United Republic of Tanzania

Ministry of Water

Guidelines for the Application of Small-Scale, Decentralised Wastewater Treatment Systems

A Code of Practice for Decision Makers

December 2018

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Foreword

Adequate investment in water supply, sanitation and hygiene (WASH) is critical to improving human development and reducing poverty. Improving WASH has been associated with improved life in child's early years, which is critical for achievement in later life. Conversely, lack of WASH has been associated with interruption of healthy childhood development and stunting, which can adversely affect other facets of development at later life. Further, lack of adequate WASH facilities contributes to waterborne diseases. For example, it is estimated that, in 2017, some 4,985 cases of cholera were reported in Tanzania, mainly because of poor access to sanitation facilities (World Bank, 2018). Additionally, it has widely been argued that Sustainable Development Goal six (SGD 6) is inextricably linked with other SGDs and targets.

A recent World Bank report on water supply, sanitation and hygiene indicates that 40 percent of the population in Tanzania lack access to improved drinking water and 80 percent rely on rudimentary and unsafe sanitation facilities (World Bank, 2018). Concerted and urgent efforts are therefore needed to accelerate the achievement of the SDG targets on WASH.

Decentralised wastewater treatment systems (DEWATS) can provide an appropriate and timely solution for wastewater management and accelerate the achievement of SDG targets on WASH. DEWATS have proven to be an effective strategy for complementing the traditional centralised wastewater management system, which is inevitably costly and complex. DEWATS provides an alternative flexible, efficient and cost effective community based sanitation solution for managing domestic and industrial wastewater.

The present guidelines support the scaling up of wastewater treatment solutions that follow the DEWATS approach. These guidelines provide fundamental guidance to all steps of a DEWATS project (from planning and throughout implementation, including operation, maintenance, monitoring and evaluation), while emphasising the importance of all aspects of an enabling environment. These guidelines also explain all steps of the sanitation chain (from containment, conveyance and treatment, to reuse, disposal or discharge).

The guidelines are consistent with the Government of Tanzania standards and policy framework in water supply, sanitation and hygiene (WASH). The guidelines support the Government's efforts to accelerate the achievement of national targets on WASH and those in SDG 6. It is our hope that various stakeholders, including communities and private sector, will use these guidelines in developing wastewater management programmes in their efforts to contribute to the achievement of water supply, sanitation and hygiene services for all.

Prof. Kitila Mkumbo
Permanent Secretary
Ministry of Water

Faecal Sludge Treatment Plant, Wailes, Dar es Salaam
Faecal Sludge Treatment Plant (designed by BORDA Tanzania, financed by UKAID) with Biogas Settler, ABR, Feeding tank and sub-surface water distribution system. The FSTP produces biogas for cooking purposes, and treated wastewater is used to irrigate the nearby banana plantation.

National Housing Corporation (NHC) Mwongozo Affordable Housing Development, Kigamboni, Dar es Salaam
On-site wastewater management system (designed by BORDA Tanzania) with septic tanks, simplified sewers, ABR, AF, PGF and sub-surface water distribution network.

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BORDA wishes to acknowledge the support of the government ministries and agencies that made the development of these guidelines possible: Ministry of Water (MoW); Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC); Ministry of Education and Vocational Training (MoEVT); Tanzanian Bureau of Standards (TBS); and Dar es Salaam Water and Sewerage Authority (DAWASA).

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Resources

In order to maintain consistency with existing and commonly referred to sector literature, and to provide a comprehensive set of guidelines for the most recommended technical solutions, content and diagrams within this document have been extracted and adapted from several resources. These are listed in the yellow boxes within the respective chapters. In particular, we would like to highlight the following publications which provided substantial content for the following chapters:

Chapter 4:

- Tilley, E., Ulrich, L., Christoph, L., Reymond, P., Schertenleib, R., & Zurbrügg, C. (2014). Compendium of Sanitation Systems and Technologies. IWA; EAWAG; WSSCC. (In particular pp. 74–165). Free PDF available at: www.sandec.ch/compendium
- Gutterer, B., Sasse, L., Panzerbieter, T., & Reckerzügel, T. (2009). Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries. BORDA; WEDC. (In particular pp. 168–229)

Chapter 5:

- Lüthi, C., Morel, A., Tilley, E., & Ulrich, L. (2011). Community-Led Urban Environmental Sanitation Planning (CLUES). Eawag-Sandec, WSSCC, UN-HABITAT. Free PDF available at: www.sandec.ch/clues
- Strande, L., Ronteltap, M., & Brdjanovic, D. (Eds.) (2014). Faecal sludge management: Systems approach for implementation and operation, Faecal Sludge Management: Systems Approach for Implementation and Operation. IWA. (In particular pp. 363–388). Free PDF available at: www.sandec.ch/fsm_book

Relevant content was extracted from these resources, according to the local Tanzanian context.

Readers are encouraged to refer to the original documents, to gain more insight into potential options.

List of Abbreviations & Acronyms

ABR	Anaerobic Baffled Reactor
AF	Anaerobic Filter
BOD	Biochemical Oxygen Demand
BORDA	Bremen Overseas Research and Development Association
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DEWATS	Decentralised Wastewater Treatment Systems
FC	Faecal Coliform
FSM	Faecal Sludge Management
HRT	Hydraulic Retention Time
LGA	Local Government Authority
M&E	Monitoring and Evaluation
O&M	Operation and Maintenance
PGF	Planted Gravel Filter
PPE	Personal Protection Equipment
QMS	Quality Management System
SoC	Statement of Change
SS	Settleable Solids
TSS	Total Suspended Solids
UASB	Up-flow Anaerobic Sludge Blanket Reactor

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Background

Sustainable Development Goal (SDG) 6.3. aims at *"halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally"* by 2030. This goal is a continuation of SDG 6.2 to *"achieve access to adequate and equitable sanitation and hygiene for all"* by 2030. To achieve these goals, sustainable and context-specific wastewater treatment systems are urgently needed.

In Sub-Saharan Africa, only three countries achieved Millennium Development Goal (MDG) target 7.C for sanitation, compared to 18 countries which met MDG target 7.C for water supply[1]. The 2016 Demographic and Health Survey estimates that 55% of Tanzania's population lack access to improved sanitation. Furthermore, the survey estimates that only 23% of excreta is managed safely, meaning that 42 million people lack adequate treatment and disposal of their wastewater and excreta[2]. In Tanzania's most populous urban areas such as Dar es Salaam and Mwanza, the percentage of safely managed wastewater and excreta is estimated to be 5-7 %[3]. This leads to contamination of drinking water resources, and further challenges and costs relating to the provision of safe drinking water. Additionally, the increased supply of drinking water in urban areas results in the increased generation of wastewater, which needs to be properly managed and treated. Thus, any expansions of water-supply networks need to be considered hand-in-hand with the improvement of wastewater and excreta management.

The situation of the growing urban poor population poses additional challenges. In the urban areas where they live, sewerage infrastructure development cannot keep pace with rapid population growth, and treatment sites for wastewater are scarce. The sanitation situation in African cities is becoming increasingly critical, as the urban population increases rapidly (an 84% increase from 199 million people in 2000 to 366 million people in 2015). This growth takes place mainly in informal settlements with practically no prior planning, and very limited infrastructure and service provision[4]. The population of Dar es Salaam (which houses almost 10% of Tanzania's inhabitants) is expected to more than double by 2030, resulting in huge challenges for practitioners in wastewater and excreta management[5].

It is becoming increasingly apparent that centralised and large-scale wastewater treatment approaches cannot adequately address the sanitation needs of the underserved population in Tanzania – particularly in cities and emerging towns – which is why solutions for urban wastewater management should consist of a combination of centralised and decentralised treatment systems. This is due to the low coverage of centralised sewer networks, huge capital investment requirements for centralised treatment plants and the rapid growth of unplanned settlements. In addition, in low-income countries where sewers and centralised wastewater treatment plants have been constructed, they have most frequently resulted in failures[6]. On the other hand, decentralised systems have proven in many applications worldwide to be highly effective in responding to the environmental and sanitation challenges of rapidly growing towns and cities.

1.2 Rationale of the Guidelines

In Tanzania there are currently no guidelines or standards explicitly for small-scale wastewater treatment systems and the reuse or disposal of the by-products from the treatment process. This document provides guidance on the holistic approach needed to implement and scale up small-scale wastewater treatment systems and should serve as the basis for the development of Tanzanian standards for Decentralised Wastewater Treatment Systems (DEWATS).

DEWATS offer a sustainable approach for wastewater treatment systems, utilising small-scale treatment plants. These solutions have been developed and tested worldwide in primarily low-income countries, and they provide viable options for the improvement of public health and environmental protection,

1 (The World Bank, 2017)
2 (The DHS Program, 2016)
3 (Brandes, 2015)
4 (AMCOW, et al., 2008)
5 (UN-HABITAT, 2014)
6 (Strande, et al., 2014)

with the additional benefits of resource reuse (e.g. biogas, biosolids and irrigation water). In 2017, more than 3,000 DEWATS had been implemented worldwide, serving more than 970,000 people by treating 57,000m^3 of wastewater daily.

While these guidelines focus on DEWATS for Tanzania, this does not imply that the DEWATS approach is the only existing solution for small-scale wastewater treatment. In the future, the feasibility of other small-scale solutions might be increased if reliable energy supply, high capacity for implementation and operation, and other components of the enabling environment become available.

In Tanzania more than thirty operational DEWATS already exist, but as they are still a relatively unknown option, further efforts are required to capacitate the sector in small-scale wastewater treatment. This shall eventually lead to the mainstreaming and scaling-up of these systems in Tanzania. In 2017, BORDA assessed twenty Tanzanian small-scale wastewater treatment systems. The results from the Monitoring and Evaluation (M&E) were used as a baseline for these guidelines and the main findings are included here.

1.3 Objective

These guidelines aim to complement the existing regulatory framework on sanitation in Tanzania, in order to foster an enabling environment for scaling up small-scale DEWATS systems through effective dissemination, regulation and law enforcement.

This document intends to provide guidance on best practices for DEWATS in Tanzania regarding all phases of a DEWATS project:

- Planning and design
- Implementation
- Handover and start-up
- Operation and Maintenance (O&M)
- Management (including M&E)

The guidelines were developed for relevant stakeholders such as ministries and local authorities, regulators, professional boards, urban planners, housing developers, public utilities, service providers, construction and consulting companies, and other private sector implementers.

