanzania and in the Eastern Africa region. In addition to the systems built in Tanzania one system has been built in Kenya at Shimo la Tewa Prison, one in Uganda for treating abattoir wastewater in combination with Sludge Blanket Reactor (SBR) system and one in Ethiopia at Modjo Tanneries for treating tanneries wastewater also in combination with SBR system. The following sections is the description of 2 selected projects in Tanzania.

3.2 The Constructed Wetland at Kleruu Teacher’s College

Before the introduction of the CW system Kleruu Teachers College was treating its wastewater through a combination of mechanical aeration system and an oxidation pond. However, operation of the mechanical system failed because of high running costs and lack of regular maintenance. Plate 1 shows the failed mechanical system. The pond was malfunctioning, ignored, lacked de-sludging and released untreated effluent to the downstream communities. The communities downstream were subjected to health risks and bad odour resulting from anaerobic decomposition of organic matter.

Plate 1. Conditions of failed mechanical system in Kleruu Plate 2. Conditions of Rehabilitated System at Kleruu

After consultation with UDSM "WSP & Constructed Wetland Research Project", a Horizontal Subsurface Flow CW was installed to replace the pond. Baffled system was introduced as seen in Plate 2. The need for intensive operation of the mechanical system ceased and the condition of the wetland after full growth of the plants.

3.3 The Constructed Wetland at Ruaha Secondary School

Ruaha Secondary School (RSS) approached the UDSM for advice on their sanitation system. RSS is built in a high water table area and during rainy seasons their leaking septic tank system overflowed into the environment. The nearby communities complained about the situation and the Iringa Municipality ordered the school to deal with the problem. One option that was being considered was to use vacuum tankers to empty the septic tanks but this was too expensive. After a visit UDSM suggested the implementation of a CW system. Due to financial limitations of the school, a self help approach was used whereby the UDSM designed the system and the school through their resident civil engineer looked after the construction. Despite instructions on the requirements of the CW construction, several errors were committed during construction which resulted in 30% extra costs.

The first CW designed for 600 people was inaugurated in May 2003 and a year after another similar unit was added in parallel. From the experience gained in the construction of the first unit, the second unit was constructed with no flaws. This brought the treatment capacity to 1200 people. In one way capacity to construct a wetland was gained by this school. The school is using the treated water for growing elephant grass for their cow project. They are also using the wetland for training their students (see Plate 3). The performance of the system is excellent.

Plate 3. Fully Grown Constructed Wetlands at RSS

Despite the fact that CW technology has been in the country over the last two decades, there has been no any documentations in terms of factors for success and failures of the technology and therefore this report is capturing the experiences of applicability of CW in Tanzania with the view of providing the factors that are important for success of CW technology. The next chapter is describing the factors for success and failure of CW technology as experienced from the existing CW systems in Tanzania.

4. SUCCESS AND FAILURE OF CONSTRUCTED WETLANDS IN SANITATION SERVICE CHAINS

4.1 Technical Factors

4.1.1 Planning Aspects

Planning is a very primary step of a CW project which aims at defining objectives for the system in relation to the exiting situation on the ground and available resources. It involves assessment of the project area thereby considering the existing topography to better configure the system, existing soil type, water table, climatic conditions for hydrological budgeting and localizing the system, substrates and macrophytes. It also involves studies to characterize the quantity and quality of wastewater to be treated using CW. Planning is regarded to be a very crucial stage as it determine the appropriateness and suitability of the system to be put in place.

Planning stage is normally faced with lack of hydrological data necessary to perform hydrological budgeting and lack of long term data for quantification and qualification of wastewater to be treated by the CW. Critical challenges are encountered in the absence of wastewater generation at the non operational sites. Under this circumstance hydrological budgeting is ignored whereas wastewater characterization is done based on the typical standard and typical parameters extracted from literatures. Furthermore, there have been few cases where CW technology is unaccepted at the planning stage simply due to lack of awareness and technical knowhow.

On the other hand, the success experience entail that there is flexibility of planning for CW use in coupling with other technologies such as septic tanks, stabilization ponds and biogas plants for maximizing treatment efficient and ensure sustainable use of resources. In addition, CW seems to be the best technology for use in water logged, high ground water table and clayey areas. It fits for decentralized wastewater treatment since can be used for small, medium and large scale communities. In the East African Region for example, out of 27 CW systems which were in use by July 2013, 2 were owned by individuals, 4 by schools and colleges, 7 were for research purposes owned by research institutions, 9 by private and public institutions such as prisons, 2 by small communities and companies and 3 by Municipals (Table 4.1).

Table 4.1: List of operation CW in the East African Region by July 2013

Year	CW Unit	Location	Wastewater Type	Scale	Flow Rate (m^3/d)	Surface Area (m^2)	Macrophytes
2013	BIL	Arusha, Tanzania	Agro processing	Full scale	150	336	Papyrus
2013	UDSM - MORUWASA	Morogoro, Tanzania	Municipal	Experimental	80	234	Reeds
2012	Miyuji Community	Dodoma, Tanzania	Domestic	Full scale	20	70	Cattails
2012	Chamazi Community	Temeke, Tanzania	Domestic	Full scale	36	168	Reeds
2012	TPCC	DSM, Tanzania	Domestic	Experimental	3.5	9	Cattails
2012	China Paper	Moshi, Tanzania	Paper recycling	Full scale	225	355	Reeds
2011	IRUWASA	Iringa, Tanzania	Municipal	Full scale	NR	NR	Cattails
2011		Arusha, Tanzania	Agro processing	Full scale	NR	NR	Diverse
2011	North Mara	Musoma, Tanzania	AMD	Experimental	5	15	Cattails
2010	Seeta High School	Mukono, Uganda	Domestic	Full scale	55	450	Papyrus
2010	Chakechake	Pemba, Zanzibar	Municipal	Full scale	350	1625	NYP
2009	Shimo la Tewa	Mombasa, Kenya	Domestic	Full scale	NR	NR	ND
2009	Mahe	Mahe, Seychelles	Domestic	Full scale	NR	NR	ND
2009	Modjo	Addis Ababa, Ethiopia	Tannery	Full scale	NR	NR	Reeds
2009	Kampala Abattoir	Kampala, Uganda	Abattoir	Experimental	NR	NR	Papyrus
2005	Dr. A. Outwater	DSM, Tanzania	Domestic	Full scale	ND	3	Reeds
2004	Ruaha SS	Iringa, Tanzania	Domestic	Full scale	20	108	Reeds
2004	MUWSA	Moshi, Tanzania	Municipal	Full scale	400	972	Reeds
2001	Mallya Prison	Shinyanga, Tanzania	Domestic	Full scale	50	NR	Reeds
2001	Bariadi Prison	Shinyanga, Tanzania	Domestic	Full scale	50	NR	Reeds
2001	Shinyanga Prison	Shinyanga, Tanzania	Domestic	Full scale	50	NR	Reeds
1998	UDSM	DSM, Tanzania	Domestic	Experimental	2	40.70	Reeds
1998	UDSM	DSM, Tanzania	Domestic	Experimental	2	13.80	Cattails
2004	Kleruu College	Iringa, Tanzania	Domestic	Full scale	44	400	Reeds
NR	Kibo Paper	Moshi Tanzania	Industrial	Full scale	NR	NR	Reeds
NR	Prof. K. Njau	DSM, Tanzania	Domestic	Full scale	NR	NR	Papyrus
NR	WAAL´S USR SS	Kibaha, Tanzania	Domestic	Full scale	ND	560	NYP

