Dissemination of the sustainable wastewater technology of constructed wetlands in Tanzania
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Team Members
Dr Richard Kimwaga
Dr. Agnes Nyomora
Dr. William Mwegoha
Dr. Anes Mahenge
Mr. Leonard Gastory

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

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Abbreviations and Acronym

KADC	Kilimanjaro Agricultural Development Centre
AGENDA	
ARI	Accounting Rate of Interest
ARU	Ardhi University
BOD	Biological Oxygen Demand
CBA	Cost Benefit Analysis
COD	Chemical Oxygen Demand
COSTECH	Commission for Science and Technology
CW	Constructed Wetland
EDC	
EDF	European Development Fund
ENVICON:	
EU	European Union
FAO	Food and Agriculture Organization
FC	Faecal Coliform
FSS	Free Water Surface
HSSFCW	Horizontal Subsurface Flow Constructed Wetland
IRR	Internal Rate of Return
IRUWASA	Iringa Urban Water Supply and Sewerage Authority
KU	Kenyatta University
MAK	Makerere University
MORUWASA	Morogoro Urban Water Supply and Sewerage Authority
MPC	
MUHAS	Muhimbili University of Health and Allied Sciences
MUWSA	Moshi Urban Water Supply and Sewerage Authority
NGO	Non Governmental Organization
NH_3	Ammonia
NH_3-N	Ammonia Nitrogen

NM-AIST	The Nelson Mandela African Institute of Science and Technology
NO_3	Nitrate
NPK	Nitrogen Phosphorus and Potassium
NPV	Net Present Value
O & M	Operation and Maintenance
ORS	Oral Rehydration Salts
OUT	The Open University of Tanzania
PBP	Pay Back Period
PUMPSEA	Peri - Urban mangrove forests as filters and potential phytoremediators of domestic sewage in East Africa
QMRA	Quantitative Microbial Risk Assessment
RSS	Ruaha Secondary School
SN FWS	Semi Natural Free Water Surface Wetlands
SSF	Sub Surface Flow
SSFCW	Subsurface Flow Constructed Wetland
TDS	Total Dissolved Solids
TIRDOT	Tanzania Industrial Research and Development Organization
TL	Trigger level
TSS	Total Suspended Solids
UCDISM	University Capacity Development for Integrated Sanitation Management
UD	Urine Diversion
UDDT	Urine Diversion Dry Toilet
UDOM	University of Dodoma
UDSM	University of Dar es Salaam
UMZA	University of Zambia
VIP	Ventilated Improved Pit Latrine
VLIR	Vlaamse Interuniversitaire Road
WHO	World Health Organization
WSP	Waste Stabilization Ponds

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1 Water Resources Management Challenges and Wastewater Reuse in Perceptive

1.1 Water Resources Management Challenges

Environmental stresses imposed by population growth, urbanization, industrialization and climate change have become a prominent theme of international concern, especially since the 1992 Earth Summit in Rio de Janeiro. One of the most affected of the natural resources is that of freshwater. Demands upon the world's supply of freshwater resources are increasing the threats and risks to both quantity and quality of this natural resource essential to human life, health, social and economic activities. These risks to water resources have raised political attention which has been translated into political commitment, within and between countries, for the protection of this vital resource. Growing concerns related to climate change highlight the urgency of the freshwater situation. Climate change impacts are expected to affect populations directly by more frequent extreme events such as floods and droughts, rising sea levels, changes in the seasonal distribution and amount and type of precipitation such as snow and rain.

Some major urban centers already face serious water shortages compounded by water pollution crises, the latter often originating from water-dependent and water-impacting agricultural and industrial activities. Questions relating to water resources management and usage cut across many economic and social sectors, including agriculture, fisheries, industry, urban development, energy, environment, tourism and public health.

With increasing economic and demographic demands coupled with climatic change stresses, the prospect of increased competition and serious disputes within and between states and sectors over water resources in the not-too-distant future become more conceivable.

In response to this problem, some wastewater professionals are reusing treated wastewater and have found it to be a reliable alternative water source

1.2 Wastewater Re-usein Perceptive

1.2.1 Growing water stress

Many parts of the world are experiencing growing water stress and water scarcity. Projections indicate that the population living in water-stressed and water-scarce countries will grow from about 1.2 billion (or 18 percent of the world population) in 2007 to 4.0 billion (or 44 percent of the world population) by 2050 (Comprehensive Assessment of Water Management in Agriculture, 2007). Water stress and scarcity may even become a concern in regions that are generally thought to have abundant water supplies, because of the unequal spatial distribution of water resources. For example, Tanzania is endowed with large fresh water bodies such as Lake Victoria, Lake Tanganyika and Lake Nyasa, but central Tanzania is semiarid. Agricultural production in many parts of Tanzania is rain fed. It is well recognized that intervention in irrigation development boosts crop production 3-4 times than that of rain fed agriculture.

The trend toward growing water stress is likely to accelerate due to climate change. The Intergovernmental Panel on Climate Change (IPCC)(2007) predicts that global warming will alter the hydrological cycles. Drought-affected areas are projected to increase in extent, with higher frequency and intensity of drought (Meehl *et al.*, 2007).

Climate change will also affect water quality in water scarce regions, with reduced river flows losing assimilative capacity, and salinity increasing (Sadoff and Muller, 2009). As a result of these changes, the demand for irrigation water and in particular for wastewater as an extremely reliable water resource will rise, and it will need to be increasingly considered as an integral component of local water resources. On one hand, the vulnerability and adaptation to climate change study has shown increasing recurrence of draughts which has affected agriculture (URT, 2003). On the other hand the third pillar of Kilimo Kwanza envisages increased use of irrigation as a way of promoting agricultural output (URT, 2009). Also the National Population Policy (2006) acknowledges the failure of current agriculture to meet the food and nutritional demands of the people due to unreliable rains and lack of irrigation schemes. One of the policy strategies being proposes is enhancement of irrigation schemes. Although the policy does not specifically mention the urban agriculture, it is implied. MKUKUTA II, Goal Number 4 recognizes the challenges of Climate Change. Some relevant clusters include Improving soil and water conservation measures including irrigation development, Supporting accelerated development and deployment of new technologies that ensure adaptation and mitigation actions (UTR, 2010). Using treated wastewater in agriculture is a potential alternative resource that may improve production conditions in farming systems and simultaneously save fresh water for domestic use.

1.2.2 Nutrients Deficiency in Agricultural Production

Agricultural production in Africa is characterized by low productivity caused by a combination of endogenous and exogenous factors. One of the factors is lack of adequate agricultural inputs such as nutrients in form of fertilizers and manure necessary for plant growth. Sub-Saharan Africa has the world’s lowest level of mineral fertilizer use. Only eight kilograms of nutrients are applied per hectare. This represents about ten percent of the world average. It is estimated that Sub-Saharan Africa imports more than 90 percent of its agricultural fertilisers. Decline in soil fertility is reported as one of the major constraints hampering rural development in Tanzania (Ley *et al.*, 2000). This has resulted in poverty, widespread of malnutrition and massive environmental degradation (Shepherd and Saule, 1998; Ley *et al.*, 2000).While this is a fact; a lot of nutrients contained in wastewater are discharged into rivers and oceans causing secondary impacts in water bodies and the environment. Consequently, essential elements, like carbon, nitrogen and phosphorus and trace elements vital for plant growth are lost in a process that consequently causes over-fertilization (eutrophication) of water bodies and the oceans. These nutrients (fertilizer) could be recovered for use in agricultural production. Such form of waste disposal is not just water and energy consumptive, but also very costly due to the necessary infrastructure and structural construction required.

Farmers around Moshi Urban Water Service Agency (MUWSA) waste stabilization ponds grow lowland irrigated paddy 2 times a year in Mid July to November and November to Mid May. Paddy cultivation in this area is intensive in that it is based on highly yielding Japanese varieties (No. 54, 56, 64) originating from KADC and heavy use of inputs (artificial fertilizers and pesticides). All interviewed farmers during a preliminary survey (Kanyeka and Nyomora,2006) reported of using at least 2 bags (100 kg) Urea or SA/acre/growing season, one bag 15 days after transplanting and the rest 25 days after (close to booting stage). This high level of fertilization could easily be replaced by using wastewater from MUWSA if other risks were abated by intensive research.

1.2.3 Growing urbanization

An ever larger share of the world population lives in cities. Particularly in developing countries, urbanization is growing very rapidly. From 2010 to 2030, the population living in urban areas in developing countries is expected to increase from about 2.6 billion to 4.0 billion in 2030; and in lower-income countries the urban population is expected to more than double from 254 million to 539 million (UNFPA, 2008). According to World Bank (2010), urban population of Tanzania is about 11 million and growing fast at a rate of about 6.2% (Thaxton, 2007). Table 1 shows the level of urbanisation in Tanzania since 1950 (McGranahan *et al.,* 2009). About 70% of the city's population live in unplanned, un-serviced, and densely populated areas and, urban farming and livestock keeping have grown substantially in the city (the number of households engaged in food production grew from 20% to more than 65% between 1970 and 1990) due to economic reforms leading to increased poverty and decreased formal employment.