1.4 Scope of the Guidelines

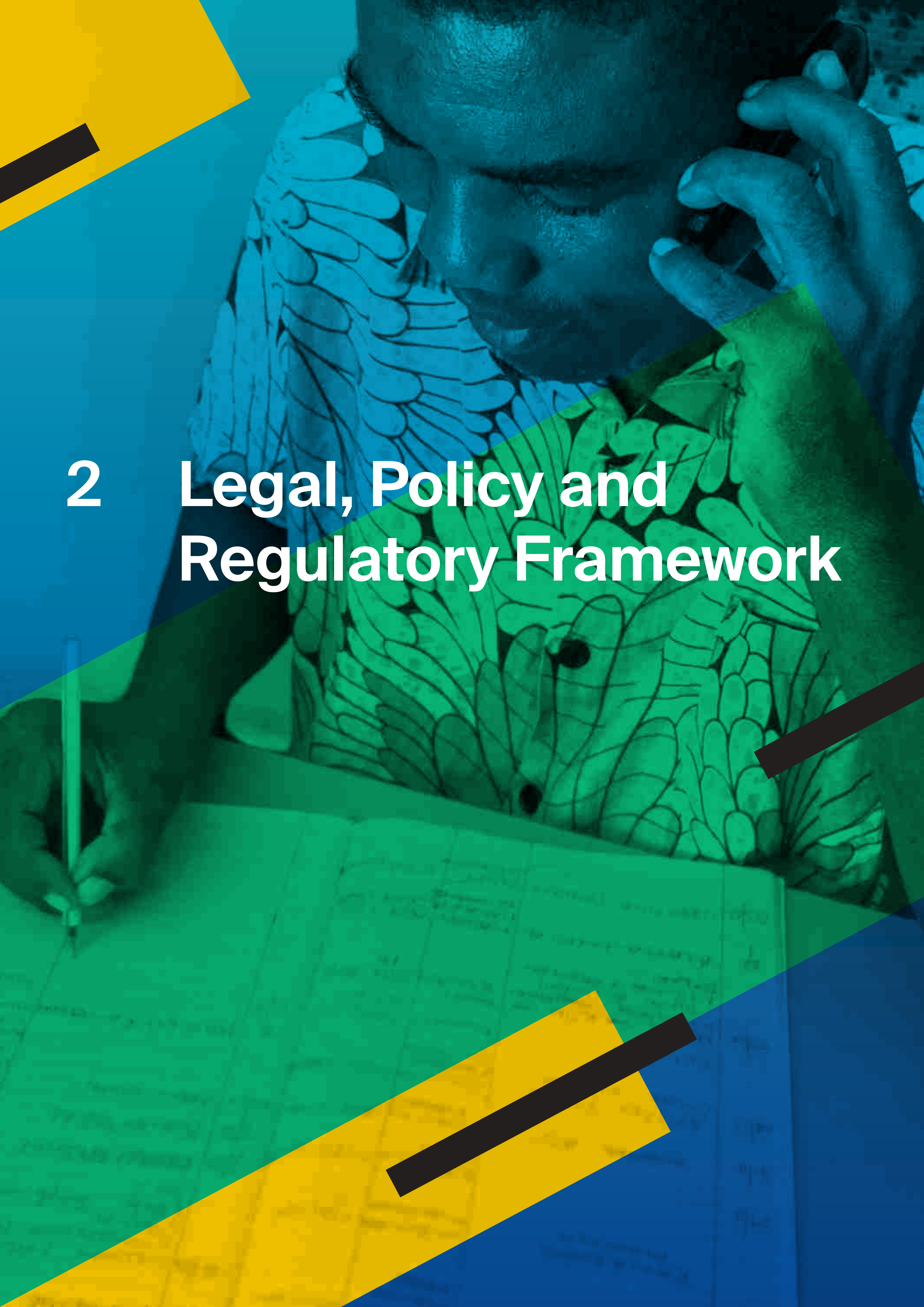
These guidelines are applicable to all activities related to the planning, design, implementation, O&M, and M&E of small-scale municipal wastewater treatment systems in Tanzania that apply the DEWATS approach. Within this document, small-scale systems are defined as single systems with a treatment capacity that ranges between 1 - 500 m^3/day, and municipal wastewater (or effluent) is defined as a mix of domestic black- and greywater generated by residential households, apartments, institutions (e.g. schools, hospitals), and small/medium enterprises (e.g. hotels, restaurants). Industrial non-organic effluents from manufacturing or chemical processes, as well as stormwater, are excluded from these guidelines. The selected systems and technologies cover all parts of the sanitation value chain after the point of wastewater generation at the user interface:

- Containment
- Conveyance
- Treatment
- Reuse and/or Disposal

This document does not provide guidance on the management of faecal sludge or septage. For more information on FSM, please refer to the following publication: Strande, L., Ronteltap, M., & Brdjanovic, D. (Eds.) (2014). Faecal sludge management: Systems approach for implementation and operation. IWA.

National Housing Corporation (NHC) Mwongozo Affordable Housing Development, Kigamboni, Dar es Salaam
On-site wastewater management system (designed by BORDA Tanzania) with septic tanks, simplified sewers, ABR, AF, PGF and sub-surface water distribution network.

2 Legal, Policy and Regulatory Framework



The Analysis of Policies, Strategies and Regulatory Frameworks for Urban Sanitation in Tanzania conducted by GIZ for Tanzania's Ministry of Water in 2017 provides a detailed description and analysis of the current Tanzanian urban sanitation frameworks. The following is extracted from this analysis (United Republic of Tanzania - MoW; GIZ, 2017).

Government Notice 2016 (GN 144/2016) on discharge of ministerial functions that was published on 22nd of April 2016 allocates ministerial responsibilities for sanitation as follows:

1. Matters on water quality and pollution control, water sources protection, sewage and drainage development are vested in the Ministry of Water.
2. Matters on preventive and curative services are vested in the Ministry of Health, Community Development, Gender, Elderly and Children.
3. Matters on regional and local government administration are vested in the President's Office. Among the functions of the Regional Administration and Local Government is coordination of urban services such as transport, water and sanitation. The administration of LGAs falls under the mandate of this Ministry.
4. Matters on environmental protection and enforcement are vested in the Vice President's Office.

Once a settlement has been declared an urban township/town, a Water Supply and Sanitation Authority (WSSA) is established by the Minister responsible for Water in consultation with the Minister responsible for Local Government Authorities. All existing waterworks, plants, equipment and other assets of the government or a local government are, without any compensation of costs incurred, transferred to the respective WSSA. This is provided by section 16(1) of the Water Supply and Sanitation Act 2009.

The establishment of a utility in any given area does not relieve the LGAs of their duties under the Public Health Act, 2009 and Environmental Management Act, 2004. The power to monitor the performance of LGAs lies with the Minister responsible for local government. Politically, LGAs are also accountable to the people through their councillors.

The analysis concludes that adequate basic legal, policy and regulatory frameworks for the provision of sanitation in urban Tanzania exist. The roles and responsibilities of the key stakeholders are well outlined and compliment each other with shared but differentiated responsibilities. However, challenges have arisen because there are multiple agents involved in the provision of sanitation services but weak collaboration both within and between different governmental departments leading to a lack of coordination between service providers. The analysis concludes that there is no organ responsible for central coordination in terms of planning, funding and enforcing sanitation rules and requirements. Consequently, the delivery and quality of sanitation services are inconsistent.

The analysis also concludes that rules seem unclear in terms of financial responsibilities and investments for urban sanitation: the manner of consultation is not provided, the basis of the amount to be recovered is not given, and who finally pays is not clear. These matters need clarification but may not require an additional policy strategy.

The level of government support and the legal and regulatory frameworks are fundamental parts of an enabling environment for any development project. There are several examples worldwide, which suggest that the provision of adequate wastewater treatment systems is very likely to fail in the absence of well-developed legal, policy and regulatory frameworks. For this reason, it is of great importance for practitioners to know the existing framework. For policy makers it is important to continuously identify and close the existing gaps within the framework.

2.1 Related Sectoral National Policies

2.1.1 National Water Policy 2002

The National Water Policy (NAWAPO) recognises that lack of safe water, poor hygiene and inadequate sanitation are major causes of sicknesses and deaths in Tanzania. Therefore, the policy highlights the need to integrate water supply, sanitation and hygiene. The policy emphasises that sufficient supply of water and adequate means of sanitation are basic human needs. One of the policy's objectives is *"to create an enabling environment and appropriate incentives for the delivery of reliable, sustainable and affordable urban water supply and sewerage services."*

2.1.2 National Health Policy 2007

The first objective of this policy includes reducing the burden of disease and infant mortality, and increasing life expectancy through, among other things, facilitating environmental health and sanitation. The policy also aims to promote awareness among government employees and the community at large that health problems can only be adequately solved through multi-sectoral cooperation. The Ministry of Health will continue to collaborate with other stakeholders with the aim of achieving better environmental health and sanitation, and will enforce the safe management of solid and liquid waste at each facility.

2.1.3 National Environmental Policy 1997

The aims of this policy include protecting water sources and preventing environmental pollution. One proposed way to achieve this is to promote technologies for wastewater treatment and recycling. Moreover, appropriate user-charges that reflect the full value of water resources shall be introduced.

2.1.4 Community Development Policy 1996

The first aim of the policy is to enable Tanzanian communities to build a better life though self-reliance and the use of locally available resources (this is also a fundamental principle of decentralised wastewater management). Tanzanians shall be enabled to join together and increase their commitment to self-development. One of the policy's objectives is to help to respond to and meet the basic needs of communities, such as:

- Food and nutrition
- Health and sanitation
- Water and environmental sanitation
- Appropriate technology for domestic energy use

The policy also aims to help guide efforts to improve rural and urban environments.

2.2 Related National Legislations

2.2.1 Water Supply and Sanitation Act No 12 (2009)

The act provides the legal framework for water supply and sanitation. It outlines the responsibilities of government authorities involved in the water sector in both urban and rural areas. It states the obligations of water supply and sanitation authorities to provide water supply and sanitation services, and it indicates their functions, powers and duties. It also assigns responsibility for the provision of adequate and reliable urban water supply and sanitation to urban water supply and sanitation authorities (UWSAs).

2.2.2 Environmental Management Act, 2004

This act defines the main roles of the National Environment Management Council (NEMC). It recognises all citizens' right to a clean, safe and healthy environment. In this context, safe wastewater management is critical for the benefit of the public at large. The act prohibits all projects with significant negative effect on the environment. The act is enforced by environmental impact assessments.

2.2.3 Public Health Act, 2009

This act emphasises a number of issues that are of public concern, including sanitation and hygiene. The act prohibits discharge of wastewater without following national standards and laws. It emphasises that all public buildings are to be equipped with sufficient sanitary facilities.

2.2.4 Energy and Water Utilities Regulatory Authority (EWURA) Act, 2001

The general function of EWURA is to regulate the provision of water supply and sanitation services by a water authority or other persons. This includes the establishment of standards related to equipment and tariffs chargeable for the provision of water supply and sanitation services.

2.2.5 Water Resources Management Act (WRMA) 11/2009

This act provides the institutional and legal framework for the sustainable management and development of water resources. Specifically, it outlines the principles for water resources management, and prevention and control of water pollution. The act prohibits discharge of waste into any waterbody including ground water without written permit. In this regard, the legislation provides guidelines and standards for the construction and maintenance of water resources structures, and the issuance and operation of water permits and registration of boreholes.

2.2.6 Urban Planning Act 8/2007

The aims of this act are to provide for the orderly and sustainable development of land in urban areas, to preserve and improve amenities, to provide for the grant of consent to develop land and powers of control over the use of land, and to provide for other related matters. This includes improving the provision of infrastructure and social services for the development of sustainable human settlements.

2.3 Related National Strategies and Plans

2.3.1 The National Environmental Health, Hygiene and Sanitation Strategy (NEHHSAS 2008–2017)

This strategy's overall goal is to improve the status of environmental health in Tanzania by focusing on providing equitable and affordable environmental health, sanitation and hygiene services to all Tanzanians. Wastewater management has been emphasised as a priority area to be addressed.