AMD= Acid Mine Drainage, ND = Not Determined, NYP = Not Yet Planted, NR = Not Recorded

4.1.2 Design Considerations

The design of CW in Tanzania has been based on the Plug Flow approach which provides a more appropriate description of a flow pattern is SSFCW. The characteristic wastewater parameters considered in the design include BOD, Total Suspended Solids (TSS), Ammonia (NH_3), Nitrate (NO_3), phosphorus Fecal Coliforms. The plug flow model as applied uses temperature dependent rate constant in the process. Besides, advanced studies in the country entails that the performance of the systems has been found to be more influenced by hydrodynamics in the system especially in tropical areas like Tanzania; hence most systems being designed recently enhance mass transfer effects into the systems.

Few challenges are experienced when designing CW system. They include lack of consistence design approach locally and globally whereby literatures reveal different designers use different methods to determine the area requirement for CW. Yet, some other more design concepts and approaches are still under research. Another challenge which is faced in Tanzania and the East Africa region is inadequate expertise to design, prepare engineering drawings, bills of quantities and cost estimates for the CW systems. The consultancy arena has not picked the technology for commercialization hence everything is depending on researchers at higher learning institutions.

The good thing about design of CW system is the possibility to address specific or all pollutant parameters of wastewater such as BOD, nutrients, fecal Coliforms, etc given varying circumstances. This is especially important when dealing with different types of wastewater i.e. domestic, municipal, industrial or acid mine drainage. Our experience entail that the area requirement for Ammonia removal when dealing with typical domestic wastewater is much bigger than for rest parameters.

4.1.3 Construction Considerations

Like any other engineering facility, the construction of CW does follow the standard and formal procedure which includes engagement of local craftsmen or contractors. Normally, they are provided with drawings and expected to ensure that the construction works adheres to the drawings and specifications, and that the works meet the engineering quality objectives, and that they are completed within the limits of time and cost of course under the supervision of the designer.

However, most contractors and local builders are not aware and knowledgeable enough to appreciate the technology and its key functional components. They consider the CW system structurally not functionally. As such they view it as a very simple facility to erect while committing a number mistakes which are the key to the function of the wetland. It does not matter how nice and detailed the engineering drawings are. The typical mistakes committed by contractors and builders include incorrect levels for inlet and outlet pipes to ensure desired hydraulic requirement, provision of wrong size of substrates and introduction of soils into the system with a view of supporting the growth of wetland plants. Under this situation, the need for very close construction supervision cannot be undermined.

On the other hand, the fact that CW can be made with locally available materials (local construction materials, liners, substrates and plants) adds value to its economic viability, social acceptability and institutional manageability. The typical materials for CW walls that have been in use so far include mass concrete, concrete blocks, pre-casted slabs, natural stones and burnt bricks; and no serious concerns have been reported regarding their use.

Plate 4a: CW built of stone At Seeta School, Uganda

Plate 4b: CW built of concrete In Mahe, Seychelles

Plate 4c: CW built of burnt bricks In Iringa, Tanzania

The common liners that have been in use are clay soils and mass concrete with very few cases of plastic liners. Substrates materials in use include limestone, metamorphosed schist rock and granite rock and all are excellently playing the treatment role.

Limestone

Metamorphosed schist rock

granite rock

The common wetland plants are *typha domingensis (cattails)*, *phragmites Mauritianus (reeds)*, *vetiver grass* and *papyrus*. Experience from Tanzania shows that reeds (*Phragmites Mauritianus)* are very effective plants for constructed wetlands (references) due to the fact that they do not have a quick turn over thus do not create as much organic debris on the surface of the wetland. Moreover, they are structurally very stable plants, and remain standing throughout its lifetime. Reeds have therefore become a plant of choice for all current practical systems in Tanzania.

	
typha domingensis	*Phragmites Mauritianus*
	
papyrus	*vetiver grass*

4.1.4 Operation, maintenance and monitoring

CW require regular monitoring and maintenance to ensure it remains functional and in a 'healthy' condition. The operational and maintenance needs 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).

The survey results on the operation of existing CWs carried out by the WSP & CW Research and Development Group of the University of Dar Es Salaam in 2010 indicated that 86% of the surveyed CWs experienced various forms of operational problems. The major problem experienced was a combination of blockage and over flooding (57.1%) whereas blockage itself constituted 14.3%. Other operational problems included seepage through the walls or leakage, storm water runoff especially during and after rainfall events and, cracks which altogether constituted 28.6%. Other challenges during the operation phase are fluctuation of flows and inadequate performance monitoring of the CW systems. Hence, the need for users' training on operation, maintenance and monitoring of CW during the commissioning phase.

Plate 5: Over-flooding of Shinyanga Prison CW as a result of poor operation and maintenance

Besides, successful case studies from users of CW in Tanzania indicate that CW effluents are in compliance with recommended local discharge standards. According to the analysis carried out by the University of Dar Es Salaam in 2010, CW significantly reduce pH, BOD, COD, and Nitrates to the recommended effluent discharge standards in Tanzania. However, some mixed results were observed for Ammonia and Phosphorus removal whereby some were compliance with regulatory requirement and others were not. Other successful cases entail that CW require minimal operation and maintenance practices and costs for running; cater for reuse of treated wastewater for gardening, horticulture, fish farming, car washing and raising of grazing pastures; create pleasing environment for recreational purposes and enhance biodiversity values due to attraction of birds, reptiles, rodents, etc.