Table 1: Urbanization levels for Tanzania 1950-2000 (based on censuses) and 2010 and 2030 (based on projections from 2002 census)

1950	1970	1990	2000	2010	2030
3.5	7.9	18.9	22.3	26.4	38.7

1.2.4 Growing urban wastewater generation

Associated with the large growth in the urban population will be a growth in urban wastewater generation. As countries' income levels rise, the levels of piped water supply and sewer networks also tend to raise, and lead to further increased wastewater flows. Provision of sanitation services has always lagged behind. Achieving the Millennium Development Goals sanitation target of cutting in half the service deficit by 2015 and achieving sanitation for all by 2025, will require significant vamping up of the pace of improvements. Utilization of wastewater for agricultural irrigation will be an additional catalyst for sanitation provision in most urban centres.

1.2.5 Growing agricultural activities in and near urban areas

The growth in the urban population will not only lead to an increasing supply of urban wastewater, but also to a growing demand for irrigation water for agricultural activities in and near urban areas. Recent estimates for West Africa suggest that about 20 million people—of an urban population of 100 million—live in households engaged in urban agriculture; in many cities they produce 60 to 100 percent of the consumed perishable vegetables (Drechsel *et al.*, 2006). Deelstra and Girardet (2005) states that "Dar-es-Salaam, one of the world's fastest growing large cities, now has 67% of families engaged in farming compared with 18% in 1967.

1.2.6 Reasons for Wastewater Reuse

The most common reasons for establishing a wastewater reuse program is to identify new water sources for increased water demand and to find economical ways to meet increasingly stringent discharge standards.

1.2.7 Public Health and Water Quality Considerations

Water quality of importance in wastewater re-use is as described below;

Physical water quality considerations - Turbidity, color, etc

Chemical water quality considerations - Chemical constituents including solids, metals, nitrogen, phosphorus, etc

Biological water quality considerations - Pathogens including bacteria, helminthes, virus,

Emerging water quality considerations - Pharmaceuticals, hormonal products, personal care products, other EDC's

CW technology which has been in the country over the last two decades provides many opportunities in different dimensions with regard to the reuse of treated the effluent from CW. This report describes the opportunities for reuse of treated effluent from CW. The opportunities described in this report are on the dimensions of Wastewater Quantity and Quality, Guidelines and Regulations (Regulatory) that Influence Wastewater Reuse in Tanzania, Water related National Policies, Human Health and Ecosystem Risk, Economic Issues and Technical issues. The following sections provide glimpse of these opportunities.

2 Wastewater Quantity and Quality Considerations

2.1 Wastewater Quantity Generated from CW

Constructed Wetlands are "eco-friendly" alternatives with potential applications ranging from secondary treatment of wastewater from various sources, to polishing tertiary treated wastewater and diffuse pollution. Constructed wetlands can effectively remove large quantities of pollutants from point sources (municipal, industrial and agricultural wastewater) and non-point sources (mines, agriculture and urban runoff), including organic matter, suspended solids, metals and nutrients to required effluent discharge standards. They utilize multiple physical, chemical and biological processes to achieve removal or transformation of pollutants in wastewater.

While CW can be designed to accomplish a variety of wastewater treatment objectives, they also provide benefits other than water quality improvement most of them gauged to reuse of treated effluents. Tanzanian experience with subsurface flow CW reveals that the systems can be designed and operated in a manner that provide reuse opportunities including irrigation agriculture, horticulture, gardening, fish farming and land rehabilitation. Only that the extent of the reuse scheme needs to be in line with the amount of wastewater being generated from the CW after treatment which actually can be estimated to be 75% – 85% of water consumption of a given project. Plates below illustrate typical schemes that are coupled with reuse of CW effluents in Tanzania.

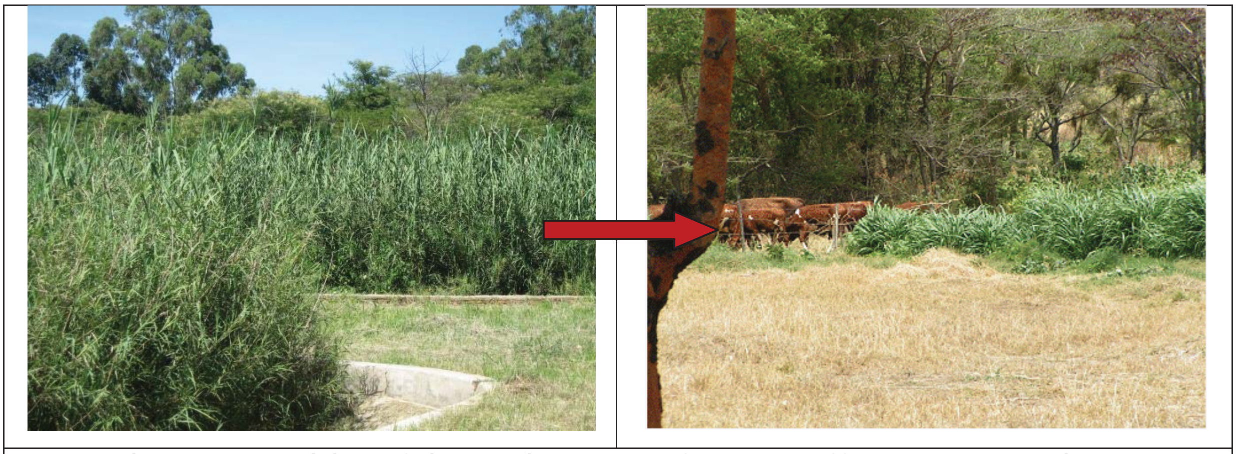


Figure 2.1. Raising of livestock pastures from CW effluents at R S School

Figure 2.2: Fish Pond in use of CW effluent at MUWSA

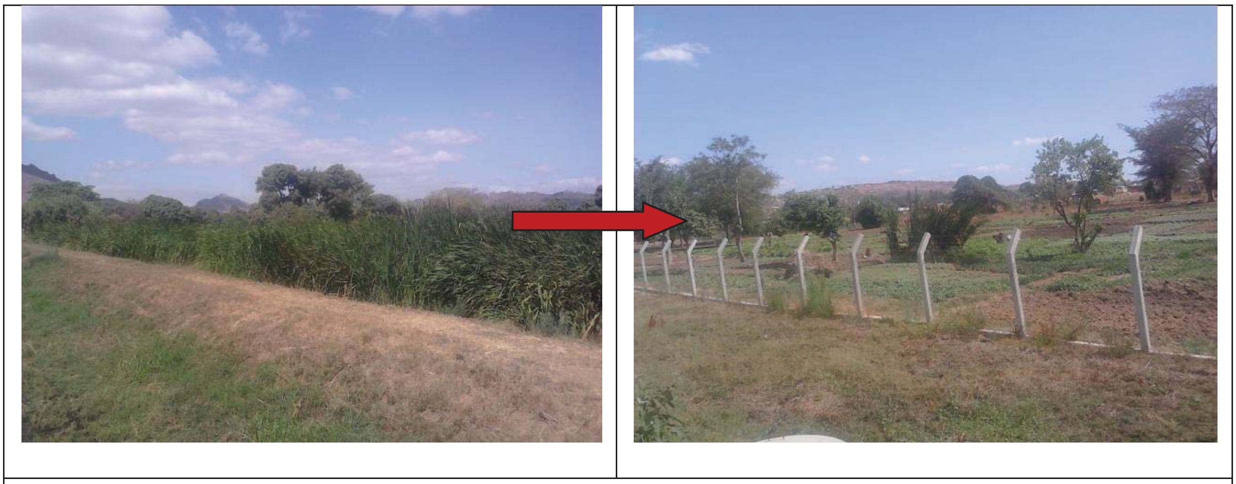


Figure 2.3: CW units for polishing municipal wasterwater in Iringa and later serving irrigated agriculture

2.2 Quality of Treated Wastewater from CW

The critical characteristic wastewater parameters considered in the design include BOD, Total Suspended Solids (TSS), Nitrate (NO_3), Ammonia (NH_3), phosphorus and Fecal Coliforms. Treated domestic and municipal wastewater provide for reuse potentials among several applications such as irrigation in agriculture, reuse in aquaculture, groundwater recharge and industrial recycling or reuse. Studies on how to assess the performance efficiency of CW technology in East Africa entail that the overall performance of the CW technology on treating domestic/municipal wastewater is satisfactory for pH control, BOD, NO_3– N and NH_3- N removal. Most effluents were found to be below the recommended national standards except for phosphorus removal (Katima et al., 2012). The paragraphs below present the performance of four CW units in Tanzania i.e. UDSM, Ruaha Secondary School, Kleruu Teachers' College and Moshi Urban Water Supply and Sewerage Authority (MUWSA), as recorded by different researchers for the period of 2005 – 2010.

pH Control: The results show that pH values in the CW influent ranged from 7.20 – 8.30 with an average of 7.66±0.57. On the other hand effluent pH values for the CW units ranged from 7.00 – 7.60 with mean value of 7.55±0.31. The results obtained reveals that pH values in the influents varied from time to time and from one source to another possibly due to variations of alkalinity in the raw sewage. Results also show that pH in the influent is higher than pH in the effluents possibly due to decrease in alkalinity in the CW cells. Performance wise, the results agree with effluent discharge standards as recommended by local authorities which require pH to be of a range of 6.5 – 8.5. However, the results revealed that for domestic wastewater pH is not a critical parameter as both the influent and effluent met the recommended effluent discharge standards.