2.3.2 National Water Sector Development Strategy 2006-2015

The strategy sets out a mechanism for implementing the NAWAPO, which aims to achieve sustainable development in the sector through an *"efficient use of water resources and efforts to increase the availability of water and sanitation services."*

2.3.3 Water Sector Development Programme Phase II 2014–2019

The Government of Tanzania through the MoW is implementing the Water Sector Development Programme (WSDP) for the period 2006–2025." WSDP II has five components: (i) Water Resources Management; (ii) Rural Water Supply; (iii) Urban Water Supply and Sewerage; (iv) Sanitation and Hygiene; (v) Programme Delivery Support"

2.4 Related National Guidelines:

- National Sanitation Options and Construction Guidelines (2012)
- Guidelines for Construction of Improved Toilets and Environmental Sanitation (2014)
- National Sanitation Campaign Implementation Guidelines (2014)
- Design Manual for Water Supply and wastewater Disposal (2007)
- Guidelines for Sustainable Management of Wetlands (2014)
- Guidelines on Management of Liquid Waste (2013)
- Guidelines for Water, Sanitation and Hygiene in Health Care Facilities (2017)
- Water and Wastewater Quality Monitoring Guidelines for Water Utilities (2014)

3 Concepts of Wastewater Management

The high variability of local conditions in urban environments means that there is no one-size-fits-all solution for wastewater treatment. In a holistic city sanitation planning approach, a combination of centralised and decentralised, small- and large-scale, and on- and off-site wastewater treatment systems may be necessary to meet the sanitation requirements of urban dwellers. In Tanzania's two largest cities, Dar es Salaam and Mwanza, 90%[7] and 95%[8] of the respective populations rely on on-site sanitation options such as pits and septic tanks connected to soak-aways or ponds. Due to rapid urbanisation, these systems are fast approaching their limits in terms of environmental impact and space limitations. This highlights the need for efficient Faecal Sludge Management (FSM) as well as increased efforts to implement wastewater treatment systems that reduce the production of faecal sludge.

Due to the below-mentioned differences between FSM and wastewater management, different guidelines are needed for each topic. While the present guidelines focus on wastewater, this does not imply that guidelines for faecal sludge are not needed.

3.1 Definition of Decentralised Systems and Comparison to Centralised Systems

Decentralised wastewater management systems include all parts of a sanitation system. In comparison to centralised systems, these systems are located at or near the point of wastewater generation. Decentralised systems can be characterised and differentiated from centralised systems along the following lines[9]:

- Volume: Decentralised systems treat relatively small volumes of water (typically 1 - 1,000 m^3/day)[10].
- Sewer type: Centralised systems typically use conventional gravity sewers, while decentralised systems typically use small-diameter gravity sewers, often employing intermediate settlers for solid-free sewers.
- Treatment technology: Centralised systems in low-income countries typically employ land-intensive technologies like waste stabilisation ponds, while decentralised systems typically use compact biological treatment modules with lower space requirements per connected user.
- Relative scale: Centralised systems are intended to serve entire communities or substantial areas of large communities. Decentralised systems serve only a portion of a community.
- Qualification level of O&M workers: Centralised systems require many high-skilled experts, whereas decentralised systems require predominantly vocationally-trained workers under the supervision of one qualified DEWATS expert.
- Low overall impact of (temporary) failure of an individual DEWATS: This is compared to failure of a centralised system, which can lead to major financial, environmental and public health impacts.

In the following section, the main pros and cons of decentralised systems are listed. Additional arguments exist and should be taken into consideration when deciding between centralised and decentralised solutions.

Positive aspects of decentralised wastewater treatment systems:

- Enabling step-wise implementation: As the availability of financial resources for system upgrades is often the limiting factor, incremental improvement presents a more pragmatic approach.
- Easier financial planning and lower financial risk: There is less investment cost per system, and the success of one system is unconnected to the success of another. Thus if one system fails, the financial loss is lower.
- Can operate with zero or minimal power: There are technologies for decentralised systems that can operate with minimum or zero power consumption.
- Less capital and lower O&M costs for the sewer system: The treatment plant in a decentralised system is situated at or near the point of wastewater generation. Therefore, only short distances of sewer are needed, and at less depth than conventional systems. These systems do not require pump stations, which reduces the implementation as well as

7 (Brandes, 2015)
8 (COWI, 2016)
9 (Hamilton, et al., 2004)
10 In these guidelines, small-scale decentralised systems are defined as single systems with a treatment capacity that ranges between 1 - 500 m^3/day (See 3.3 Definition of Small-Scale and Large-Scale Systems)

the O&M costs. Additionally, solids-free sewer systems are frequently used in combination with decentralised systems.

- Increased potential of resource reuse: In decentralised systems, the quantity of treated wastewater is lower than in centralised systems. In addition, the possibility for reuse (e.g. gardening) is higher, because the treated wastewater can be used at multiple locations, homogeneously spread in the area.
- Low water requirements for waste transportation: Shorter sewers can operate with lower water requirements for flushing.
- Reducing the risk of system failure: Easy financial planning and lower requirements for O&M (in the case of DEWATS) compared to centralised systems serve to reduce the risk of system failure.

Negative aspects of decentralised wastewater treatment systems:

- Diseconomy of scale of wastewater treatment plants regarding capital and O&M costs: The bigger the system, the lower the cost per user.
- Flow variations and high peak flow factors lead to increased investment costs per connection: The smaller the wastewater system, the higher the fluctuation of wastewater flow and concentration. This leads to higher costs for decentralised systems, because the components of these systems need to be relatively large.
- High effort for monitoring a large number of systems: Due to the larger number of individual systems, the effort for law enforcement by effluent monitoring is increased.

Decentralised systems are particularly suitable for urban and peri-urban areas such as informal settlements or new housing developments that are located far from centralised sewerage infrastructure. Decentralised systems are also suitable in small-to-medium size towns that do not have centralised infrastructure in place and where the diseconomy of scale for sewer infrastructure outweighs the economy of scale for a centralised treatment plant. However, economies of scale also apply to decentralised systems (but with a lower range of connections), where a reasonable scale and population density is required to reduce the total capital cost per connection.

3.2 Definition of On-Site and Off-Site Systems

An on-site system is a wastewater collection and treatment system that is installed on a demarked and specified piece of land owned by a private person or entity. Hence, the landowner is fully responsible for this treatment system. An off-site system is a wastewater collection and treatment system installed on public land. Hence, this is a publicly owned and publicly and/or privately managed wastewater treatment system. This is a central point that influences the whole project cycle.

3.3 Definition of Small-Scale and Large-Scale Systems

Within these guidelines, a small-scale wastewater treatment system refers to a plant that treats up to 500m^3 of wastewater per day. The DEWATS approach is also applicable for larger systems with a treatment capacity of up to 1,000m^3 per day. However, larger systems require more detailed specifications, such as on energy for pumping. Additionally, larger systems are required to meet stringent effluent standards due to the increased volume of wastewater and load of contaminants being emitted from the system.

3.4 Faecal Sludge and Wastewater

Many faecal sludge treatment technologies are based on those developed for wastewater treatment, but it is important to note that these technologies cannot be directly transferred. Faecal sludge mainly consists of excreta and thus its characteristics differ from wastewater, which has a direct impact on the efficiency of treatment mechanisms[11]. In comparison to wastewater, faecal sludge typically has a higher solid content and a higher concentration of pollutants, pathogens and inorganic pollutants. Besides this, faecal sludge characteristics differ widely between different on-site sanitation technologies and system management types. The quantity and characteristics of faecal sludge also depend on the design and construction of the user interface (toilet type), how the technology is used, how the faecal sludge is collected, and the frequency of collection. For example, the characteristics of faecal sludge from a public toilet are substantially different to sludge

11 (Spellman, 1997)

Faecal Sludge

Parameter	**High Strength** (e.g. public toilet)	**Low Strength** (e.g. private septic tank)	**Municipal wastewater** (See definition in part 1.4)
COD [mg/l]	20,000 to 50,000	< 15,000	500 to 2,000
BOD [mg/l]	App. 7,600	840 to 2,600	300 to 500
COD/BOD [-]	5:1	10:1	2:1
NH_4-N [mg/l]	2,000 to 5,000	< 1,000	30 to 70
TSS [mg/l]	> 30,000	App. 7,000	200 to 700
P_{total} [mg/l]	450	150	9 to 63
Helm. Eggs [No./l]	20,000 to 60,000	App. 4,000	300 to 2,000
FC [CFU/100ml]	10^{52}	10^{52}	10^4 to 10^{52}

Table 1: Characteristics of faecal sludge and wastewater
(Strauss & Montangero, 2002; Strande, et al., 2014; ATV-DVWK-A 198, 2003)

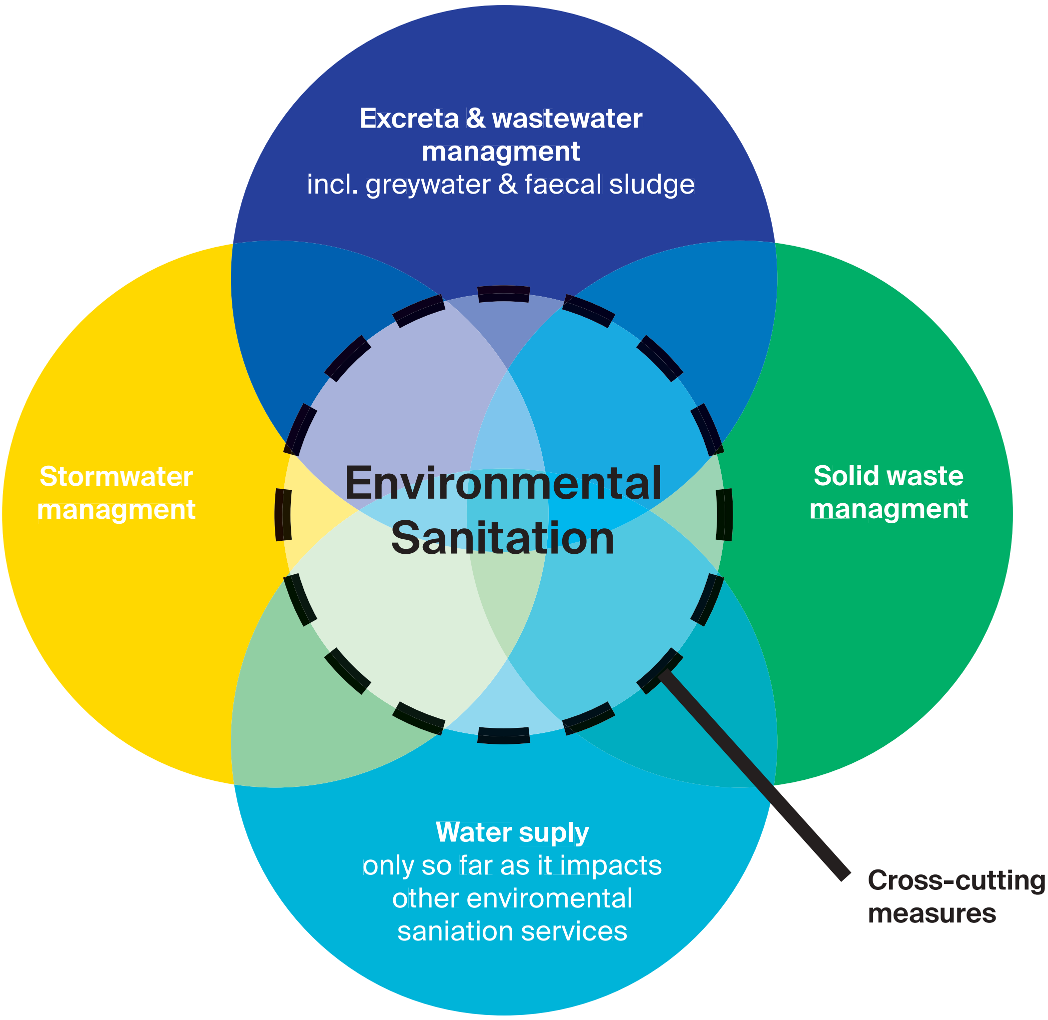


Figure 1: Components of environmental sanitation

Figure 2: The value chain for decentralised wastewater management

from a private septic tank. The approximate characteristics of faecal sludge (high strength and low strength) and wastewater are listed in Table 1. Due to the unique characteristics of wastewater and faecal sludge, not only must the management and treatment system be adapted, but also discharge standards need to differ.