Biodiversity in CW

4.2 Socio-Economic Factors

4.2.1 Social Mobilization and Awareness Rising

Social mobilization is a concept which involves the creation of a social movement for initiatives in development projects. This movement aims to create a major thrust to solve problems of national magnitude by promoting participation of all possible sectors and levels of society, mobilizing local resources and using indigenous knowledge. It aims to enhance people's creativity and productivity through mass campaign. This concept is of extreme relevance for a real change can be initiated by orchestrating a joint attack against the alarming sanitation situation with minimum social conflict. The participation of people in any development programme is the pre-requisite for sustaining any achievement. Social mobilization involves not only people in the community, but all sectors and levels of society as well as service delivery agencies, i.e. where local resources are tapped to its fullest which ensures the sustainability of the programme.

The strategies adopted for the above objectives are spelled out as follows:

- to increase the awareness of all communities of the benefits of sanitation improvements using CW technology with the help of appropriate communication media;
- to promote affordable and appropriate CW technology with an emphasis on defecating in a fixed place and on construction of home-made latrines;
- to mobilize resources and build alliances with all potential partners -such as political leaders, local governments, professional groups, NGOs, CBOs, women groups, educational and religious institutes, mass media, cultural groups, etc.- for sanitation improvement through dialogues and advocacy campaigns.

So for a CW technology to be successful, it is very important that social mobilization in the intervention area be implemented. Unfortunately this is an area that has not been well given due attention in the implementation of the CW technology in Tanzania and therefore it is recommended to be given more focus and emphasis.

4.2.2 Costs considerations of CW

The success and failure of constructed wetlands in Tanzania to great extent depends on costs for putting up a facility in place as well as the O&M costs. People who would like to adopt the CW technology are ill informed about the costs categories let alone the exact figures for these cost categories. The following sections therefore describe different categories associated with constructed. The description of these categories will form the basis for cost benefit analysis as it will be explained later. The overall cost for CW implementation includes capital and operating cost. For the sake of easing the report, these categories will be discussed separately. It has however to be taken into account that these cost categories will be used to establish the total financial costs for selected CW in Tanzania that will be subjected to CBA. On the other hand, table below provides the average amount of money for the various cost categories which form part of CW investment costs. The costs (per square meter) have been established based on the typical CW units designed and constructed in Tanzania.

4.2.2.1 Investment/capital cost

The capital costs consist of five (5) items as follows:

Land Costs

Under this cost, the following items will have the cost implications; cost of land, loss of productivity, loss of Single Farm Payments (SFP). The value of the land lost depends both on the surface area and land use. The larger the farmyard, the larger the wetland required and the land taken. In addition, a buffer area is recommended between wetland cells (e.g. 5 m wide) and between cells and grazed areas/water bodies (≥ 10 m) for maintenance and contingency, which considerably increases the overall area needed.

Site assessment, planning, design, supervision

In this phase of the CW project, the costs that will be incurred will be for preliminary hydrological, soil, ecological, archaeological surveys investigations as well as for design plans and supervision.

Construction

Overall construction costs are site-specific linked to the materials costs, piping work, excavation works, reworking of topsoil, fencing and concrete structures, etc. There is also a cost associated to the labor and the media.

Planting

The cost for planting depend mainly on the planting density and species used (reeds, bulrushes, grasses), and on plant or seed availability (e.g. if plants can be transplanted from an existing wetland or pond and if the area was already a wet grassland before construction). Guidance on transplanting usually recommends sourcing from accredited nurseries, to avoid damage to existing habitats and inadvertent introduction of exotic species. The recommended planting density is about 2 plants m^2.

Table 4.2: Typical amount for the various cost categories of CW

Item	Units	Average Amount (Tshs)
Site assessment, planning, design, supervision	M^2	32,785
Construction materials	M^2	36,800
Labour charges for construction works	M^2	23,950
Substrates (Aggregates)	M^2	53,850
Macrophytes (Plants)	M^2	2,550

Decommissioning

In some cases, for example, if CW land use activity ceases, land is sold, the CW reaches the end of its life time, or legislation changes, it might be necessary to decommission the wetland, carrying out simple earthworks to fill the CW or to transform it. In such a case, sediment can be left in situ, cells can be filled using available material, pipes and liners have to be removed and properly disposed of, and vegetation can be harvested to use in other CFWs or left in situ. The CW can also be transformed into an amenity wetland, if a permanent source of water is available.

4.2.2.2 Maintenance and monitoring cost

Maintenance

Maintenance activities appeared to be neglected for the CWs investigated, mainly due to the absence of regulatory requirements, lack of financial incentives and lack of information and understanding of the maintenance needed. Indeed, regular maintenance activities are needed to ensure CW integrity and function, such as removal of material obstructing pipes, grass cutting on the edges, removal of sediment, replanting areas where establishment failed, and level control on a regular basis.

Monitoring

Most of the CWs are indeed completely unmonitored after construction, resulting in poor performance being undetected and in the lack of corrective actions. Due to absence of regulation and enforcement in the field, the cost of monitoring which could be borne by farmers or local authorities is currently unknown, and could be significant if the "polluter pays" principle is fully applied and farmers are required to address this issue.

However, water sampling and analysis is necessary to ensure that the effluent is not impacting negatively on the receiving water body, especially in sensitive areas, and during rainy periods when peak pollution occurs.

One thing to note is that in order for CW technology to be successful, it is important for CW to be cost effective which means that one has to minimize the costs for those items that seem to bring high costs. In this substrate which seem to contribute significantly to high cost need to be looked at and think on how to come up with an alternative substrate materials.

4.2.3 Benefits Aspects of CW

Quite often CW technology is not easily up taken up because users are not well informed about the benefit associated with CW. Well known benefits will help the CW to be easily up taken up and thus it's successful. This section aims at developing a framework for the identification of the benefits associated with the use of constructed wetlands for wastewater treatment.

Financial Benefit Categories of Constructed Wetlands

Constructed wetlands may provide, to a certain extent, most of the benefits associated with natural wetlands. An economic perspective is embraced throughout the section and the possibility of using economic valuation methods to estimate the benefits in monetary terms is discussed. It has however to be taken into account that these benefits categories will be used to establish the total financial benefits for selected CW in Tanzania that will be subjected to CBA.

Functions and Benefits of Constructed Wetlands

Constructed wetlands perform many functions that provide goods and services to society. Following a classification proposed by a Wetland Reserve Program report for natural wetlands (WRP, 1994a) wetland functions can be grouped into the four broad categories of (i) hydrology/water quality, (ii) landscape enhancement, (iii) fish and wildlife habitat, (iv) recreational and educational activities. The wetland function related to hydrology and water quality includes supply of treated water suitable to be reused in several applications, increase of surface quality and recharge of aquifers.