BOD Removal: For the assessed CW units, influent BOD concentrations ranged from 51 - 200mg/l with average concentration of 127.75±61.02mg/l. The effluent BOD concentration ranged from 12 – 41 mg/l. The inter-average BOD concentration is 22.00±12.94 mg/l. This is equivalent to the system efficiency of 82.78% for BOD removal. Generally, the results entails better performed of the CW units as the BOD in the effluents met recommended effluent discharge standards by local authorities.

Nitrate Removal: The results showed that characteristic Nitrate Nitrogen in raw domestic/municipal wastewater range from 26.30 – 35.30 mg/l whereas Nitrate concentration in CW effluents ranged from 11.30 – 11.44 mg/l. The influent and effluent averages were 30.80±4.50 mg/l and 11.37±0.07 mg/l respectively. This is equivalent to the CW efficiency of 63.08% on nitrate removal. The results entails better performance of the CW units as the effluents met recommended effluent discharge standards by local authorities.

Ammonia Removal: Influent ammonia concentrations for the assessed CW units ranged from 24.87– 77.30 mg/l with average concentration of 51.09±26.22 mg/l. The effluent Ammonia concentration ranged from 10.35 – 33.00mg/l. The inter-average Ammonia concentration in the CW effluent was 21.68±11.33 mg/l. This is equivalent to the system efficiency of 57.57% for Ammonia removal. Though the overall performance efficiency did not meet recommended effluents discharge standards by local authorities, some individual CW did meet (Table 2.1).

Phosphorus Removal: Laboratory analysis of wastewater samples showed that Phosphorus concentration in raw domestic/municipal wastewater ranged from 18.10 – 56.50 mg/l whereas Phosphorus concentration in CW effluents ranged from 6.72±1.20 – 39.90mg/l. The influent and effluent averages were 50.50±6.00 mg/l and 29.00±6.00 mg/l respectively. This is equivalent to the CW efficiency of 42.57% on nitrate removal. These results entail that CW is fairly poor on the removal of Phosphorus to meet recommended effluent discharge standards as recommended by local authorities in East Africa. However, this might be contributed by the types of substrates used and operation hydrodynamics in the individual CW units

Table 2.1: Laboratory results for some CW units treating domestic and municipal wastewater

CW Unit	Location	pH	BOD_5 (mg/L)	NO_3-N (mg/L)	NH_3-N (mg/L)	Phosphorus (mg/L)	Reference
UDSM (Reeds)	Inlet	7.2	50.70	NR	NR	NR	Bilha, 2006
	Outlet	7.0	18.00	NR	NR	NR	
Ruaha SS	Inlet	8.30	200.00	35.30	77.30	44.50	Njau *et al*., 2010
	Outlet	7.60	41.00	11.30	33.00	18.10	
Kleruu College	Inlet	NR	1245	NR	NR	NR	Katima, 2005
	Outlet	NR	12.00	NR	NR	NR	
MUWSA, Moshi	Inlet	7.47	135	26.30	24.87	56.5	Njau *et al*., 2010 MUWSA
	Outlet	7.45	17	11.44	10.35	39.9	
Average	Inlet	7.66±0.57	127.68±61.15	30.80±4.50	51.09±26.22	50.50±6.00	
	Outlet	7.35±0.31	22±12.94	11.37±0.07	21.68±11.33	29.00±10.90	
Local Requirement		6.5 – 8.5	30	50	10	6	
Efficiency (%)			82.77	63.08	57.57	42.57	

3 Guidelines and Regulations (Regulatory) that Influence Wastewater Reuse in Tanzania

3.1 Introduction

In order for treated effluent to be re-used it must follow some regulatory aspects in terms of guidelines and standards. For Tanzania, the opportunity that is available for re-use of treated effluent is the presence of guidelines and standard for re-use of wastewater both at international and national level. At the international level there are WHO guidelines and for national level there are standards for discharge of effluents to receiving waters. It has to be noted that for international guidelines the focus has been on the reuse of wastewater, excreta and greywater all of which can be treated by CW technology. The descriptions of these guidelines and standards follow in the next section.

3.2 Regulatory Wastewater Reuse Criteria

3.2.1 International Guidelines (WHO Guidelines)

3.2.1.1 Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture

The overall objective of these Guidelines is to encourage the safe use of wastewater and excreta in agriculture and aquaculture in a manner that protects the health of the workers involved and of the public at large. In this context “wastewater” refers to domestic sewage and municipal wastewaters that do not contain substantial quantities of industrial effluent; “excreta” refers to night soil and to excreta derived products such as sludge and septage. Health protection considerations will generally require that some treatment be applied to these wastes to remove pathogenic organisms. Other health protection measures are also considered, including crop restriction, waste application techniques and human exposure control.

The Guidelines are addressed primarily to senior professionals in the various sectors relevant to wastes reuse, and aim to prevent transmission of communicable diseases while optimizing resource conservation and waste recycling. Emphasis is therefore on control of microbiological contamination rather than on avoidance of the health hazards of chemical pollution, which is of only minor importance in the reuse of domestic wastes and is adequately covered in other publications. Purely agricultural aspects are considered only in so far as they are relevant to health protection.

Hygiene standards applied to wastes reuse in the past, based solely on potential pathogen survival, have been stricter than necessary. A meeting of sanitary engineers, epidemiologists and social scientists, convened by the World Health Organization, the World Bank and the International Reference Centre for Waste Disposal and held in Engelberg, Switzerland, in 1985, proposed a more realistic approach to the use of treated wastewater and excreta, based on the best and most recent epidemiological evidence. The recommendations of the resulting Engelberg Report have formed the basis for these Guidelines. The Guidelines are presented in four separate volumes the descriptions of which follows below.

3.2.1.2 Guidelines for the safe use of wastewater, excreta and greywater. Volume 1: Policy and regulatory aspects

Volume 1 of the Guidelines presents policy issues and regulatory measures distilled from the technical detail found in volumes 2, 3 and 4. Those faced with the need to expedite the development of policies, procedures and regulatory frameworks, at national and local government levels, will find the essential information in this volume. It also includes summaries of the other volumes in the series.

3.2.1.3 Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture

Volume 2 of the Guidelines explains requirements to promote safe use concepts and practices, including health-based targets and minimum procedures. It also covers a substantive revision of approaches to ensuring the microbial safety of wastewater used in agriculture. It distinguishes three vulnerable groups: agricultural workers, members of communities where wastewater-fed agriculture is practiced and consumers. It introduces health impact assessment of new wastewater.

3.2.1.4 Guidelines for the safe use of wastewater, excreta and greywater. Volume 3: Wastewater and excreta use in aquaculture

Volume 3 of the Guidelines informs readers on the assessment of microbial hazards and toxic chemicals and the management of the associated risks when using wastewater and excreta in aquaculture. It explains requirements to promote safe use practices, including minimum procedures and specific health-based targets. It puts trade-offs between potential risks and nutritional benefits in a wider development context. Special reference is made to food-borne trematodes.

3.2.1.5 Guidelines for the safe use of wastewater, excreta and greywater. Volume 4: Excreta and greywater use in agriculture

Volume 4 of the Guidelines for the safe use of wastewater, excreta and greywater provides information on the assessment and management of risks associated with microbial hazards. It explains requirements to promote the safe use of excreta and greywater in agriculture, including minimum procedures and specific health-based targets, and how those requirements are intended to be used. This volume also describes the approaches used in deriving the guidelines, including health-based targets, and includes a substantive revision of approaches to ensuring microbial safety.

3.3 Standards for Effluents and Receiving Waters in Tanzania

Tanzania has no specific wastewater reuse guidelines at the present juncture, though it is in order to use the international guidelines like WHO and FAO. Despite the fact that Tanzania has no specific wastewater reuse guidelines, it has developed standards for effluents and receiving waters in Tanzania which in a way provides an opportunity for wastewater re-use provided the standards for effluents are adhered to. The following section describes standards for effluents and receiving waters in Tanzania.

The purpose of the standard is to indicate the quality of effluents permitted to be discharged into water bodies. The use therefore is meant to promote a consistent approach towards prevention of water pollution in Tanzania. The standard does not cover requirements for hazardous effluents such as radioactive materials and hospital wastes. For the purpose of application of this standard, pollution is defined as the introduction by man, directly or indirectly, or substances or energy into the environment resulting in deleterious effects of such a nature as to endanger human health, harm leaving resources and ecosystems, and impair or interfere with amenities and other legitimate uses of the environment. Receiving water is defined as a perennial body of water, stream and watercourse receiving the discharged effluent and effluent as water or wastewater discharged from a containing space such as treatment plant, industrial process, lagoon, etc. Hazardous wastes is defined as any discarded material containing substances known to be toxic, mutagenic, carcinogenic, or teratogenic to humans or other life forms; ignitable, explosive, or highly reactive alone or with other materials and water pollution as the impairment of suitability of water from some considered purpose. The standards for effluents and receiving water in Tanzania are shown in Table 2.