Another fundamental difference between wastewater management and FSM is the need for physical emptying and transportation of faecal sludge. Typically, a variety of service providers with different technologies and methods for faecal sludge emptying and transportation can be found operating simultaneously in any given geographical region[12]. The management of faecal sludge leads to a high risk of exposure for service providers to physical, chemical and biological hazards during emptying, transport and discharge of faecal sludge. This is due to the nature of the tasks which are carried out without suitable barriers to human contact with harmful substances in the faecal sludge.

Wastewater systems are favourable over faecal sludge systems, as no wastewater infiltrates the ground on-site. Furthermore, wastewater treatment systems are preferable because of their lower O&M costs as compared to faecal sludge systems. If the willingness to pay for household sewer connections and wastewater surcharges can be ensured, wastewater treatment systems are the most suitable option.

Wastewater and FSM should also be seen as one part of environmental sanitation. Environmental sanitation can be seen as a set of activities to achieve a sanitary physical environment. Environmental sanitation goes one step further than the traditional notion of "sanitation" which is limited to the immediate aspects of human excreta and/or the provision of toilets. This approach includes excreta and wastewater management, solid waste management, stormwater management and partly also water supply.

3.5 Sanitation System or Value Chain

A sanitation system is a context-specific series of technologies and services for the management of human waste, i.e. for collection, containment, transport, transformation, and utilization or disposal. A well planned and designed small-scale wastewater treatment system incorporates the concept of a value chain, in which the resource (wastewater) is stored (containment), transported (conveyance) and processed (treatment) to obtain a product (e.g. treated water, biogas or biosolids). This is illustrated in Figure 2.

12 (Strande, et al., 2014)

3.6 Enabling Environment

An enabling environment is a set of interrelated conditions that empower development actors to engage in development policies, strategies and projects in a sustained and effective manner. This includes political, legal, institutional, financial and economic, educational, technical and social aspects. An enabling environment is important for the success of any development investment; without it, the resources committed to bringing about change will be ineffective. The six key elements of an enabling environment include:

1. The level of government support, in terms of political support and favourable national policies and strategies.
2. The legal and regulatory framework, with appropriate standards and codes at national and municipal levels.
3. The Institutional arrangements that accept and support the community-centred approach used.
4. Effective skills and capacity ensuring that all participants understand and accept the concepts and planning tools.
5. The financial arrangements that facilitate the mobilisation of funds for implementation and O&M.
6. The socio-cultural acceptance, i.e. matching service provision to the users' perceptions, preferences, and commitments to both short-term and long-term participation.

Within these guidelines, it is important to emphasise that the success of a small-scale wastewater treatment system depends on a vast array of variables which are not limited to the technical implementation of the system. If any of the named key elements of the enabling environment is not sufficiently provided, a small-scale wastewater treatment system is very likely to fail.

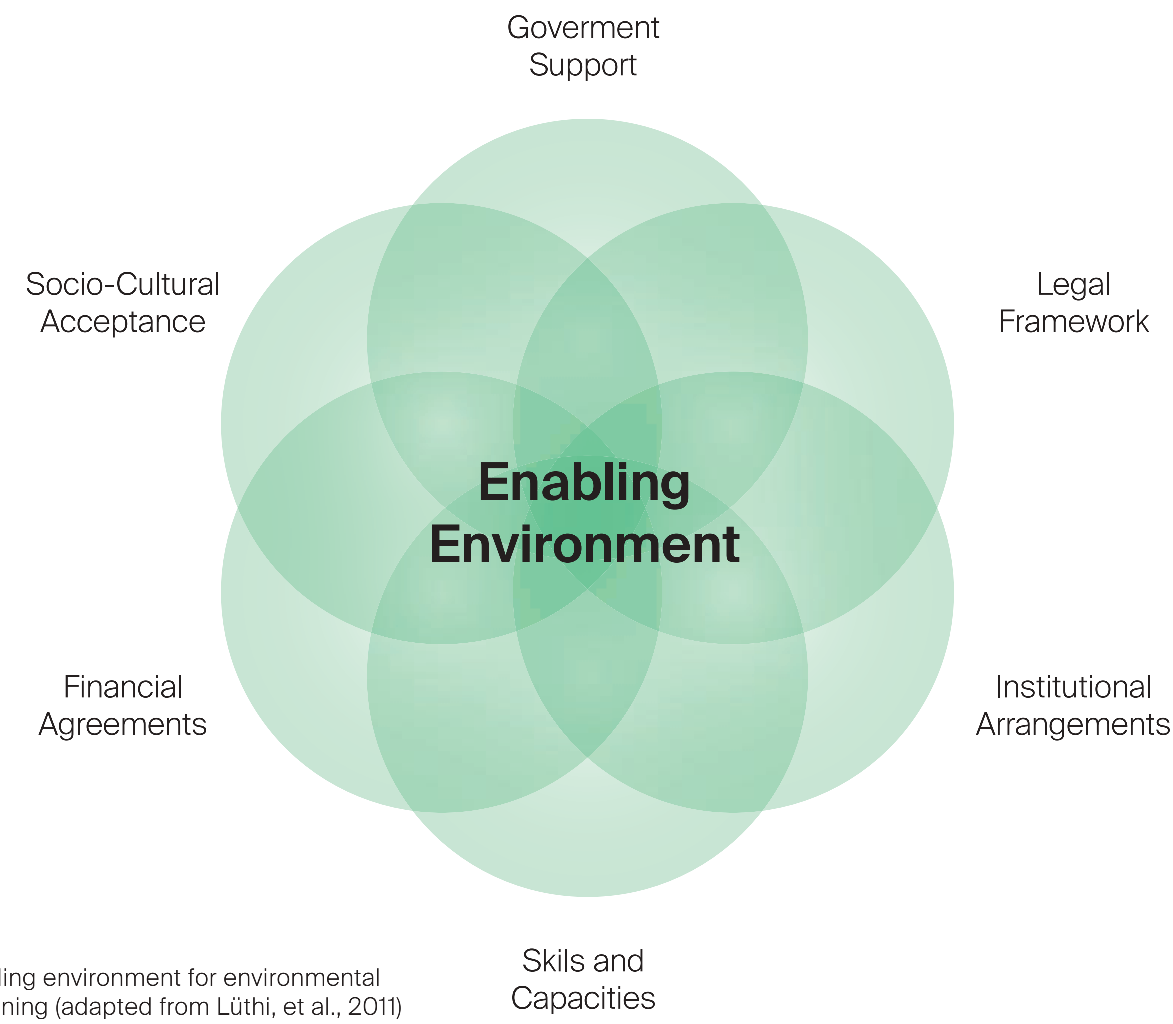


Figure 3: Enabling environment for environmental sanitation planning (adapted from Lüthi, et al., 2011)

The planning processes and concepts for assessing and creating an enabling environment are explained comprehensively in the CLUES guidelines. These help to assess and foster favourable conditions for environmental sanitation planning in challenging urban environments. Most of the critical elements to support an enabling environment should be identified or become evident during the planning process. Ideally these elements should be identified, at least in broad terms, prior to starting the planning and consultative process, so that the entire process does not start off with unrealistic expectations or misconceptions.
The CLUES guidelines can be found online:
www.sandec.ch/clues
Lüthi, C., Morel, A., Tilley, E., & Ulrich, L. (2011). Community-Led Urban Environmental Sanitation Planning (CLUES). Eawag-Sandec, WSSCC, UN-HABITAT.

3.7 Compliance with Effluent Standards

Standards are essential for the monitoring of wastewater treatment systems of different scales, according to effluent discharge and applicability for reuse.

In Tanzania the discharge of wastewater to the environment is currently regulated by the effluent standards TZS. 860:2006.

The guidelines on the following pages provide recommendations for incremental, stepwise implementation of standards to support the enabling environment for small-scale wastewater treatment systems, with a customised approach that takes into account context specific situations and needs.

For further reading, please refer to the following publications. These publications are also the main sources for the information provided in this chapter.

1. WHO. (2001). Water Quality: Guidelines, Standards and Health: Assessment of risk and risk management for water-related infectious disease. IWA.
2. Allaoui, M., Schmitz, T., Campbell, D., & de la Porte, C. A. (2015). Good Practices for Regulating Wastewater Treatment. UNEP, WaterLex.
3. Tayler, K., & Parkinson, J. (2003). Effective strategic planning for urban sanitation services: fundamentals of good practice. GHK International.
4. von Sperling, M. (1999). Stepwise Implementation of Water Quality Standards. XXVII Congresso Interamericano de Engenharia Sanitária e Ambiental. Associação Brasileira de Engenharia Sanitária e Ambiental.
5. WHO. (2006). Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture. World Health Organization.

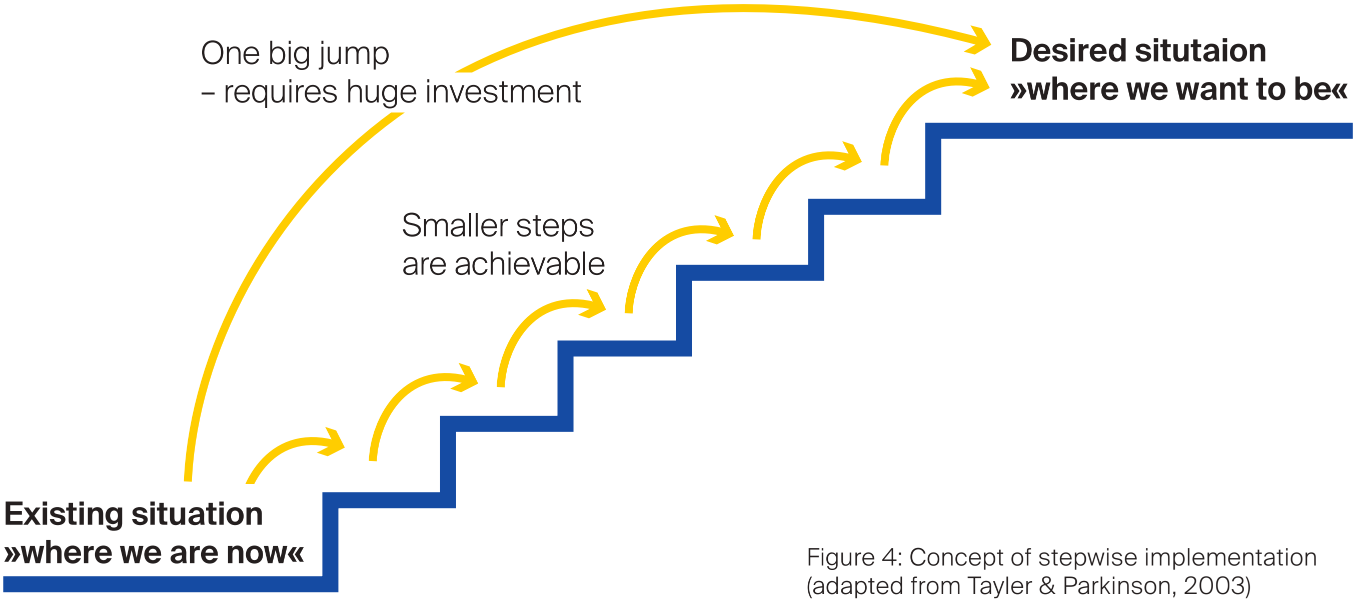


Figure 4: Concept of stepwise implementation (adapted from Tayler & Parkinson, 2003)

3.7.1 Stepwise implementation

The concept of stepwise implementation applies to both the technical implementation of wastewater treatment systems and the implementation of national standards for effluent quality. The concept is based on the idea that small steps of improvement are more feasible compared to a single large step, and eventually these small steps will lead to the same or an even higher level of improvement. This is visualised in Figure 4.