The development of a habitat for fish and wildlife may provide benefits related to production of food and fiber through harvesting, protection of fisheries, aquaculture as well as educational and cultural activities. According to the land context in which they are placed, free water surface constructed wetlands can also significantly enhance landscape aesthetics by introducing a pleasant natural element in the landscape. Closely related to the habitat and landscape functions is the provision of opportunities for recreationists.

Economic goods and services provided by constructed wetlands through the four main functions are grouped in Table 4.3 into goods and services to which a price is attached in relevant markets and goods and services for which no relevant market exists (non-market benefits). The former include supply of reusable water, food and fiber production, protection of fisheries and aquaculture. The latter are increase of surface- and groundwater quality, aquifer recharge, educational, cultural and recreational activities, land development and existence and bequest of biodiversity. Lambert (2003) points out that “market failures related to ecosystems include the fact that many wetlands (1) provide services that are public goods, (2) many wetlands services are affected by externalities and (3) property rights related to ecosystems and their services are often not clearly defined”. Table 4.3 provides wetlands functions and goods and services from which the valuation method is based on.

Though difficult to quantify the benefits of CW in monetary terms, but when quantified using economic valuation methods, some insights on the benefits both socially and economically can be realized

4.2.4 Cost Benefit Analysis

From economic point of view it is important to show the economic viability of CW technology for its success. CW technology can be seen to have failure or successes based on the CBA. Economic viability is based on CBA from data collected from CW in Ruaha Secondary School.

Table 4.3. Constructed wetland functions, related economic values and suggested valuation methods.

		Wetland function	Good or service provided	Valuation Method
Market benefits		Hydrology / Water Quality	Supply of reusable water	market price
Market benefits		Fish and Wildlife Habitat	Food and fiber production (harvesting)	market price
Market benefits			Protection of fisheries / Aquaculture	market price
Non-market benefits	Use Values	Hydrology / Water Quality	Increase of surface water quality	contingent valuation, avoided cost analysis
Non-market benefits	Use Values		Groundwater recharge	contingent valuation, avoided cost analysis
Non-market benefits	Use Values	Fish and Wildlife Habitat	Educational/cultural activities	contingent valuation, travel cost
Non-market benefits	Use Values	Recreation and aesthetics	Recreational activities	contingent valuation, travel cost
Non-market benefits	Use Values	Landscape enhancement	Land development	stated preference methods, hedonic method
Non-market benefits	Non-use values	Fish and Wildlife Habitat	Existence and bequest value of biodiversity and biological resources	contingent valuation

Source:

The CBA that was carried out in this study was based on only one constructed wetlands project in Tanzania, namely at RSS. We base our financial CBA on the following data and assumptions (Balkema, et al., 2010):

- The project life time is set to 10 years, assuming that a constructed wetland (CW) will in fact last longer than that, the residual value of the CW at the end of the project life-time is set to half the construction value in year 0.
- The average expected inflation rate in Tanzania is set to 8.7%.
- The interest on a commercial loan for a period longer than 5 years is 15.7%.
- The following cash outflows for the non-financial operations for a constructed wetland project are distinguished: (1) design costs of the Constructed Wetland (in year 0); (2) building materials (in year 0); (3) other construction costs such

as wages (in year 0) and (4) Operation and Maintenance costs (in year 1 through 9).

- The cash inflows of the non-financial operations of the project consist of all direct and indirect cash inflows caused by implementing the project, in this case: the reduction of sanitation costs caused by the constructed wetland. For instance avoidance of costs of waste dumping; or avoidance of cleaning costs of the existing system which is replaced by or extended with the newly constructed wetlands. In most cases these are avoided costs by not having to empty the septic tank as often as before. For the case study of constructed wetlands at Ruaha Secondary School in Iringa,

In Tanzania, the following data was collected:

- The initial costs of the project are completely covered by grants.
- The total construction costs for the CW are relatively low, because the university (UDSM) does not charge for the design of the wetland, furthermore the construction is taken care of by students and employees of the school. Therefore, the only construction costs are the TSh. 3,121,250 (US$ 2,500) for construction materials.
- Operation & Maintenance of the Wetland is TSh. 420,000 (US$ 340) per year for wage costs and costs of measuring the water quality on various indicators.
- The introduction of the CW reduces the cleaning cost of the school's septic tank that was its dominant sanitation technology until then: instead of emptying the tank 4 times a month, it now needs to be emptied only once a year. Emptying the septic tank costs TSh. 25,000 (US$ 20).

In the case of Ruaha Secondary School the constructed wetland is financial feasible because of the relatively high avoided costs of not having to empty the septic tank as often as before implementing the wetland. The calculated Net Present Value (NPV) is 2,807,000 TSh. (US$ 2,250), the Internal Rate of Return (IRR) 33% (compare to nominal interest rate of 16%) and the Pay Back Period (PBP) lies between 4 and 5 years. As a sensitivity analysis, switching values are calculated indicating at what rise investment or maintenance costs or a drop in benefits (less avoided costs) the NPV will become zero. In the case of the Ruaha Secondary School investment costs higher than 7,047,000 TSh. (5,640 US$) (2,3 times the realized investment costs) would make the project financially unattractive (NPV = 0). Similarly, doubling the operation and maintenance costs would make the project financially unfeasible (NPV = 0) and 35% lower avoided costs would make the project financially unfeasible as (NPV = 0). From these indicators for sensitivity we conclude that the project is a rather safe investment in financial terms. In addition, the investment costs for the Ruaha Secondary School constructed wetland project were granted, as such the project was without a doubt a financial success.

Based on the Ruaha case study we conclude that in cases where relatively high cost can be avoided by implementing a constructed wetland the investment will be financial feasible. In Ruaha the avoided cost, on yearly basis, was as high as 38% of the initial investment In the literature no comparable analyses were found using similar avoided cost situations, although reference can be found on comparison of costs for different wastewater treatment systems. For instance, in his economic analysis (Chapter 7) Okurut (2000) compares the costs for a constructed wetland with a waste stabilization pond for the treatment of wastewater for 4000 p.e. in Uganda and concludes that constructed wetlands are economically competitive. Land costs for the WSP was estimated to be 30% higher as a larger area is required, while the operating and maintenance costs are similar for both systems (Okurut 2000, p149), therefore making constructed wetlands the most attractive option.