Table 2.2: Standards for effluents and receiving waters in Tanzania

Parameter	Unit	Effluent Standard		Standard for receiving water			
		TCL	MPC	TL	MPC 1	MPC 2	MPC 3
PH		-	6.5-8.5	-	6.5-8.5	6.5-8.5	6.5-9.0
TDS	mg/l	2500	3000	1700	2000	2000	2000
TSS	mg/l	60	100	-	-	-	-
Conductivity	uS/cm^3	400	-	-	-	-	-
BOD_5	mg/l	25	30	3.5	5	5	10
COD	mg/l	45	60	-	-	-	-
Chloride-Cl	mg/l	650	800	170	200	200	400
Sulphate-SO_4	mg/l	500	600	500	600	600	600
Ammonia-N	mg/l	7.5	10	0.35	0.5	0.5	0.5
Nitrate- N	mg/l	35	50	35	50	50	100
TDS	mg/l	2500	3000	1700	2000	2000	2000
TSS	mg/l	60	100	-	-	-	-
Conductivity	uS/cm^3	400	-	-	-	-	-
BOD_5	mg/l	25	30	3.5	5	5	10
COD	mg/l	45	60	-	-	-	-
Chloride-Cl	mg/l	650	800	170	200	200	400
Sulphate- SO_4	mg/l	500	600	500	600	600	600
Ammonia-N	mg/l	7.5	10	0.35	0.5	0.5	0.5
Nitrate-N	mg/l	35	50	35	50	50	100
Nitrite-N	mg/l	0.75	I	-	-	-	-
Phosphate-PO_4	mg/l	4.5	6	-	-	-	-
Cyanide-total	mg/l	0.75	I	0.035	0.5	0.5	0.1
Cyanide –WAD	mg/l	0.35	0.5	-	-	-	-
Cyanide – Free	mg/l	0.075	0.1	-	-	-	-
Oil & Grease	mg/l	3.5	5	0.35	0.5	I	5
Phenols	mg/l	0.15	0.2	0.0015	0.002	0.002	0.1
Total hydrocarbons (dissolved & emulsified)	mg/l	-	-	-	-	-	-

Arsenic	mg/l	0.15	0.2	0.04	0.05	0.1	0.1
Cadmium	mg/l	0.075	0.1	0.04	0.GS	0.1	0.2
Chromium (total)	mg/l	0.75	1	-	-	-	-
Chromium (hex)	mg/l	0.05	0.1	0.04	0.05	0.1	0.1
Copper	mg/l	0.75	1	2.5	3	3	4
Iron (total)	mg/l	2	3	0.75	1	1.2	1.5
Lead	mg/l	0.075	0.1	0.075	0.1	0.1	0.2
Mercury	mg/l	0.004	0.005	0.00075	0.001	0.001	0.002
Nickel	mg/l	0.4	0.5	0.04	0.05	0.05	0.1
Zinc	mg/l	0.75	1	0.15	0.2	0.2	0.5

Note:

TL = Trigger level, which if exceeded, requires investigation of a potential problem and action if necessary; the level acts as a warning.

4 National Policies

Policy instrument is one of the most important enabling environments for providing an opportunity for reuse of treated wastewater. We are summarizing below the policies that are in country that can help adaptation of CW technology in the country.

4.1 National Water Policy (2002)

The Policy intends to provide guidance in water resources. Generally, the policy provide enabling environment for reuse of treated wastewater. One of the policy objectives is to promote sustainable water use and conservation. The policy specifically states that, "*In order to ensure that water resources are used in sustainable manner, conserved and that ecological system and biodiversity are sustained one of the means is to undertake/employ; rainwater harvesting, wastewater recycling and desalination of seawater for increasing the availability of water resources*".

Another important objective of the Policy is to improve the health and conditions of people through integrating water supply and sanitation services and hygiene education. Constructed wetland is a low cost sanitation system which its treated effluent can be used as water supply for irrigation, industrial activities, etc.

Another objective of the Policy is t*o have a wastewater treatment system which is environmentally friendly*. The policy state that*, "in order to ensure domestic and industrial wastewater is not haphazardly discharged to contaminate water sources and the environment one of the means is for Urban Water Supply and Sewerage entities to co-operate with industries and other institutions in the research and development of least cost technologies for wastewater treatment and recycling*". Again, constructed wetlands are low cost sanitation systems whose treated effluent can be recycled.

Another objective of the Policy is to manage the Water Demand. The policy state that, "Water demand in urban areas is increasing at a rate, which is not proportional to the rate of expansion of water supply and sewerage services. This is due to high rate of urbanisation, increase of industrial activities and significant unaccounted-for-water that includes leakage, wastage and illegal connections. *Water demand management measures will be undertaken to conserve and use the available water efficiently and equitably, by instituting*". Treated effluents from constructed wetlands can be reused to reduce the rate of water demand.

4.2 Sanitation and Hygiene Policy (2011, Draft One)

The Policy intends to provide guidance towards improvement of sanitation and hygiene of a community. One of the policy objectives is to develop technologies which are simple and appropriate to sanitation and hygiene. The Policy specifically states that, "*The Government in collaboration with stakeholders will carry out various studies focusing on appropriate, simple and low cost technology in sanitation and hygiene; The Government in collaboration with stakeholders will build capacities to professionals to design technologies suitable to low income households; The*

Government in collaboration with stakeholders shall sensitize communities on the use of appropriate, simple and low cost technology in sanitation and hygiene" . Constructed wetland is a low cost sanitation system and its treated effluent may be reused for activities such irrigation, aquaculture which may generate food, income, etc.

4.3 National Environmental Policy (1997)

The National Environmental Policy (NEP) is the overarching policy that sets broad goals for environmental protection and committing Tanzania to sustainable development of its natural resources. The policy provides guidance on sectoral policies.

Among the policy objectives discussed in the water and sanitation sector is promotion of technology for efficient and safe water use, particularly for water and **wastewatre treatment and recycling**; and preventing, reducing and controlling pollution of the marine and coastal waters, including from land-based sources of pollution.

Under industrial sector the policy advocates for installation of resource saving and waste recycling facilities and controlling industrial emissions.

Although the policy do not specifically list the technologies to be used, it can be seen that under this policy there is provision for CW to be used and its treated effluent to be recycled.

5. Human Health and Ecosystem Risk

Wastewater reuse presents an opportunity to alter current practice and change the types and degrees of risk. Relative to the risks associated with current wastewater management, wastewater reuse could increase or decrease human health and ecosystem risks via the consumption of or exposure to pathogenic microorganisms, heavy metals, harmful organic chemicals such as endocrine disrupting compounds and pharmaceutically-active compounds (Stagnitti et al. 1999). Of these, pathogenic microorganisms are generally considered to pose the greatest threat to human health (Toze, 2006). A wide variety of pathogenic microorganisms is found in wastewater, including bacteria, viruses, protozoans and parasitic worms. The symptoms and diseases associated with such infections are also diverse including typhoid, dysentery, gastroenteritis, diarrhea and vomiting. The concentration of pathogens in wastewater is dependent on the source population and the susceptibility to infection varies from one population to another.

In recent times, the risks to human health arising from wastewater irrigation of horticultural crops have been determined using *Quantitative Microbial Risk Assessment (QMRA)* (Hamilton et al. 2005c). QMRA is a four-step process comprising of (i) hazard identification, (ii) exposure assessment, (iii) dose-response modelling and (iv) risk characterisation (Haas et al. 1999). Modelling efforts have been limited by the availability of adequate data for defining the dose-response relation. Trials where subjects are subjected to prescribed doses of pathogens is clearly conditional upon ethics, and few such experiments have been undertaken. Perhaps not coincidently, most of such studies were undertaken some time ago. Current QMRA models therefore have to make use of surrogate species or strains, e.g. rotavirus, when defining dose-response relations. Thus a poor knowledge of the infectivity profiles of most pathogens remains and is a key constraint for the development of rigorous QMRA models for wastewater reuse.

The primary objective of any wastewater reuse project must be to minimize or eliminate potential health risks. In most developing countries like Tanzania, direct wastewater reuse projects are normally practiced in urban areas. Indirect use occurs when treated; partially treated or untreated wastewater is discharged to reservoirs, rivers and canals that supply irrigation water to agriculture. Indirect use poses the same health risks as planned wastewater use projects, but may have a greater potential for health problems because the water user is unaware of the wastewater being present. According to WHO (1989), health hazards associated with direct and indirect wastewater use are of two kinds: the rural health and safety problem for those working on the land or living on or near the land where the water is being used, and the risk that contaminated products from the wastewater use area may subsequently infect humans or animals through consumption or handling of the foodstuff or through secondary human contamination by consuming foodstuffs from animals that used the area

5.1 Effects on farm workers or wastewater treatment plant workers

There is risk of infection among workers using partially treated wastewater for irrigation. The first study (Katzenelson *et al.*, 1976) suggested increases in salmonellosis, shigellosis, 14 typhoid fever and infectious hepatitis in farmers and their families working on or living near fields sprinkler irrigated with effluent from oxidation ponds (retention 5-7 days), but the study was methodologically flawed. The second study (Fattal *et al.*, 1986b) found a twofold excess risk of clinical 'enteric' disease in young children (0-4 years) living within 600-1000m from sprinkler irrigated fields, but this was in the summer irrigation months only, with no excess illness found on an annual basis. The third study (Fattal *et al.*, 1986c and Shuval *et al.*, 1989) found that episodes of enteric disease were similar in Kibbutzim most exposed to treated wastewater aerosols (sprinkler irrigation within 300-600m of residential areas) and those not exposed to wastewater in any form. The wastewater was partially treated in ponds with 5-10 days retention reaching a quality of 10^4-10^5 coliforms/100ml.