The effects of a stepwise implementation are listed and explained below:

- Polluters are more likely to afford gradual investment for control measures: Polluters and/or water authorities will find it much more feasible to divide investments into different steps, than to make a large and in many cases unaffordable investment.
- The present value of construction costs is reduced: The division of construction costs into different stages leads to a lower present value than a single large initial cost. This aspect is more relevant in countries where, due to inflation, interest rates are high.
- The cost-benefit of the first stage is likely to be more favourable than in the subsequent stages: In the first stage, when environmental conditions are poor, a large benefit is usually achieved with a comparatively low cost. In the subsequent stages, the size of the benefit is not as substantial, but the associated costs are high. The cost-benefit ratio is then less favourable.
- Operators have more time and better conditions to ascertain the particular water or wastewater characteristics: The operation of the system will involve monitoring, which will enable operators to develop more specialised knowledge of the water or wastewater characteristics. The design of the second or subsequent stages will be based on actual characteristics observed during monitoring, and not on generic values taken from the literature.
- There is the opportunity to optimise operation, without necessarily undergoing a physical expansion: Experience in the operation of the system will lead to a good understanding of its behaviour. This will allow, in some cases, the optimisation of the process (improvement of efficiency or capacity) without necessarily requiring the physical expansion of the system. The first stage will be analogous to a pilot plant.
- There is time and opportunity to implement, in the second stage, new techniques or better-developed processes: The availability of new or more efficient processes for water and wastewater treatment is always increasing with time. Process development is continuous and fast. The second or subsequent steps can make

use of better and/or cheaper technologies, which would not be possible within a single large step.

- The country has more time to develop its own standards: As time passes, the experience in operating the system and evaluating its positive and negative implications in terms of water quality, health status and environmental conditions will lead to the establishment of standards that are truly appropriate for local conditions.
- The country has more time and better conditions to develop a suitable regulatory framework and institutional capacity: Experience obtained in the operation of the system and in setting up the required infrastructure and institutional capacity for regulation and enforcement will also improve progressively, as the system expands in the second and subsequent stages.

3.7.2 Relationship between Treatment Performance, Effluent Standards and the Size of the Treatment Plant

The standards for effluent discharge should also depend on the size of the treatment plant: the smaller the treatment plant is, the less stringent the effluent standards need to be. Additionally, with smaller treatment plants, the option of recycling or reusing treated wastewater can be considered, instead of discharging into waterbodies. In many countries worldwide, this principle is recognised in effluent standards. There are two main reasons for this:

1. Small treatment plants treat only low volumes of wastewater, but the capacity of the receiving waterbody to handle a specific loading (see Equation 1) is constant. Thus, the quality of the effluent treated in a large-scale system must be higher, because the loading should not exceed a critical value.

Load = concentration x volume Equation 1

2. The treatment performance of large-scale systems can be higher than small-scale systems, because of the economy of scale: the larger a system, the lower the price for each user. High investments and O&M costs for advanced treatment are only financially feasible if the system is large enough.

3.7.3 The Relationship between Characteristics of the Receiving Waterbody and Effluent Standards

Effluent standards need to be adapted according to the quality, self-cleaning capacity and function of the receiving waterbody. For example, the discharge of effluent into waterbodies used for freshwater supply or in conservation areas – as well as the volume ratios between the inflowing wastewater and the receiving body – must be strongly regulated.

International School of Tanganyika (IST) Staff Housing Complex, Upanga, Dar es Salaam (project managed by Architectural Pioneering Consultants - APC)
On-site wastewater management system (designed by BORDA Tanzania) with Biogas Settler, and PGF. The system produces biogas for cooking purposes, and treated grey-water is recycled for flushing toilets and irrigation around the campus.

4 Components of DEWATS

The term Decentralised Wastewater Treatment Systems (DEWATS) was developed by an international network of organisations and experts. In these guidelines, the term DEWATS is applied in singular or plural form, referring to a chosen specific technological modular system, linked up with management and operations, that is part of a whole-system approach. This "systems approach" includes a whole range of different integral elements, and it is part of the value chain within sustainable sanitation services, specifically targeted at urban and peri-urban areas. This approach incorporates lessons learned from the limitations of conventional centralised and decentralised wastewater treatment systems, thereby helping to meet the rapidly growing demand for small-scale wastewater treatment solutions.

The modular technology is characterised by the following:

- DEWATS encompasses an approach, not just a technical hardware package. Besides technical and engineering aspects, the specific local economic and social situations are also taken into consideration.
- DEWATS provides treatment for wastewater flows with close COD/BOD ratios from 1m3 to 1000m3 per day and unit.
- DEWATS can treat wastewater from domestic or industrial sources, and are suitable to provide primary, secondary and advanced secondary treatment for wastewater from sanitation facilities, housing colonies, public entities like hospitals, or from businesses, especially those involved in food production and processing.
- DEWATS can be an integral part of comprehensive wastewater and sanitation strategies. The technological systems should be perceived as being complementary to other centralised and decentralised wastewater treatment options.
- DEWATS can provide a renewable energy source depending on the technical layout (e.g. biogas supplies energy for cooking, lighting or power generation).
- DEWATS is based on a set of design and layout principles.

The technologies following the DEWATS approach have demonstrated effective treatment performance in applications in different parts of the world. To scale up DEWATS, BORDA Africa conducts DEWATS trainings with the objective of capacitating different practitioners in the sector. The applicability of BORDA DEWATS in Tanzania is fostered by long-term worldwide experience with and documentation of these systems. Supporting material created in the course of BORDA DEWATS projects includes:

- A Quality Management System (QMS) tool which stipulates the standards and procedures for implementing and operating a DEWATS successfully
- Training packages (biogas curriculum, QMS training, etc.)
- Design tools
- Manuals for operation, maintenance and management
- Monitoring tools

The main benefits of DEWATS are:

- Public health is safeguarded: By protecting drinking water sources, DEWATS treatment options will reduce the pollution load of groundwater and surface water sources.
- Time efficient: Less than 12 months are required for planning and implementing DEWATS.
- Sustainability through informed choice: Communities choose the DEWATS system and components they prefer.
- Professional design and workmanship: Technical options are tested and subjected to rigid quality control.
- Cost efficiency: The investment and O&M costs are low.
- Reduced need for monitoring: Due to low operation costs, the risk of reducing the treatment to save money (e.g. by turning off aerators in activated sludge processes) is minimised.
- Strengthened capacities through training and capacity building: Stakeholders are trained and assisted to plan, implement and manage DEWATS independently or in co-management arrangements.
- Replication: Trained local facilitators and urban planners ensure future DEWATS replications and scaling up within the target cities.

A selection of technologies suitable for the Tanzanian context are listed below, considering each stage along the sanitation value chain. Components are combined in

For further reading and detailed design information, please refer to the following publications. These publications are also the main sources for the information provided in chapters 4–5.

1. Tilley, E., Ulrich, L., Christoph, L., Reymond, P., Schertenleib, R., & Zurbrügg, C. (2014). Compendium of Sanitation Systems and Technologies. IWA; EAWAG; WSSCC.
2. DEWATS and Sanitation in Developing Countries: A Practical Guide; BORDA; 2009
3. Gutterer, B., Sasse, L., Panzerbieter, T., & Reckerzügel, T. (2009). Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries. BORDA; WEDC.
4. von Sperling, M., & de Lemos Chernicharo, C. A. (2005). Biological Wastewater Treatment in Warm Climate Regions. IWA.
5. Reynaud, N. (2014). Operation of Decentralised Wastewater Treatment Systems (DEWATS) under tropical field conditions.
6. Strande, L., Ronteltap, M., & Brdjanovic, D. (Eds.) (2014). Faecal sludge management: Systems approach for implementation and operation, Faecal Sludge Management: Systems Approach for Implementation and Operation. IWA.

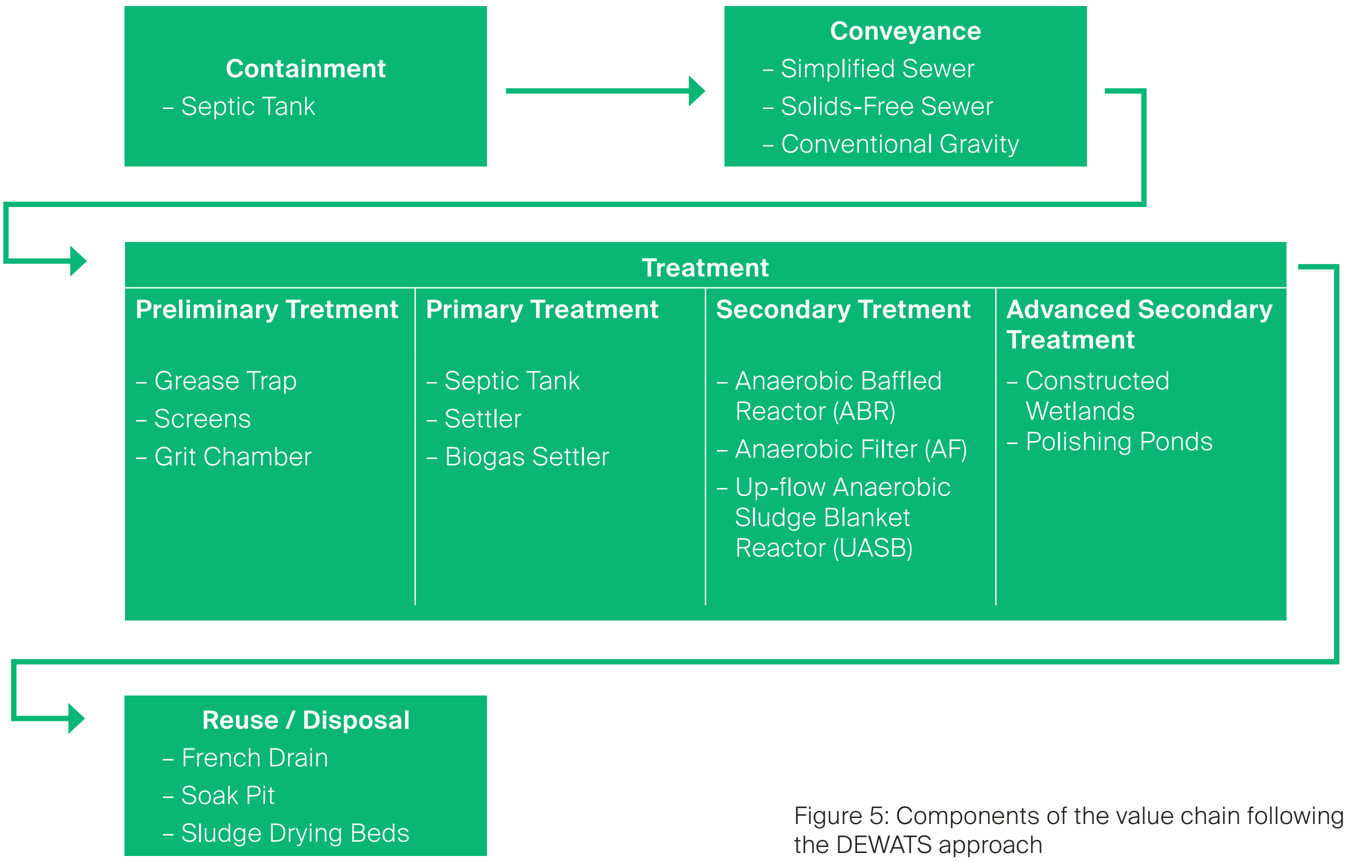


Figure 5: Components of the value chain following the DEWATS approach

accordance with the wastewater influent and the required effluent quality. Sanitation appliances (user interface) and components that are solely related to FSM are not listed here, as they are excluded from the scope of these guidelines (see part 1.4 on page 13). These guidelines do not contain specific design considerations, but only brief descriptions, and general pros and cons of the respective modules and technologies.