Mannino et al. (2008) compare the costs of semi natural free water surface wetlands (SN FWS) to activated sludge wastewater treatment plants, and conclude that the wetlands were more economical. Despite high development costs, estimated to be six- to nine-fold higher for the wetlands than for the activated sludge plants (Mannino , 2009) p.125, note: excluding land costs!). The total cost needed to give an annual wastewater treatment service per i.e. were calculated to be two- to eight-fold lower over the entire 20 years lifespan, respectively based on a discount rate of 5 and 10%

(Mannino (2008) p.124 and p.127). Mainly due to lower maintenance costs, the higher development costs where more than offset in 2 to 3 years (Mannino 2008, p.127). These finding are a bit more promising but in the same range as our results.

4.2.5 Societal Cost Benefit Analysis

All data in the previous section, supporting the implementation of constructed wetlands, refer to direct and indirect costs for the investor, but as for any water and sanitation project the main benefits are societal. Since fewer people get sick and fewer children die of diarrhoeal diseases the benefits for the society are much larger. This should be taken into account on national and international level. To strengthen the arguments for the discussions on policy making and setting soft loans and subsidies we include a societal cost benefit analysis. In the Ruaha School project the student population at the school is the target population. This is a secondary school (children aged between 12 and 18), there are no children under five which are most likely to die of diarrhoeal diseases, and therefore no mortality rate needs to be calculated for this CBA.

- The total population at the Ruaha Secondary School is 750. The table summarizes the estimated health impacts caused by the construction of a constructed wetland. The technology is estimated to prevent between 9 and in 28 diarrhoeal incidents (low and high case) (Hutton, 2004). Assuming an average of three days off school per case of diarrhoea there are 27 to 84 days of school attendance gained.

These health benefits need to be transformed into economic benefits with the help of the following statistics:

- Patient expenses avoided due to avoided illness: The avoided costs of treatment of ill children involve the cost of medicine (ORS). The average cost of diarrhoea treatment per child in Sub Sahara Africa is TSh. 7,200 (US$5.50)4.

- Value of child days gained of those with avoided illness. When a child is ill (assumed to be 3 days on average) at least one of the parents has to stay at home to take care of the child; assuming that this parent is usually working, this would lead to income losses. The average daily wage of one parent is set to Tsh.4,000 (US$ 3.2) per day.

The societal Accounting Rate of Interest (ARI) can be calculated based on the long-term interest rate on Tanzanian government bonds, which is approximately 4% ex-inflation.

- For the socio-economic CBA, the actual costs for the design of the constructed wetland which the university (UDSM) provided for free are also needed. These costs are estimated to be10% of the wetland construction costs.
- The shadow wage rate is approximately zero in Tanzania.

If taking these societal benefits in account in the CBA makes the project even more attractive to invest in, the NPV calculated is as high as 11,100,000 TSh. (8,880 US$) and the real IRR is 493% (compare with the real ARI of 4%) and the payback period is as short as 1 year. Even if the avoided costs of the frequent emptying of the septic tank before constructing the wetland is set to zero, the NPV calculated remains positive namely 2,200,000 TSh. (1,760 US$) and the IRR remains high (106%) and the investment can still be paid back within one year. From this it is safe to conclude that investments in water and sanitation facilities should be facilitated by governments and international institutions as the cost of not financing these projects is high not only in terms of suffering but even in terms of money.

We are not the only ones concluding that not investing in water and sanitation in developing countries costs money. Hutton and Haller (2004) report that the total annual economic benefits of water and sanitation interventions in the East African region are estimated to be 52 US$ (2000) per person when realizing access to improved water supply and sanitation for all, and 72 US$ (2000) with addition of minimal water disinfected at point of use (Hutton and Haller (2004), p.34, p.46).

Benefit Cost ratio's for the East Africa Region are estimated to be 12 when realizing access to improved water supply and sanitation for all, and 15 for addition of minimal water disinfected at point of use (Hutton and Haller,2004). These Benefit Cost ratios drop to 2 and 3 when high costs and low benefits are assumed (Hutton and Haller, 2004). So even for the lowest estimates benefits are twice as high as the costs. Investments in water and sanitation in developing countries are not only needed from humanitarian point of view but are also paying back.

4.2.6 Financing Mechanisms

CW technology has not been well up taken because stakeholders are not well informed about different financing mechanisms for the technology. Understanding and applying one of the financial mechanisms is a key to success or failure of the CW. In order for the CW technology to be effectively adapted, there are must be financial mechanisms in place. Financial mechanisms, in this context, mean sources of funds for both capital costs and operation and maintenance costs. This study has identified some financial mechanism available in Tanzania for easy adaptation of CW technology. The financial mechanisms can be available at different levels as explained below;

National Level

At national is National government through Municipal Councils whose functions will be;

- Allocate funds for sanitation and hygiene education,
- Lobby external support agencies for discretionary terms for financing waste management, hygiene promotion and sanitation,
- Provide financial incentives to local governments which can deliver efficient and effective sanitation and hygiene promotion programmes,
- Develop and finance micro-credit schemes managed by Non-Governmental organization (e.g. SACOSS) or the private sector to target households and work

with private sector leaders and product manufacturers to create programmes for extending credit to members of the most vulnerable communities.

- Provide loan security to households that have no collaterals

Local Level

At local level are Local governments (participating wards) whose functions will be;

- Review the effectiveness of sanitation and hygiene promotion programmes and ensure that funds are not used to finance high-cost, low-impact investments,
- Make subsidy programmes clear and transparent;
- Create incentives to develop new technologies to reduce cost;
- Create micro-credit and credit guarantee programmes to target households and provide incentives for local manufacturers to extend credit to the poorest households

Communities and Civil Societies Level

At this level, the communities and societies will have the following functions;

- Scrutinize public accounts and check on reported spending on sanitation and hygiene promotion to help increase accountability and reduce wastage;
- Propose alternative institutional and technical approaches that could reduce costs and ensure that these are well-known and well publicized,
- Develop micro-credit schemes to fund household sanitation improvements and create mechanisms for generating user fees for funding continuing operation and maintenance of facilities.

Household Level

The household level will have the following roles in funding;

- Participate in community schemes and/or micro-credit schemes,
- Pay back loans to loan providers
- Contribute maintenance fee to user groups.

Entrepreneurship Level

The functions for this level will be;

- Offer poor households with low-interest credit to purchase their products (e.g. CW etc)
- Work with local governments, No-governmental organization and/or banks to develop micro-credit schemes
- Develop cost-effective products and services for poor communities and households.