No excess of enteric disease was seen in wastewater contact workers or their families, as well as in the general population living near the fields. This prospective study is considered to be conclusive, having a superior epidemiological design. In instances where the sewage water has not received treatment, the level of pathogenic organisms is likely to be higher whether the use is occurring directly from raw sewage or from raw sewage that has been blended with other water supplies. In both instances, pathogenic organisms will reach the agricultural fields. These pathogenic organisms, as with treated sewage, have the potential to contaminate both the soil and the crop depending upon how the irrigation water is used. The critical element is to understand that whether treated, partially treated, or untreated water is used, pathogenic organisms are present and the use site must be managed in a manner that minimizes or eliminates the potential for disease transmission.

5.2` Effects on Consumers of Vegetable Crops

When vegetables are irrigated with treated wastewater, there is some potential of transmission of *Ascaris* infection. The microbiological quality of the water can directly affect the consumer of that crop because of the risk of infection from that crop. Shuval *et al*. (1986a) defined three levels of risk in selecting a crop to be grown. They are presented here in increasing order of public health risk:

Low(est) risk to consumer (field worker protection still needed)

- Crops not for human consumption (for example cotton, sisal).
- Crops normally processed by heat or drying before human consumption (grains, oilseeds, sugar beet).
- Vegetables and fruit grown exclusively for canning or other processing that effectively destroys pathogens.
- Fodder crops and other animal feed crops that are sun-dried and harvested before consumption by animals.
- Landscape irrigation in fenced areas without public access (nurseries, forests, green belts).

Increased risk to consumer and handler

- Pasture, green fodder crops.
- Crops for human consumption that do not come into direct contact with wastewater, on condition that none must be picked off the ground and that spray irrigation must not be used (tree crops, vineyards, etc.).
- Crops for human consumption normally eaten only after cooking (potatoes, eggplant, beetroot).

- Crops for human consumption, the peel of which is not eaten (melons, citrus fruits, bananas, nuts, groundnuts).
- Any crop not identified as high-risk if sprinkler irrigation is used.

Highest risk to consumer, field worker and handler

- Any crops eaten uncooked and grown in close contact with wastewater effluent (fresh vegetables such as lettuce or carrots, or spray-irrigated fruit).
- Landscape irrigation with public access (parks, lawns, golf courses).

Another path of infection is from direct contact with the crop or soil in the area where wastewater was used. This path is directly related to the level of protection needed for field workers. The only feasible means of dealing with the worker safety problem is prevention. The following are a few of many low and high risk situations:

- Low risk of infection
- Mechanized cultural practices
- Mechanized harvesting practices
- Crop is dried prior to harvesting
- Long dry periods between irrigations

High risk of infection

- High dust areas
- Hand cultivation
- Hand harvest of food crops
- Moving sprinkler equipment
- Direct contact with irrigation water

5.3 Ecosystem Risk

Wastewater irrigation poses several threats to the ecosystem via contamination by nutrients, heavy metals, and salts. Increased loads of nitrates in wastewater may increase the risk of groundwater contamination (Stagnitti et al. 1998). The risks can be markedly reduced, however, by appropriately matching plant production systems to effluent characteristics (Snow et al. 1999). High-yielding crops with large amounts of nitrogen in their biomass would be more effective than tree plantations at reducing nitrate leaching. However, the most important sustainability constraints are due to salinity and sodicity. Salinity is a pragmatic constraint for many horticultural reuse schemes. Sodicity induces changes in the soil's physical properties, the most notable effect being the dispersion of soil aggregates. Dispersion, in combination with other processes, such as swelling and slacking, can affect plants through decreasing the permeability of water and air through the soil, water-logging, and impeding root

6 Economic Issues

6.1 Introduction

Reuse of treated effluent also provides economic opportunities in terms of products from re-use. From economic point of view it is important to show the economic viability of CW technology for its opportunity. One can look the economic opportunity from two faces, namely Cost Benefit Analysis and Financial Analysis of the Selected Sanitation Options from use of e.g. nutrients from treated wastewater. The following sections explain these faces of opportunity starting with CB analysis from an existing CW system in Tanzania in Ruaha Secondary School and then demonstrate the financial analysis of the Selected Sanitation Options which are pit latrine and ecological sanitation (UDDT) by using nutrients that are considered as fertilizers in the waste.

6.2 Cost Benefit Analysis from CW

Economic viability is based on CBA from data collected from CW in Ruaha Secondary School (RSS). The CBA analysis 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.

6.2.1 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 see 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) p. 85). 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.

6.3 Financial Analysis of the Selected Sanitation Options

This section compares the costs of the two short-listed options, taking into accounts all components of the system. This is intended to highlight the various cost aspects that may not be very obvious at the beginning of a project because often people only consider the cost of the toilets and do not consider what happens to the excreta later on, nor are the O & M costs of the entire system normally taken into consideration.

Financial costs of the selected sanitation include cost of Labor, Building materials, empting and disposal as shown in the tale below.

Table 6.1: Cost comparison of the proposed toilet

Part	Singe vault VIP	Single vault UD dry toilet	Comments
Construction cost	1,000,000	1,700,000	Cost depends on material used
Collection and transportation of sludge to treatment plant	120,000	60,000	Cost depend on volume of waste
Operation and Maintenance	10,000	80,000	Cost for UD include empting urine tank after every three weeks, buying ashes and toilet paper.

Note: Amount given for O&M are for one year, simply because the structures are robust enough requiring only cleaning.

The present Worth and Net Present Value were calculated using table above. The values obtained for present worth are shown in the table below:

Table 6.2: Calculated Present worth values

Toilet type	Present Worth Value (Tshs).
Pit latrine	1,545,049
Urine Diversion toilet	2,286,951

6.3.1 Benefit analysis

Having determined the present values of alternative systems, benefits of each alternative was calculated so as to calculate the Net present value. Quantification of the benefits of sanitation focus on generation of fertilizer, reduction of disease and the subsequent increase in productive life expectancy, increase in work capacity, and the reduction of demand for medical facilities and drugs.

6.3.2 Benefits from Urine Diversion Toilet (UDT)

Table 6.3: Percent distribution of nutrients in adult faeces

	Kg per year
Nitrogen (N)	4.55
Phosphorus (P)	0.6 i.e. (1.33kg$P_2 0_5$)
Potassium (k)	1.3 i.e. (1.53kgK_2O)
Total	6.55 of NPK

(Source, (Esrey, 1998)

The above table shows the amount excreted by a Tanzanian adult per year. A family of six people produces an equivalent of 40 kg NPK per year. Fertilizers available in Tanzania consist of NPK 22:6:12. The numbers in NPK 22:6:12 refer to the content of N, P and K respectively in percentage of the total weight of the fertilizer. (Jönssen, H., Stintzing, A.R., Vinneras, B., and Salomon, E., 2004). A bag of 50kg costs Tshs.75,000 i.e Tshs 1,500 per kg.

The Fertilizer costs Tshs 1,500 per kg. So the excreta produced worth Tshs 150,000 per year. Assume the toilet lasts for 10 years, using the discount rate of 20% then the present value of the benefit of Tshs 150,000 from UD toilet is Tsh. 628,876 The Net present value of the UD toilet is (2,286,951-628,876) =Tshs 1,658075 i.e (1.658million) while the VIP toilet gives a Net present value of Tshs1,545,049 (1.545million). Thus the actual cost of UD toilet is 1.728million while for VIP toilet is 1.545million without taking into account cost for constructing a treatment plant for the pit latrine.

Table 6.4: Summary cost

Cost	Single Vault VIP toilet	Single vault UD toilet
Present Worth value (million Tshs)	1,545,049	2,286,951
Net Present Value (million Tshs)	1,545,049	1,658075

The option with the lowest NPV would be the economic choice to invest in, but also it is necessary to account for the long-term sustainability advantages during the lifetime of these options, Thus from table 6 above, costs for UD toilet and VIP is almost the same, then UDDT is the best option for poor people in peri-urban that's meet the criteria's set which includes protection of ground water which is the dependent source of water for people.

This last example demonstrate the same principles that can be used with CW to realize the economic benefits emanating from reuse of treated effluents and hence its economic opportunity.

7 Technical issues

7.1 Technical Feasibility of Constructed Wetlands

The potential for application of CW technology in the developing world is enormous. Most of the developing countries have warm tropical and subtropical climates that are conducive for higher biological activity and productivity, hence better performance of wetland systems. Tropical and subtropical regions are known to sustain a rich diversity of biota that may be used in wetlands. Although land may be a limiting factor in dense urban areas, constructed wetlands are potentially well suited to smaller communities where municipal land surrounding schools, hospitals, hotels and rural areas is not in short supply (Kivaisi, 2001).

In addition, successful case studies from users of CWs in Tanzania reveals that CWs have lower total lifetime costs, lower capital costs than conventional treatment systems, lower air and water emissions, lower secondary wastes, lower operations and maintenance costs and ability to tolerate high fluctuations in flow. Besides, the technology is ideal for decentralized wastewater treatment and from health point of view, the systems (mainly the subsurface type of CWs) do discourage mosquito breeding sites and in that way contribute positively in combating malaria.

For the large population of dwellers living in informal densely populated urban and poor rural areas in low income countries, who experience lack and inadequacy of sanitation services and particularly exposed to wastewater related nuisances daily, CW technology promise significant benefits not only in environmental sustainability but also in terms of public health and economic gains.