4.1 Containment

Containment technologies collect and store wastewater at the user interface on-site. Containment technologies are usually applicable for low-cost, non-sewered sanitation (faecal sludge) systems as intermediate storage, but can also serve as pre-treatment modules for small-scale wastewater treatment systems. The main containment technology applicable for wastewater treatment technologies is the septic tank. In the vast majority of situations, containment systems are already installed on-site but are often improperly designed, constructed and maintained, which poses severe environmental hazards. Apart from septic tanks providing some degree of pre-treatment, the effluent usually contains high concentrations of pollutants, which can carry severe public health and environmental burdens, especially in densely populated urban areas and in the vicinity of drinking water sources. Hence, proper sealing of containment options is crucial for environmental sanitation. Containment systems can also be implemented to buffer peak flows.

4.2 Conveyance

Technologies presented in this section are sewer-based technologies, using water from waterborne toilets as a conveying medium.

4.2.1 Simplified Sewer

A simplified sewer describes a sewerage network that is constructed using smaller diameter pipes laid at a shallower depth and at a flatter gradient than conventional sewers. This sewer system generally does not apply pumping. For these reasons, simplified sewers allow for a more flexible design at lower costs. Simplified sewers can be installed in almost all types of settlements and are especially appropriate for dense urban areas where space for on-site technologies is limited. They should be considered as an option where there is a sufficient population density (about 150 inhabitants per hectare) and a reliable water supply (at least 60 L/capita/day).

Pros	Cons
✓ Makes wastewater transport to the treatment plant more efficient	⊗ Requires expert design and construction
✓ Costs can be offset with access permits	⊗ Can lead to odours if not properly maintained
✓ Lower costs for construction and O&M due to less depth and no pumping.	

Table 2: Pros and cons of simplified sewers

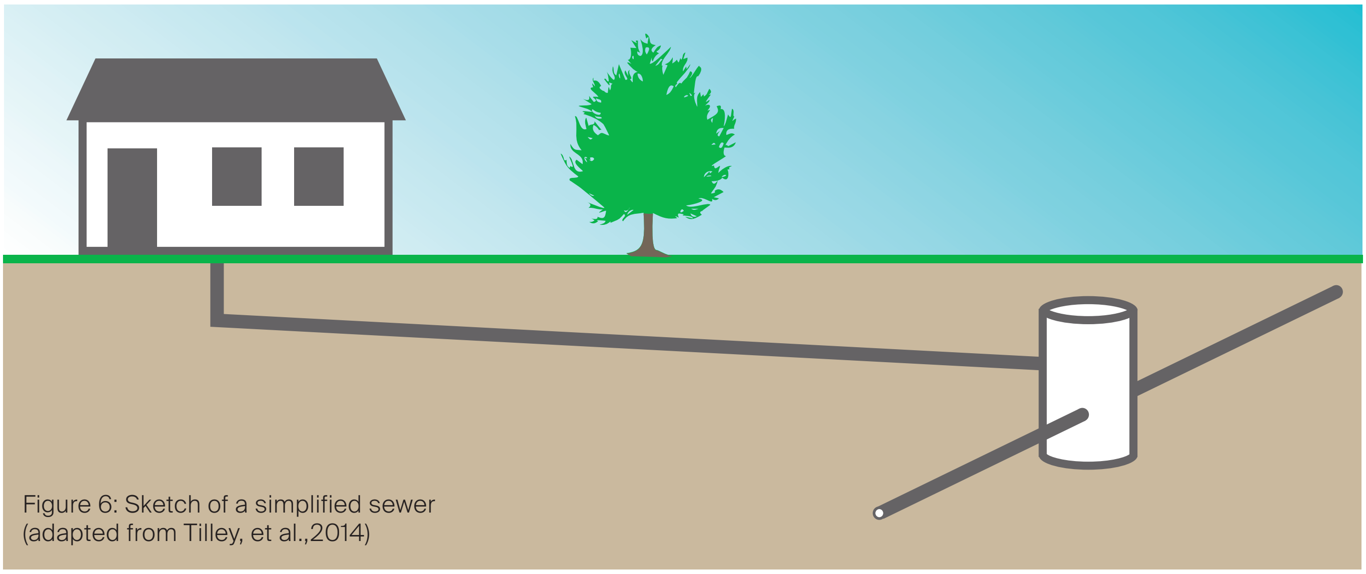


Figure 6: Sketch of a simplified sewer (adapted from Tilley, et al.,2014)

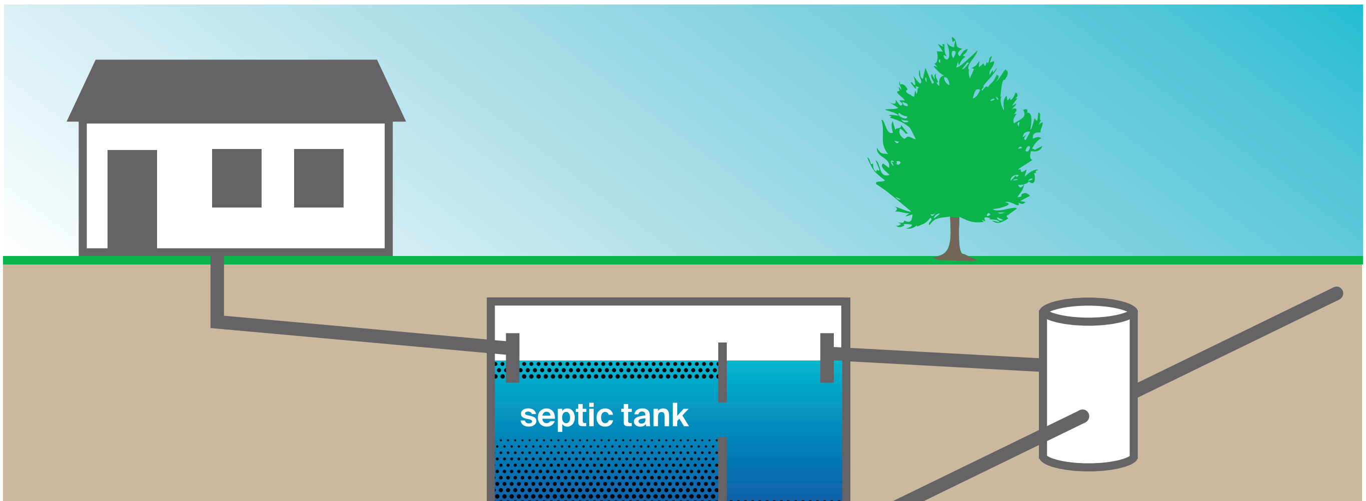


Figure 7: Sketch of a solids free-sewer (adapted from Tilley, et al., 2014)

4.2.2 Solids-free Sewer

A solids-free sewer is a network of small-diameter pipes that transports pre-treated and solids-free wastewater (such as septic tank effluent). It can be installed at a shallow depth and does not require a minimum wastewater flow or slope to function.

This type of sewer is best suited to medium-density (peri-)urban areas and less appropriate in low-density settings. It is most appropriate where effluents cannot otherwise be disposed of on-site (e.g. due to low infiltration capacity or high groundwater table). It is also suitable where there is undulating terrain or rocky soil. A solids-free sewer can be connected to existing septic tanks where infiltration is no longer appropriate (e.g. due to increased housing density and/or water use).

Pros	Cons
✓ Does not require a minimum gradient or flow velocity	⊗ Space for interceptors is required
✓ Can be used where water supply is limited	⊗ Interceptors require regular desludging to prevent clogging
✓ Lower capital costs than conventional gravity sewers	⊗ Requires training and acceptance to be used correctly
✓ Low operating costs	⊗ Requires repairs and removals of blockages more frequently than a conventional gravity sewer
✓ Can be extended as a community grows	⊗ Requires expert design and construction
✓ Greywater can be managed concurrently	⊗ Leakages pose a risk of wastewater exfiltration and groundwater infiltration and are difficult to identify

Table 3: Pros and cons of solids-free sewers

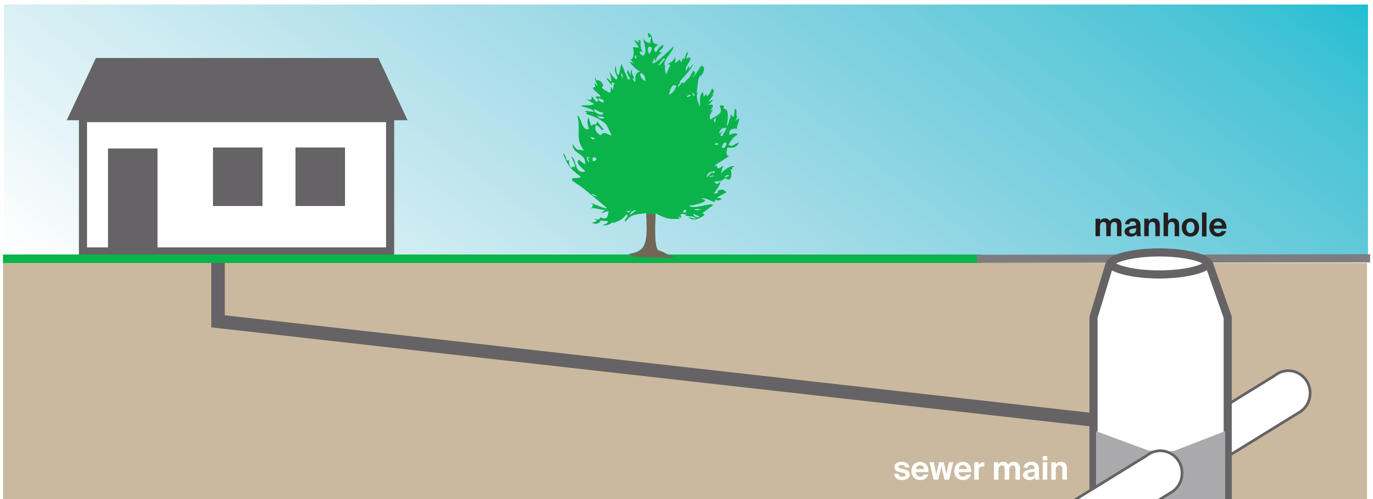


Figure 8: Sketch of a conventional gravity sewer
(adapted from Tilley, et al., 2014)

4.2.3 Conventional Gravity Sewer

Conventional gravity sewers are large networks of underground pipes that convey blackwater, greywater and, in many cases, stormwater from individual households to a (semi-)centralised treatment facility using gravity (and pumps when necessary).