Financial Institutions Level

These financial institutions will give soft loans for sanitation (e.g. CW) activities and investments (services and facilities installation)

International organizations and external funding agencies Level

These agencies will have the following functions;

- Allocate sufficient resources to the sector
- Mobilize other development partners to contribute funds.
- Compile and disseminate information on a variety of cost effective sanitation alternatives and effective behavior change strategies
- Compile and disseminate information on effective programmes for mobilizing financial resources, including micro-credit schemes, targeted subsidies etc.

It has to be noted that, there is no any single financial mechanism that has been explained above that can be used alone meaning that different financial mechanisms have been looked at together to create the complementarily of one another.

4.3 Public Health and Environmental Factors

4.3.1 General background

Sanitation is any system that promotes sanitary (sterile), or healthy, living conditions. It includes systems to manage wastewater, stormwater, solid waste, and household refuse and it also includes ensuring that people have safe drinking water and enough water for washing (IRC symposium, 2008). Sanitation facilities include sanitary toilets, sewers and wastewater treatment plants as well as more simple technologies such as latrines and septic tanks. The focus is on the safe management of human excreta which is full of dangerous bacteria that can cause diseases like cholera, typhoid, infectious hepatitis, polio, cryptosporidiosis, and ascariasis (Global Poverty Info, 2013). Sanitation includes both the 'software' of understanding why health problems exist and what steps people can take to address these problems, and 'hardware' such as toilets, hand-washing facilities, sewers and wastewater treatment units, which constitute Sanitation Service Chain.

Sanitation services are defined as the (i) containment, (ii) collection, (iii) treatment, (iv) disposal and (v) re-use of excreta and solid and liquid waste. Together, they combine to break the cycle of diseases that spread when human excreta and waste are not managed properly (Mazubane and Brisley, 2003). It is the hygienic means of promoting health through prevention of human contact with the hazards of wastes. So CW technology like any sanitation system has to promote health as it has been explained above.

So CW technology as an acceptable sanitation service and to be successful can be described in three levels as described hereunder:

- **Basic service**

At this level all households have reasonable access to a safe, relatively robust, private sanitation facility, available hand washing facilities, relatively weak desludging and other long term maintenance provisions, and non-problematic environmental impact or safe disposal of sludge. This is typical of most acceptable rural and peri-urban sanitation services.

- **Improved service**

At this level, all users have easy access at all times to a convenient, private, safe, robust sanitation facility which seals against flies and bad odors, has nearby hand washing facilities, where minimal effort is required for desludging and long term maintenance, and there is non-problematic environmental impact or safe disposal of sludge.

- **Highly improved service**

At this level, users have immediate access at all times to a convenient, private, safe, robust, secure sanitation facility which seals against flies and bad odours, as well as having immediate access to hand, anal and latrine cleansing facilities with soap, where minimal or no effort required for designing or long term maintenance, and there is positive environmental impact, e.g. productive re-use of safe by-products.

4.3.2 Environmental Considerations

Based on the reality of sanitation services in Tanzania, and considering all the functional area of the sanitation service delivery chain, there are four key service parameters and indicators, which determine the success or failure of Sanitation service including CW technology in Tanzania

- **Accessibility**

  ✓ ***Success:*** All Constructed Wetland Systems built in Tanzania are based in Public Institutions, with considerably large space, making all of them conveniently accessible. However, accessibility may be limited to some other areas in the general public thanks to lack of urban and rural planning, which may possibly constitute a challenge in establishing these systems.

  ✓ ***Failure:*** Many informal settlements are found throughout the country, and it is not uncommon for private land owners to refuse the provision of basic services, including those related to sanitation. On the maintenance front, the desludging of full latrines is difficult as is the management of increasing quantities of greywater. Both of these are costly and access becomes a problem when settlements grow and become congested. Greywater is frequently poured into pit latrines, which disrupts their functioning and leads them to fill quickly (Kunane, 2010).

- **Use**

  - ✓ ***Success:*** This is concerned with safe and hygienic use of the facility by the communities, with regard to distance from users, effort required for use, safety, privacy, dignity, minimizes flies and bad odors, waiting time in the case of communal facilities. As a success in Tanzania, Engineered Wetland Systems as part of the Sanitation Service Chain, have been able to meet the functional requirements for safe use; since these systems are mainly Horizontal Sub-Surface Flow. This type of flow pattern has been commended for dealing with bad odors and flies, which are functional elements for safe and hygienic use of the sanitation service chain

  - ✓ ***Failure:*** The available data (GIZ, 2012) estimate that by 2010, just 10% of all Tanzanian households have access to improved sanitation. Only 50% of schools had basic sanitation in 2007 and only one in ten schools had water supply (UNICEF, 2007). Access of households to open pit latrines or latrines without slabs was estimated at 50% for rural and 71% for urban areas (Tanzania Demographic and Health Survey, 2010).

- **Reliability and Sustainability**
  - ✓ **Success:** Constructed Wetland systems in Ruaha Secondary School and Moshi UWSA' have recorded a success stories as regard achieving sustainable operation and performance, largely due to proper institutional arrangements and general acceptance by the communities in these areas.
  - ✓ ***Failure:*** Some communities experience difficulties around the incorrect use of Constructed Wetland facilities, vandalism and theft. Practical example is the

newly installed Constructed Wetland in Morogoro, Tanzania, under the COSTECH project; whereby the installed valves in the pipework are stolen noe and then, making the system malfunction.

- **Environmental protection**
  - ✓ ***Success:*** Constructed Wetlands with Horizontal Sub-Surface Flow have often shown success under those below-stated environmental conditions.
  - ✓ ***Failure:*** Protection entails environmentally safe containment, collection, treatment, disposal and re-use of excreta and urine; and productive re-use of safe by-products. However, there are at least four sets of challenges in addressing sanitation backlogs. Physical challenges include the congestion of settlements, poor soil conditions and high water tables, plus frequent proximity to natural watercourses (many settlements are sited on floodplains). This makes VIP unsuitable and technical innovations to get round this have not always succeeded. Institutional challenges abound, with lack of coordination between role-players a hurdle, plus delays in service delivery resulting from significant delays in the formal processes required for the institutionalization and regularization of informal settlements.