7.2 WSP and CW Research Group

This is a team of experts and researchers who introduced CW technology in Tanzania and the East African Region at large. The group stand to be a very important institution and therefore opportunity for dissemination of CW in the region. It is based at the College of Engineering and Technology, University of Dar Es Salaam since 1995. It is made up of multi-disciplinary scientists and engineers who are experts in various fields related to wastewater management and sanitation including civil/water resources engineering, civil/geotechnical engineering, chemical and process engineering, environmental engineering, botany, zoology, health and marine sciences, sociology. As time goes on, some members of the group have been moving to other institutions while scientist and researchers from other institution have been joining the group. As such, currently, the research has a total of 16 members based at the University of Dar Es Salaam (UDSM), Ardhi University (ARU), The Nelson Mandela African Institute of Science and Technology (NM-AIST), The Open University of Tanzania (OUT), Muhimbili University of Health and Allied Sciences (MUHAS), University of Dodoma (UDOM) and Tanzania Industrial Research and Development Organization (TIRDO). The group is continually working on CW and other innovative technologies. Actually, the group is an authority when it comes to CW technology in East African Region.

Figure 7.1: Section of the UDSM Research Group at work

To date the group profile includes the following research projects:

- Integrating constructed wetlands technology with urban agriculture and fish farming for improved agricultural productivity through use of recycled wastewater (ongoing project). It is a three year research project which intends to demonstrate that wastewater that has been adequately treated in constructed wetland can be safely used in irrigation of crops and fish farming. The project is funded by the Commission for Science and Technology (COSTECH) of Tanzania.
- Dissemination of the sustainable wastewater technology of constructed wetlands in Tanzania (ongoing project). This is a two year project designed to evaluate value addition of Constructed Wetland Technology in the sanitation service chain in Tanzania. The project is funded by the Vlaamse Interuniversitaire Road (VLIR) of Belgium.
- Integrated process for sustainable agro-process waste treatment and climate change mitigation in eastern Africa (Ongoing project). It is a three years project which focuses on optimizing biogas production, wastewater treatment, wastewater reuse (nutrient recovery) from banana winery plant. The project is funded by Sida through Bioinnovate programme.
- The EU-Project: “University Capacity Development for Integrated Sanitation Management in Eastern and Southern Africa (UCDISM)” started from January 2009. This project was funded by the European Union under the 9th European

Development Fund (EDF), ACP-EU Cooperation Programme in Higher Education (EDULINK) and scheduled from January 2009 to December 2011. Despite the fact that the project has just ended, the Masters Programme in sanitation is still running at UDSM, with the enrolment of about 12 students every year. The three-year project was coordinated by University of Siegen and its implementing partners included the University of Dar Es Salaam as a hosting institution, Kenyatta University, Kenya (KU), Makerere University, Uganda (MAK) and University of Zambia, Zambia (UMZA)

- Transfer of CW technology for decentralized wastewater treatment (Bio-Earn Innovation Fund by SIDA: 2009 – 2010)
- Constructed Wetland for decentralized wastewater treatment in Seychelles and at Shimo la Tewa Prison, Kenya (2009/2010)
- Mtoni – Msingini stormwater drainage and sewerage system incorporating waste stabilization pond and constructed wetland for wastewater treatment (2008 – 2011)
- Development of efficient technologies for sustainable treatment of high strength wastewater in Eastern Africa (Bio Earn programme by SIDA: 2008 – 2010)
- Peri - Urban mangrove forests as filters and potential phytoremediators of domestic sewage in East Africa (EU funded PUMPSEA Project: 2004 – 2009)
- Application of CW for polishing Waste Stabilization Ponds effluents (1998 – 2002)
- Ecological modelling of Waste Stabilization Pond systems (1995 - 1998)

The group builds capacity of CW technology and has prepared and developed Design Manual, Operation and Maintenance Manual and Construction Instructional Manual for the CW for use in Tropical Climatic countries. In addition, the group has developed a website and a network of consultants and NGOs working together in the commercialization and dissemination of CW technology in Tanzania and the East African Region. Currently, the group is working in close collaboration with the following partners in the network:

≈ WWS Design and Development Company Limited: This is a consulting firm providing consultancy services in water, wastewater and sanitation issues. The company is based in Dar Es Salaam and among other things it provides technical expertise in the design, construction supervision and capacity building regarding new innovative wastewater and sanitation technologies including Constructed Wetland Technology.

≈ AGENDA and ENVICON: These are local NGOs based in Dar Es Salaam, Tanzania. The research group maintain and strengthen close links with them to better harness their experience, resources and facilities for the success CW technology dissemination. In the previous and ongoing undertakings, the collaboration with these organizations has been very successful especially on working with media, awareness raising, materials dissemination and issues related to documentary and communication startegies. The results of this collaboration are extremely well received by target participants.

8.0 Estimation of the yield of products

Food security is closely linked with water security. Between 30 and 40 percent of the world's food comes from the proportion of the total cultivated land which is irrigated (16%) Irrigation using WW provide double benefit. In Tanzania a minimal research has been done on estimating yield of crops fertilized/irrigated using WW. A pot experiment conducted at MORUWASA by UDSM WSP research team revealed that yields of Paddy and Swisschard were either increased by dilute WW extracted from the 1st maturation pond or depressed by concentrated WW (See Figures 1 and 2).