Because they can be designed to carry large volumes, conventional gravity sewers are very appropriate to transport wastewater to a (semi-) centralised treatment facility. Construction of conventional sewer systems in dense, urban areas is complicated because it disrupts urban activities and traffic. Conventional gravity sewers are expensive to build and a professional management system must be in place, as the installation of a sewer line is disruptive and requires extensive co-ordination between authorities, construction companies and property owners.

Pros	Cons
✓ Less maintenance compared to simplified and solids-free sewers	⊗ Very high capital costs
✓ Greywater and possibly stormwater can be managed concurrently	⊗ High O&M costs
✓ Can handle grit and other solids, as well as large volumes of flow	⊗ A minimum velocity must be maintained to prevent the deposition of solids in the sewer
	⊗ Requires deep excavations
	⊗ Difficult and costly to extend as a community changes and grows
	⊗ Requires expert design, construction and maintenance
	⊗ Leakages pose a risk of wastewater exfiltration and groundwater infiltration and are difficult to identify

Table 4: Pros and cons of conventional gravity sewers

4.3 Treatment

Treatment technologies are classified according to different levels depending on their treatment objectives and removal efficiency (see Figure 9 and Table 5). The following section is divided into the below-mentioned treatment levels.

As DEWATS make use of various natural biological and physical treatment processes that require different boundary conditions to function efficiently, DEWATS are comprised of a series of treatment units, each providing an ideal environment for the removal of certain groups of pollutants.

In the following chapter, a summary of the treatment performance for each relevant technology is provided.

Additionally, "bubbles" are used to present the treatment performance of DEWATS and findings observed during the M&E activities, which occurred in parallel to the development of this document. The treatment performance is presented as an average removal rate of all evaluated systems. The number of systems evaluated is mentioned in brackets (X Systems) in each bubble.

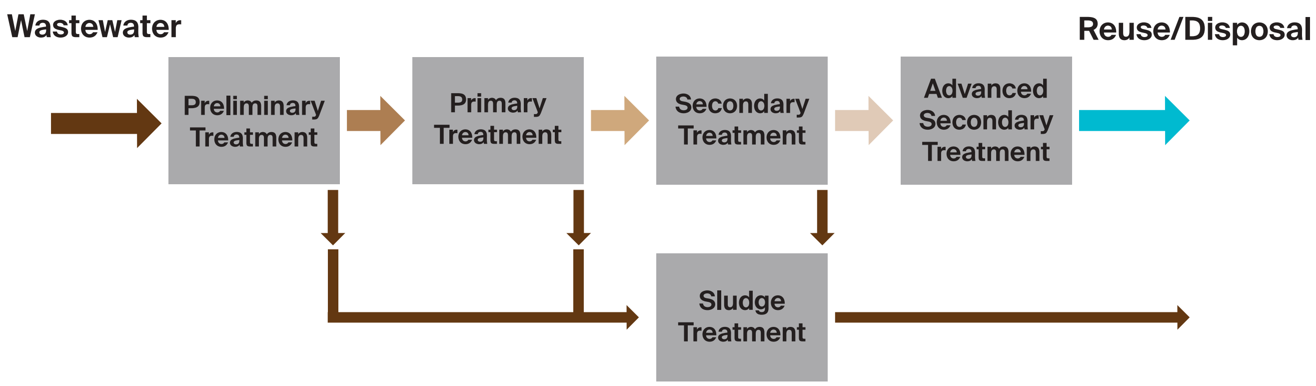


Figure 9: Flow diagram of a typical wastewater treatment system

Level	Removal
Preliminary	▶ Coarse solids (larger material and sand)
Primary	▶ Settleable solids (SS) ▶ Particulate (suspended) BOD (associated to the organic matter component of the SS)
Secondary	▶ Particulate (suspended) BOD (associated to the particulate organic matter present in the raw sewage, or to the non-settleable particulate organic matter, not removed in the possibly existing primary treatment) ▶ Soluble BOD (associated to the organic matter in the form of dissolved solids)

Table 5: Wastewater treatment levels

To enable evidence-based decisions, it is also recommended to consult the results of the 4S research project which conducted the first systematic assessment of small-scale sanitation systems in South Asia. In this assessment more than 300 small-scale sanitation systems were evaluated in detail. The results can be found at the following URL: www.sandec.ch/4S

4.3.1 Preliminary Treatment

Preliminary treatment is the removal of wastewater or sludge constituents such as oil, grease, and various solids (e.g. sand, fibres and trash). Built before a conveyance or treatment technology, preliminary treatment units can retard the accumulation of solids and minimise subsequent blockages. They can also help reduce abrasion of mechanical parts and extend the life of the sanitation infrastructure.

Pros	Cons
✓ Relatively low capital and operating costs	⊗ Frequent operational tasks required
✓ Reduced risk of damaging subsequent Conveyance and/or Treatment technologies	⊗ Removal of untreated solids and grease is required regularly

Table 6: Pros and cons of preliminary treatment

4.3.1.1 Grease Trap

The goal of the grease trap is to trap oil and grease so that it can be easily collected and removed. Grease traps are chambers made out of brick, concrete or plastic, with an odour-tight cover. Baffles or tees at the inlet and outlet prevent turbulence at the water surface and separate floating components from the effluent.

Grease traps should be applied where considerable amounts of oil and grease are discharged. They can be installed at single households, restaurants or industrial sites. Grease removal is especially important where there is an immediate risk of clogging (e.g. a constructed wetland (CW) for the treatment of greywater). In the case of domestic wastewater, grease removal is not very necessary if a septic tank is installed in the system. When there is high grease loading (e.g. wastewater from canteens), a grease trap can be installed before the septic tank. In a grease trap, bio-degradable solids should have no time to settle and therefore the retention time is low.

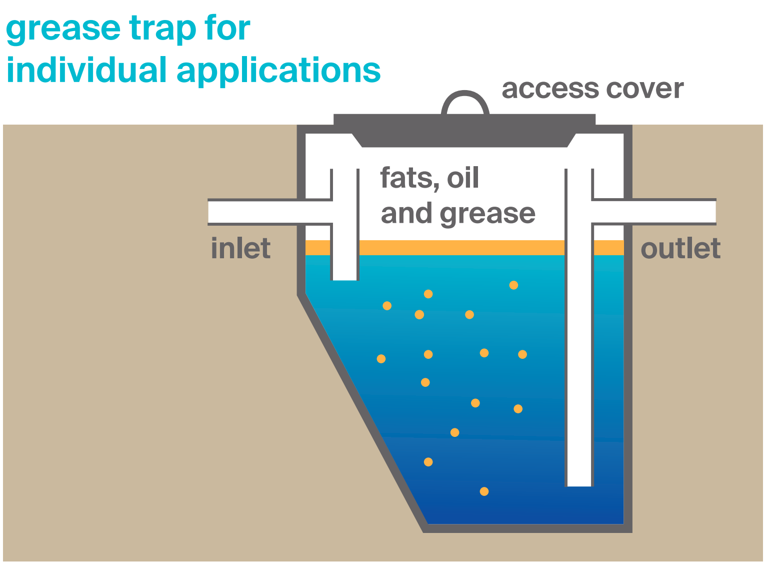


Figure 10: Section view of a grease trap (adapted from Tilley, et al., 2014)

4.3.1.2 Screens

Screening aims to prevent coarse solids, such as plastics, rags and other trash, from entering a sewage system or treatment plant. Solids get trapped by inclined screens or bar racks. The spacing between the bars usually is 15 to 40 mm, depending on cleaning patterns. Screens can be cleaned by hand or mechanically raked. The latter allows for more frequent solids removal and, correspondingly, smaller spacing between the bars.

Screening is essential where solid waste may enter a sewer system, as well as at the entrance of treatment plants. Trash traps, e.g. mesh boxes, can also be applied at strategic locations like market drains. In DEWATS for small-scale wastewater treatment, screening is usually avoided since screens increase the operational requirements (cleaning).

4.3.1.3 Grit Chamber

Where subsequent treatment unit components could be hindered or damaged by the presence of sand, grit chambers (or sand traps) allow for the removal of heavy inorganic matter (e.g. grit particles) through settling, while lighter, principally organic particles remain in suspension.

A grit chamber helps prevent sand deposits and abrasion in wastewater treatment plants. This is particularly important where roads are not paved and/or stormwater may enter the sewer system, because in these cases more sand or grit ends up in the system. Nevertheless, the intrusion of stormwater is avoided in DEWATS.

4.3.2 Primary Treatment

Primary treatment aims at the removal of:

- SS
- Floating solids

After passing through the preliminary treatment units, sewage still contains non-coarse TSS, which can be partially removed in sedimentation units. A significant portion of this TSS is comprised of organic matter. Therefore, its removal by simple processes such as sedimentation implies a reduction in the BOD load directed to the secondary treatment stage, where its removal is more expensive.

4.3.2.1 Septic Tank

A septic tank is a watertight chamber made of concrete (e.g. reinforced concrete, blocks), fibreglass, PVC or other plastic. In a septic tank, settling and anaerobic processes reduce solids and organics, but the treatment is only moderate. Dissolved matter leaves the tank nearly untreated. If the effluent of the septic tank is conveyed to a treatment system, the septic tank can be used in a small-scale wastewater treatment system as pre-treatment and to buffer the fluctuation of concentrations.

Findings from M&E activities 2017 - see Page 38

Removal Rate:
SS 66.7%
(1 System)

A septic tank consists of a minimum of two, sometimes three compartments. The compartment walls extend 15-30cm above the liquid level. Avoiding surface or stormwater intrusion during rainy season shall be considered during the design. To prevent the wastewater from flowing backwards into the system, the outlet is constructed 10-15cm below the inlet. The first compartment occupies about two-thirds of the total septic-tank volume. All chambers are normally the same depth. The total volume of a septic tank can be estimated by assuming 80 to 100l per domestic user. The exact volume depends on the wastewater characteristics. Usual hydraulic retention time (HRT) is approximately 2 days.

The treatment efficiency of septic tanks ranges from 25% to 50% COD removal. The removal rates drop drastically when accumulated sludge fills more than two-thirds of the tank. To avoid this, frequent desludging is necessary.

A septic tank is appropriate where there is a way of dispersing or conveying the effluent. If septic tanks are used in densely populated areas, on-site infiltration (e.g. French drains) should not be used. Infiltration of the effluent can lead to contamination of groundwater aquifers. Oversaturation of the ground can cause wastewater to rise to the surface, posing a serious health risk.