- **Wastewater Quality**

- ***Success:*** Findings from the study by Yhdego (1992) on Waste Stabilization Ponds System revealed the following:
  - The removal efficiencies of permanganate value, biochemical oxygen demand, and suspended solids were observed to be 68.9%, 71.5%, and 71.39%, respectively. The final effluent quality for BOD_5 and SS were 59.5 mg/1 and 58.33 mg/1, respectively. These values are high compared with the recommended value of 30 mg/1. The analysis found that there is a good correlation between BOD and PV concentrations. Thus, values of PV may be used to estimate the concentrations of BOD_5 if quick results are required.

- Removal efficiency of FC was 99.9573% and the mean survival in the effluent was 127 x 10z FC/100 ml. Further treatment is needed to achieve lower FC concentrations.
- The removal efficiency of NH_3-N (89.16%) is high compared with the expected efficiency of the ponds.
- Dissolved oxygen was found to decrease with increasing depth, because of active oxygen utilization at the pond bottom, re-aeration, and algal oxygen production at the surface.

A combination system of wastewater stabilization ponds and constructed wetland utilizing *Phragmitis ssp* or *Typha latifolia* has been able to achieve removal of 88.5% BOD, 87% COD, 89% TSS, 74% O-N and 99% fecal coliform rendering the effluent suitable for irrigation of ornamental plants although with time there was a tendency of accumulation of phosphorus. In this respect, water that has passed through the wetland could be used to irrigate crops and/or introduced to a fishpond (Denny et al, 1997). In Uganda, findings show that constructed wetland is effective in the reduction of fecal coliforms, nitrogen (ammonium), organic and suspended matter that meet the Uganda National Standards for effluent discharge (Kiwanuka and Kelderman, 2001).

- **Scale and affordability**

Scale and affordability are also crucially important service parameters, addressed in the research through data aggregation and analysis.

4.3.3 Functional Considerations

According to Kvarnström et al. (2008), the use of a function approach could improve Sanitation Service Chain tree as depicted in the following Sections:

4.3.3.1 Environmental Functions

- ***Integrated Resource Management***

  The sanitation system is connected to and works productively with the related systems for water, nutrients, and energy provision, through integrated management of storm water, wastewater, fecal sludge, grey water and solid waste collection.

- ***Nutrient Containment***

Protection of the environment by controlling releases of nutrients to water bodies and the environment; requires some treatment and/or storage methods; includes nutrients from both grey water and excreta flows.

- ***Nutrient Reuse***

Closing the loop on nutrients through reuse of treated human waste, e.g. in agricultural production or soil rehabilitation.

- ***Pathogen Elimination***

Secondary treatment that will destroy pathogens in the excreta and grey water.

4.3.3.2 User Functions

- ***Grey Water Management***

Means no stagnant water in the user environment, also eliminating exposure to pathogens, insects, and filth.

- ***Access***

The users have safe, reliable access to the sanitation facilities 24-hours a day, including privacy, personal safety, and shelter.

- ***Excreta Containment***

Contains the human excreta and sets barriers to pathogen transport; therefore includes no flies; no fecal matter lingering; hand-washing facilities are present. The facility should be clean and odor-free to preserve a clean/pleasant experience for the user and encourage use.

4.4 Institutional Considerations

4.4.1 Importance of Institutional arrangement

The institutional arrangement is one of the most important factors towards success or failure of sanitation systems through proper operation and maintenance. In order for the proper operation and maintenance of the sanitation systems, the right units/departments must be in place with all key roles and functions covered and clearly understood. These units must also have enough resources to carry out their roles. The following are wetlands constructed in different institutions by WSP and CW research group. These institutions have different arrangement pertaining to waste management. The importance of institutional arrangements towards success or failure of CW can be demonstrated using the CW systems that have been constructed in the country. The following section below explains different systems in Tanzania and how institutional arrangement has played significant role in either success or failure of CW.

4.4.2 Description of 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 625 m^2 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. The idea of constructing a wetland at this collage was brought by WSP and CW research group as part of the pilot study and therefore, it 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. Furthermore, the college doesn't have a proper arrangement in dealing with waste management. The non functionality of the CW in Kleruu has been to large extent been attributed by lack of the institutional arrangement at the college dealing with waste management.

Plate 6: Constructed Wetland and Mechanical Aeration Chamber at Kleruu TTC

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 idea of having this system was brought to WSP and CW research group by Ruaha School. The school through its environmental unit was seeking solutions to management of their wastewater as their soak away pit was not performing well due to nature of the soil. 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. The wetland is performing very well. The school has a unit which is dealing with environmental issues like solid waste and wastewater management e.t.c. The unit is making good efforts in proper operation and maintenance of the constructed wetland system. Also, the school has incorporated the environmental studies (theory and practical) in their curriculum to which students get general knowledge in environmental management.

Training students on environmental sampling

CW effluent reuse for cow project

Plate 7: Constructed Wetland System at 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 idea of constructing a wetland at this authority was brought by WSP and CW research group as part of the pilot study. 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 $400m^3$/day. The effluent from the HSSFCW is reused for irrigation in the pilot paddy farm and aquaculture farming (fish pond). The wetland is generally performing well. MUWSA is an institution which is directly related to urban wastewater management, it has got a unit which is responsible to wastewater management and its staff is dedicated to their work.

Plate 8: HSSFCW System owned by MOUWASA-Moshi Municipality

Plate 9: Fish pond and paddy farms downstream of the CW system

***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 5376 m^2. The designed flow rate was 81 L/sec with the operational flow rate of 80 L/sec. The idea of having constructed wetland system was brought to WSP and CW research group by the industry. 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. This institution doesn't have a special arrangement for operation and maintenance of the constructed wetland system.

Plate 10: HSSFCW system at Kibo Paper Mill, Moshi Municipality

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 50 m^3/d.

Figure 11: HSSFCW System at Shinyanga Prison

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 (Figure 10). The size of the system is 55m × 20m wide with the area of 1100m^2 designed and constructed for treating domestic sewage. The average flow rate to the system is 50m^3/d.

Plate 12: HSSFCW system at Malya Prison

The system also experience clogging and overland flow (flow channeling). Several plant species which were not originally planted have emerged, making diverse plant community as indicated in figure 10. As in case of Shinyanga prison, the prison doesn't have a proper arrangement in dealing with waste management and the staff is generally not dedicated to waste management.

4.4.3 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. 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 mauritianus*. 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.

5. CONCLUSIONS AND RECOMMENDATIONS

Despite the fact that CW technology has been in the country over the last two decades, there has been no any documentations in terms of factors for success and failures of the technology and therefore this report has captured the experiences of applicability of CW in Tanzania with the view of providing the factors that are important for success of CW technology. A number of factors need to be considered for the success of CW technology. These factors are broadly categorized as Technical factors, socio-economic factors Costs considerations of CW Benefits Aspects of CW Financing Mechanisms Public Health and Environmental Factors and Institutional Arrangement.