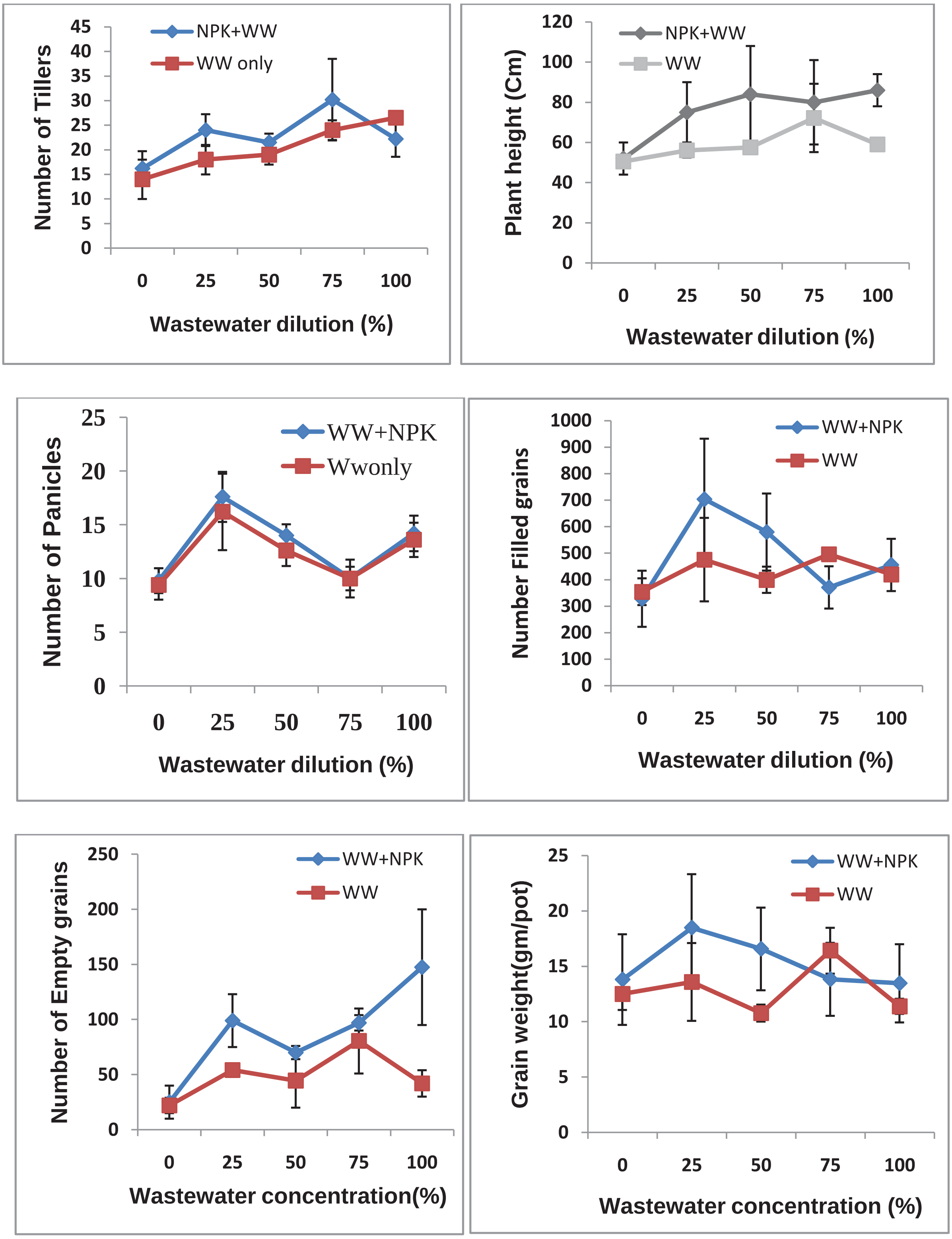


Figure 8.1: **Performance of paddy under different WW concentrations**

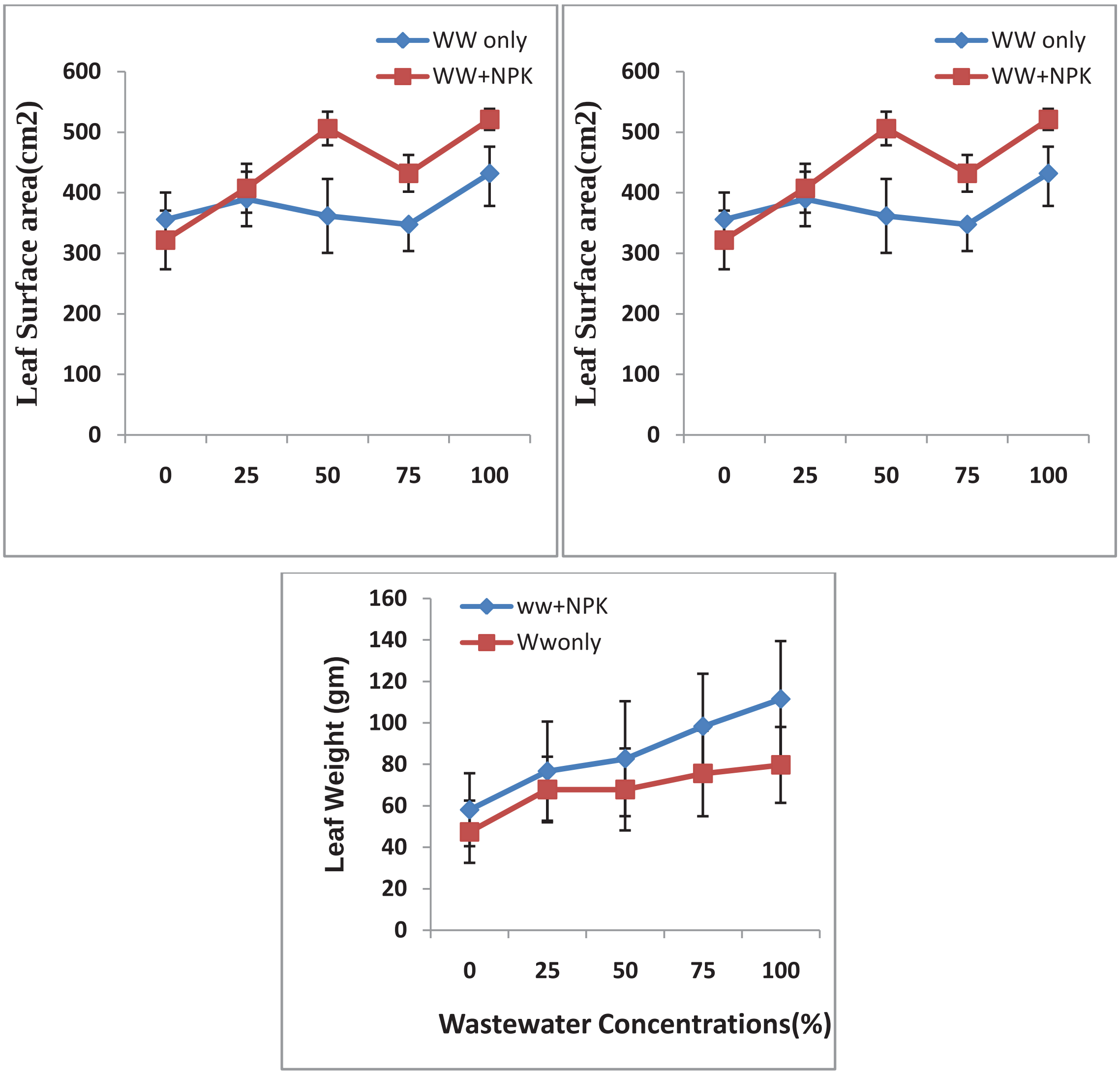


Figure 8.2. Performance of swisschard under different WW dilutions

9 Products from wastewater re-use

9.1 Irrigation water

The estimated volume of wastewater generated from the population using septic tanks and sewerage systems in Tanzania are 18.17*106m3/yr and 28.87*106m3/yr respectively, while the volume of industrial waste water is 683,717m3/day (UNEP, 2009). It is not known how much of this is channeled into the few constructed wetlands established already but the potential is high.

9.2 Nutrients dissolved in WW

Agricultural production in Africa is characterized by low productivity caused by a combination of endogenous and exogenous factors. One of the factors is lack of adequate agricultural inputs such as nutrients in form of fertilizers and manure necessary for plant growth. Sub-Saharan Africa has the world's lowest level of mineral fertilizer use. Only eight kilograms of nutrients are applied per hectare. This represents about ten percent of the world average. It is estimated that Sub-Saharan Africa imports more than 90 percent of its agricultural fertilizers. Decline in soil fertility is reported as one of the major constraints hampering rural development in Tanzania (Ley *et al.*, 2000). This has resulted in poverty, widespread of malnutrition and massive environmental degradation (Shepherd and Saule, 1998; Ley *et al.*, 2000).While this is a fact; a lot of nutrients contained in wastewater are discharged into rivers and oceans causing secondary impacts in water bodies and the environment

On the other hand Wastewaters contain nutrients such as nitrogen and phosphorous. It is estimated that each person on average excretes about 4 kg N and 0.4 kg P in urine, and 0.55 kg N and 0.18 kg P in feaces per year (www.**wateralliance.org**/issues.html). These are essential elements for plant growth and if retrieved from WW could be recycled back for plant growth. On the other hand, if these nutrients are left to flow into a water body, they may cause eutrophication of water bodies, especially in slow moving waters in streams, canals and lakes.

9.3 Sludge

Sludge is the general term for the undigested or partially digested slurry or solid that results from the storage or treatment of blackwater in on-site sanitation systems namely the stabilization and maturation ponds of the WSP. This is normally scooped out to prevent silting of the ponds. The sludge is normally spread out to dry in the sun. When it is dried, it offers another source of organic fertilizer which is still high in nutrients. Informal observations from MUWSA CW showed great performance of paddy using sludge as fertilizer while from fields around MORUWASA maize and tomatoes produced good crop when fertilized with sludge only.

10. Irrigated crops (produce)

There are about 1.0 million ha of irrigable land in Tanzania but currently only 150,000 ha are cultivated under irrigation for lack of capacity to irrigate (water limitation and infrastructure to deliver it to the fields (http://www.tanzania.go.tz/agriculture.html). On the other hand, due to climate change, only irrigation holds the key to stabilizing agricultural production in Tanzania and elsewhere to improve and assure basic food security, increase farmers' productivity and incomes. High valued crops such as vegetables produce and cash crops include off-season maize, sugar cane, tea, coffee and cut flowers needs to be irrigated in Tanzania. These crops and others including pasture, public gardens and park plants could profit even more if waste water was used instead of pure water from taps and shallow wells storm water channels currently used.

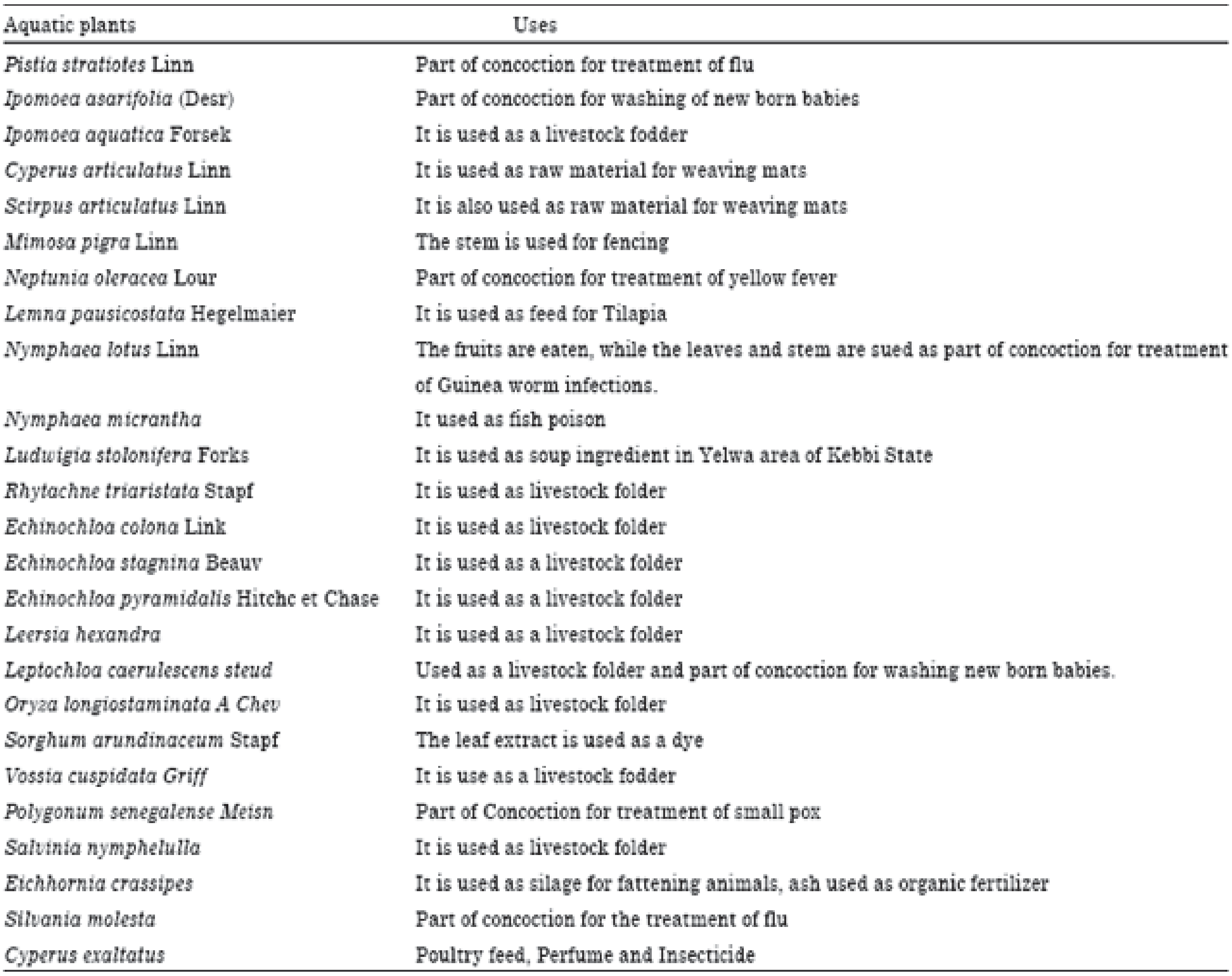
11. Harvested plants

Constructed wetlands incorporate water/aquatic plants (macrophytes) as part of their system. These functions in absorption of nutrients including those of heavy metals and sequestering them into their various organs leaving the waste water fairly devoid of nutrients overload. The more actively growing the plants are the higher is the efficiency of nutrient absorption. They are classified as emergent, suspended/floating and submerged plants.

Emergent plants have their root system anchored in the sediments. These are plants that are rooted in shallow water with vegetative parts emerging above the water surface. It is thought that emergent macrophytes are the most particularly productive of all aquatic macrophytes since they make the best use of all three possible states—with their roots in sediments beneath water and their photosynthetic parts in the air (Westlake, 1963). Westlake (1966) reported the net yield of emergent macrophytes to range from 35 to 85 tonnes DM/ha/year in fertile ponds.
They include various genera and species such as cattails or Typha spp, reeds or Phragmitis spp, cyperus. Suspended plants include the duckweed, azolla, water cabbage, water lilies, etc. A partial list is as indicated in Table 11.1.

The macrophytes are harvested for various purposes including food, thatching, construction, and livestock feed. Harvesting should be done regularly to ensure sprouting of new growth which maintains high photosynthetic activity and therefor high metabolic activities of transport and translocation of nutrients and metabolites. An annual or bi-annual regime of harvesting plants is recommended.

Table 11.1. Aquatic plants that can be used as macrophytes and other uses



Aquatic plants	Uses
Pistia stratiotes Linn	Part of concoction for treatment of flu
Ipomoea asarifolia (Desr)	Part of concoction for washing of new born babies
Ipomoea aquatica Forsek	It is used as a livestock fodder
Cyperus articulatus Linn	It is used as raw material for weaving mats
Scirpus articulatus Linn	It is also used as raw material for weaving mats
Mimosa pigra Linn	The stem is used for fencing
Neptunia oleracea Lour	Part of concoction for treatment of yellow fever
Lemna pausicostata Hegelmaier	It is used as feed for Tilapia
Nymphaea lotus Linn	The fruits are eaten, while the leaves and stem are sued as part of concoction for treatment of Guinea worm infections.
Nymphaea micrantha	It used as fish poison
Ludwigia stolonifera Forks	It is used as soup ingredient in Yelwa area of Kebbi State
Rhytachne triaristata Stapf	It is used as livestock folder
Echinochloa colona Link	It is used as livestock folder
Echinochloa stagnina Beauv	It is used as a livestock folder
Echinochloa pyramidalis Hitchc et Chase	It is used as a livestock folder
Leersia hexandra	It is used as a livestock folder
Leptochloa caerulescens steud	Used as a livestock folder and part of concoction for washing new born babies.
Oryza longiostaminata A Chev	It is used as livestock folder
Sorghum arundinaceum Stapf	The leaf extract is used as a dye
Vossia cuspidata Griff	It is use as a livestock fodder
Polygonum senegalense Meisn	Part of Concoction for treatment of small pox
Salvinia nymphelulla	It is used as livestock folder
Eichhornia crassipes	It is used as silage for fattening animals, ash used as organic fertilizer
Silvania molesta	Part of concoction for the treatment of flu
Cyperus exaltatus	Poultry feed, Perfume and Insecticide

12. Fish farming

World fish consumption has increased from 45 million tonnes in 1973 to more than 130 million in 2000 and the FAO estimates an additional 40 million tonnes of seafood will be required by 2030, just to maintain current levels of consumption (Sustain Aqua, 2009). In order to serve this increasing demand in the long run, sustainable alternatives have to be strengthened. The most promising of these is the aquaculture industry. With a growth rate of 8% per year since the 1980's, aquaculture is probably the fastest growing food-production industry, that today accounts for almost half the fish consumed globally, up from 9% in 1980.

Treated waste water from constructed wetlands can be used as a multifunctional resource in a polyculture system to produce economically and ecologically viable fish and co-products as well as utilization of the high nutrient content in waste water to get highly nutritious protein from fish to improving food security.

Aquaculture in the United Republic of Tanzania has a vast but as yet untapped potential. The industry is dominated by freshwater fish farming in which small-scale farmers practice both extensive and semi-intensive fish farming. Small fish ponds of an average size of 10 m x 15 m (150 m^2) are integrated with other agricultural activities such as gardening and animal and bird production on small pieces of land. The United Republic of Tanzania is currently estimated to have a total of 14 100 freshwater fishponds scattered across the mainland.
The distribution of fishponds in the country is determined by several factors such as availability of water, suitable land for fish farming, awareness and motivation within the community on the economic potential in fish farming.

So far fish farming utilizing constructed wetlands in Tanzania have had very limited coverage. It is still at experimental stage just as usage of constructed wetlands is. Two experimental fish ponds connected to constructed wetlands are known. One at UDSM-WSP and another at MUWSA-WSP all stocked with tilapia fish which seems to be hardy. At a stocking rate of 3 fingerling/m^2, the fishes are ready for harvesting 6 months later. They have proved to work well to the extent that the technology can be multiplied throughout Tanzania.

13. Valorization of By-products

Besides provision of irrigation water and nutrients, constructed wetlands offer other goods and services generally summed up as valorization. Valorization is the use or application of an object, process or activity so that it makes money, or generates value, with the connotation that the thing validates itself and proves its worth when it results in earnings, a yield. Thus, something is "valorized" if it has yielded its value or value addition (Wikipedia).

In wastewater reuse Valorization is the conversion of waste water and biomass to energy, fuels and other useful materials, with particular focus on environmental indicators and sustainability goals. It entails re-use of macrophytes that are harvested at maturity into various crafts and artifacts, as well as use of crops e.g. pasture to feed humans and livestock. Emerging rooted plant species and free-floating plants stand out for their biomass, productivity, and plant cover as detailed in Table 11.1.

Biological and esthetic functions- Emergent macrophytes can provide a suitable habitat for wildlife and offer nesting sites for birds and mammals. Macrophytes can enhance the esthetic value of the CW especially when flowering species such as *Nymphaea alba,* water hyacinth *Eichhornia crassipes* and ***Ranunculus sphaerospermus*** are present and form one of the most attractive ecotourism thus changing the scenario from the ‘eye sore’ of blackwater to sightseeing scenery.

Energy production (renewable fuel source) - Some macrophytes can utilized directly for biomass energy or are incorporated into biogas

Agricultural purposes (Composting purposes and organic soil conditioner, Production of fertilizer, Soil amendment)

Forage(Aquatic plants growing in nutrient-enriched wastewaters are often high in crude protein and digestible organic matter and serve as valuable animal feed) Industrial purposes and product developments (Packing material and Construction purposes such as building, insulation and thatching material, fibre boards diverse handicrafts including weaving material, basketry, etc,

Edible, medicinal & aromatic (Several aquatic species are edible e.g. *Helosciadium nodiflorum* and *Nasturtium officinalis* medicinal as well, some species are aromatic and melliferous such as *Mentha aqua*.

Plate 12.1: Phragmitis rhizome netting useful in consolidating and stabilizing sediments

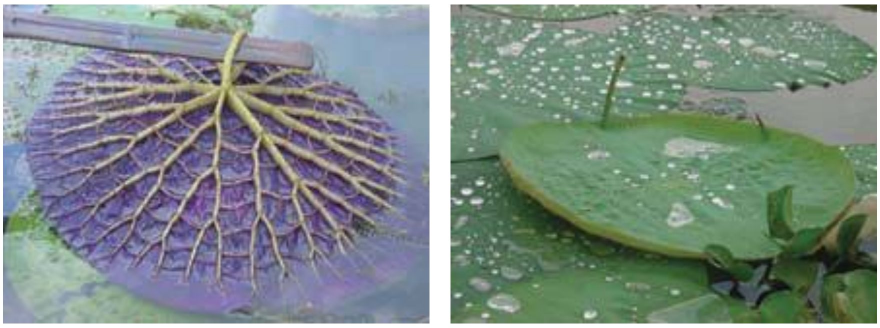


Plate 12.2: Abaxial and adaxial sides of a Lotus plant that are used in Asia as plates

Plate 12.3: Asian Wild rice (*Zizania latifolia*) stems harvested for vegetable

Plate 12.4: North American wild rice (*Zizania palustris*) harvested for grain

Plate 6: Wastewater used to irrigate vegetables in Daressalaam

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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