Our review of the above factor therefore show that under technical factors planning is a very primary and important step of a CW project which aims at defining objectives for the system in relation to the exiting situation on the ground and available resources. It involves assessment of the project area thereby considering the existing topography to better configure the system, existing soil type, water table, climatic conditions for hydrological budgeting and localizing the system, substrates and macrophytes. On the other hand, the success experience entail that there is flexibility of planning for CW use in coupling with other technologies such as septic tanks, stabilization ponds and biogas plants for maximizing treatment efficient and ensure sustainable use of resources. In addition, CW seems to be the best technology for use in water logged, high ground water table and clayey areas. It fits for decentralized wastewater treatment since can be used for small, medium and large scale communities.

Moreover the design of CW in Tanzania has been based on the Plug Flow approach which provides a more appropriate description of a flow pattern is SSFCW. The characteristic wastewater parameters considered in the design include BOD, Total Suspended Solids (TSS), Ammonia (NH_3), Nitrate (NO_3), phosphorus Fecal Coliforms. Few challenges are experienced when designing CW system. They include lack of consistence design approach locally and globally whereby literatures reveal different designers use different methods to determine the area requirement for CW. Yet, some other more design concepts and approaches are still under research. The good thing about design of CW system is the possibility to address specific or all pollutant parameters of wastewater such as BOD, nutrients, fecal Coliforms, etc given varying circumstances.

On Construction of Constructed Wetland aspect, most contractors and local builders are not aware and knowledgeable enough to appreciate the technology and its key functional components. They consider the CW system structurally not functionally. As such they view it as a very simple facility to erect while committing a number mistakes which are the key to the function of the wetland. It does not matter how nice and detailed the engineering drawings are. The typical mistakes committed by contractors and builders include incorrect levels for inlet and outlet pipes to ensure desired hydraulic requirement, provision of wrong size of substrates and introduction of soils into the system with a view of supporting the growth of wetland plants. Under this situation, the need for very close construction supervision cannot be undermined.

Under Operation, Maintenance and monitoring, the survey results on the operation of existing CWs carried out by the WSP & CW Research and Development Group of the University of Dar Es Salaam in 2010 indicated that 86% of the surveyed CWs experienced various forms of operational problems. The major problem experienced was a combination of blockage and over flooding (57.1%) whereas blockage itself constituted 14.3%. Other operational problems included seepage through the walls or leakage, storm water runoff especially during and after rainfall events and, cracks which altogether constituted 28.6%. Other challenges during the operation phase are fluctuation of flows and inadequate performance monitoring of the CW systems. Hence, the need for users' training on operation, maintenance and monitoring of CW during the commissioning phase.

On socio-economic factor, social mobilization is a concept which involves the creation of a social movement for initiatives in development projects. This movement aims to create a major thrust to solve problems of national magnitude by promoting participation of all possible sectors and levels of society, mobilizing local resources and using indigenous knowledge. It aims to enhance people's creativity and productivity through mass campaign. This concept is of extreme relevance for a real change can be initiated by orchestrating a joint attack against the alarming sanitation situation with minimum social conflict. The participation of people in any development programme is the pre-requisite for sustaining any achievement. Social mobilization involves not only people in the community, but all sectors and levels of society as well as service delivery agencies, i.e. where local resources are tapped to its fullest which ensures the sustainability of the programme.

The strategies adopted for the above objectives are spelled out as follows:

- to increase the awareness of all communities of the benefits of sanitation improvements using CW technology with the help of appropriate communication media;
- to promote affordable and appropriate CW technology with an emphasis on defecating in a fixed place and on construction of home-made latrines;
- to mobilize resources and build alliances with all potential partners -such as political leaders, local governments, professional groups, NGOs, CBOs, women groups, educational and religious institutes, mass media, cultural groups, etc.- for sanitation improvement through dialogues and advocacy campaigns.

So for a CW technology to be successful, it is very important that social mobilization in the intervention area be implemented. Unfortunately this is an area that has not been well given due attention in the implementation of the CW technology in Tanzania and therefore it is recommended to be given more focus and emphasis.

The success and failure of constructed wetlands in Tanzania to great extent depends on costs for putting up a facility in place as well as the O&M costs. People who would like to adopt the CW technology are ill informed about the costs categories let alone the exact figures for these cost categories. Quiet often CW technology is not easily up taken up because users are not well informed about the benefit associated with CW. Well known benefits will help the CW to be easily up taken up and thus it's successful.

CW technology has not been well up taken because stakeholders are not well informed about different financing mechanisms for the technology. Understanding and applying one of the financial mechanisms is a key to success or failure of the CW. In order for the CW technology to be effectively adapted, there are must be financial mechanisms in place. Financial mechanisms, in this context, mean sources of funds for both capital costs and operation and maintenance costs. This study has identified some financial mechanism available in Tanzania for easy adaptation of CW technology and therefore its success.

Sanitation services are defined as the (i) containment, (ii) collection, (iii) treatment, (iv) disposal and (v) re-use of excreta and solid and liquid waste. Together, they combine to break the cycle of diseases that spread when human excreta and waste are not managed properly. It is the hygienic means of promoting health through prevention of human contact with the hazards of wastes. So CW technology like any sanitation system has to promote health as it has been explained above.

The institutional arrangement is one of the most important factors towards success or failure of sanitation systems through proper operation and maintenance. In order for the proper operation and maintenance of the sanitation systems, the right units/departments must be in place with all key roles and functions covered and clearly understood. These units must also have enough resources to carry out their roles. The following are wetlands constructed in different institutions by WSP and CW research group. These institutions have different arrangement pertaining to waste management. The importance of institutional arrangements towards success or failure of CW can be demonstrated using the CW systems that have been constructed in the country.

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VLIR-UOS
Mailing address: VLIR-UOS | PO box 103 Elsene Naamsepoort | 1050 Elsene | Belgium
[e] info@vliruos.be

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Promoter:
Thomas More University College | Kleinhoefstraat 4 | 2440 Geel | Belgium
[e] rob.van.deun@thomasmore.be

Local Partner:
University of Dar es Salaam, College of Engineering and Technology (CoET)
Waste Stabilization Ponds and Constructed Wetland Research and Development Group (WSP-CW)
University of Dar es Salaam | P.O. Box 35131 | Dar es Salaam | Tanzania
[e] knjau30@yahoo.com