Pros	Cons
✓ Simple and robust technology	⊗ Low reduction of pathogens, solids and organics
✓ No electrical energy is required	⊗ Regular desludging must be ensured
✓ Low operating costs	⊗ Effluent and sludge require further treatment and/ or appropriate discharge
✓ Long service life	
✓ Small land area required (can be built underground)	

Table 7: Pros and cons of septic tanks

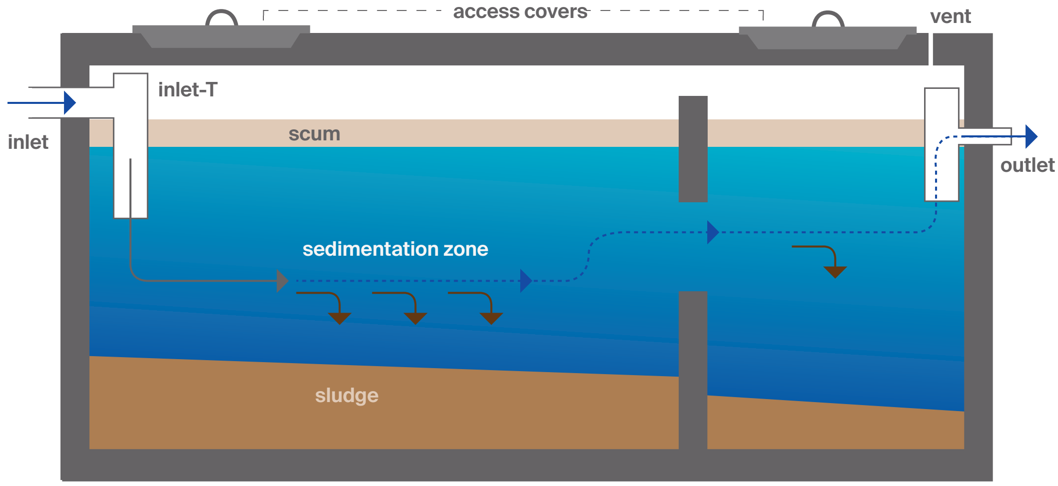


Figure 11: Section view of a septic tank
(adapted from Tilley, et al., 2014)

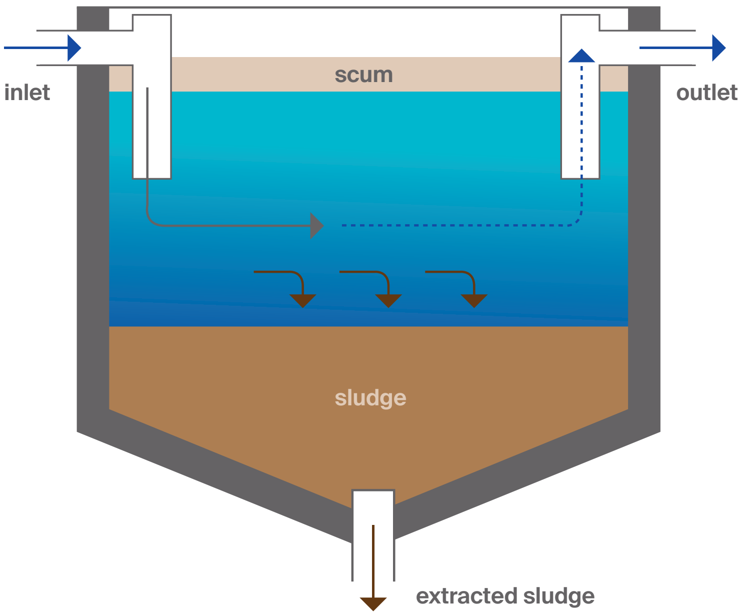


Figure 12: Section view of a settler
(adapted from Tilley, et al., 2014)

4.3.2.2 Settler

A settler is a primary treatment technology for wastewater; it is designed to remove TSS by sedimentation. It may also be referred to as a sedimentation or settling basin/tank, or clarifier. The low flow velocity in a settler allows settleable particles to sink to the bottom, while constituents lighter than water float to the surface. In comparison to septic tanks, the HRT of a settler is low since anaerobic digestion is usually not the aim.

The choice of a technology to settle solids is governed by the size and type of the installation, the wastewater characteristics, the management capacities, and the desirability of an anaerobic process, with or without biogas production. The installation of a primary sedimentation tank is of particular importance for technologies that use a filter material. Settlers can also be installed as stormwater retention tanks to remove a portion of the organic solids that otherwise would be directly discharged into the environment.

Pros	Cons
✓ Simple and robust technology	⊗ Low treatment efficiency (only in cases where the settler is not connected to a subsequent treatment)
✓ Efficient removal of TSS	
✓ Relatively low capital and operating costs	
✓ Can be built underground	

Table 8: Pros and cons of settlers

4.3.2.3 Biogas Settler

A DEWATS Biogas Settler is usually a gas- and watertight dome-shaped sub-surface structure. It is typically constructed with bricks or cement mortar/plaster. The primary function of the settler is to separate the incoming wastewater into liquid and solid components, allowing the digestion of organic solids. The microbial digestion process occurs under anaerobic conditions (without oxygen) and results in the generation of biogas.

The by-products of this treatment process are (a) a digested slurry (digestate) that is stabilised and thus can be used as a soil amendment and (b) biogas that can be used for energy. Biogas is a mix of methane, carbon dioxide and other trace gases which can be converted to heat, electricity or light.

Often, a Biogas Settler is used as an alternative to a septic tank or a settler, since it offers a similar level of treatment, but with the added benefit of biogas production. In this case, the digestate can be further treated (e.g. in an anaerobic baffled reactor (ABR)). The accumulated solids must then be desludged frequently.

This technology can be applied at the household level, in small neighbourhoods, or for the stabilisation of sludge at large wastewater treatment plants. It is best used where regular feeding is possible. The biogas production is high for "thick" substrate (low water content). The water content of wastewater is low enough to enable operation without stirring.

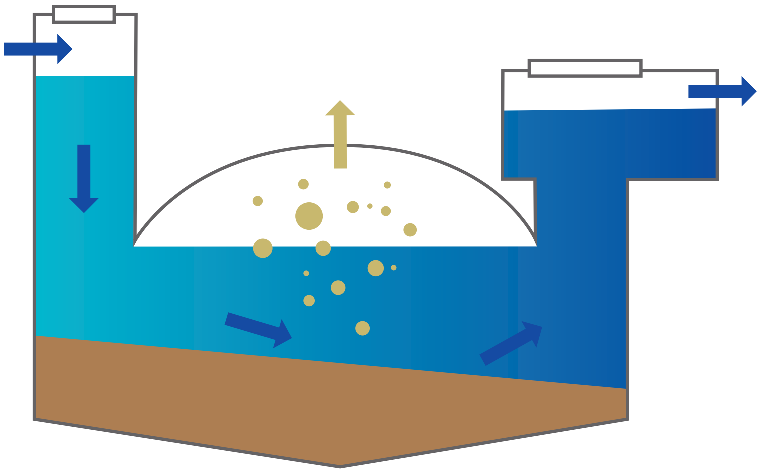


Figure 13: Biogas Settler
(adapted from Tilley, et al., 2014)

The reactor volume depends on the HRT. The longer the HRT, the better the treatment, but also the larger the reactor. Commonly the HRT is between 15 and 30 days. The total reactor volume also depends on the needed storage volume for the produced gas. This depends on the gas production and on the pattern of gas utilisation (e.g. constant usage for a refrigerator or variable usage for cooking). External gas storage (outside of the biogas settler) can be also implemented. The gas outlet should be a minimum of 30cm above the substrate level, to avoid clogging of the outlet by scum.

Pros	Cons
✓ Generation of renewable energy	⊗ Requires expert design and skilled construction
✓ Small land area required (most of the structure can be built underground)	⊗ Requires good O&M capacity
✓ No electrical energy required	⊗ Biogas production using wastewater is low
✓ Conservation of nutrients	⊗ Biogas emission due to leakage or no usage has a strong negative impact on the climate
✓ Long service life	
✓ Low operating costs	
✓ Low sludge production due to high compression of sludge in the biogas settler	

Table 9: Pros and cons of Biogas Settler

4.3.3 Secondary Treatment

The main objective of secondary treatment is the removal of organic matter. Organic matter is present in the following forms:

- Dissolved organic matter (soluble or filtered BOD) that is not removed by merely physical operations, such as the sedimentation that occurs in primary treatment;
- Organic matter in suspension (suspended or particulate BOD), which may have been largely removed in primary treatment, but whose solids with slower settleability (finer solids) remain in the liquid mass.

The secondary treatment processes are conceived in such a way as to accelerate the decomposition mechanisms that naturally occur in the receiving waterbodies. Thus, the decomposition of the degradable organic pollutants is achieved under controlled conditions and at smaller time intervals than in the natural environment.

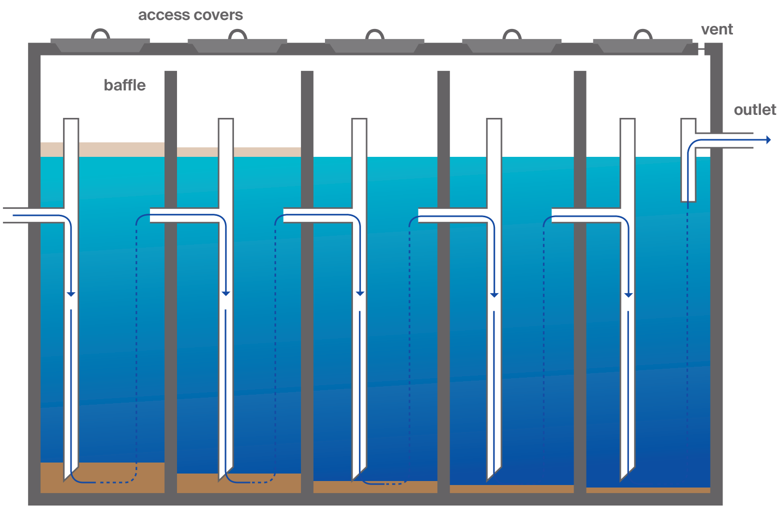


Figure 14: Section view of an ABR (adapted from Tilley, et al., 2014)

Findings from M&E activities 2017 - see Page 38

Removal Rate:
SS 83.4 %; COD 43.5 %
TSS 25.0 %; BOD 45.0 %
(8 Systems)

4.3.3.1 Anaerobic Baffled Reactor (ABR)

An ABR is a modified septic tank with a series of baffles under which the wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment. The up-flow chambers provide enhanced removal and digestion of organic matter. BOD can be reduced by 70% to 90%, which is far superior to its removal in a conventional septic tank. The main function of an ABR is the conversion of particulate matter into soluble BOD, as well as a certain percentage of soluble BOD into Methane (CH_4). This is achieved by de-coupling HRT from Solids Retention Time.

This technology is easily adaptable and can be applied at the household level, in small neighbourhoods or even in bigger catchment areas. It is most appropriate where a relatively constant amount of blackwater and greywater is generated.

This technology is suitable for areas where land may be limited, as the tank is most commonly installed underground and requires a small area. However, a vacuum truck should be able to access the location for desludging purposes. ABRs are not efficient at removing nutrients and pathogens. The effluent usually requires further treatment.

An ABR ideally consists of 3–5 sequential chambers. The up-flow velocity (max. 1m/h) limits the height of the reactor. The HRT of the liquid portion (i.e. above the sludge volume), which should not be less than 8 hours, determines the ABR's volume. This leads to large but shallow tanks, making the system uneconomical for large plants. A chamber should not be longer than 60% of the height.

Pros	Cons
Simple and durable	Requires expert design and construction
Highly resistant to organic and hydraulic shock loads	Low reduction of pathogens and nutrients
No electrical energy is required	Effluent and sludge require further treatment and/or appropriate discharge
Low operating and maintenance costs	
Low risk of blockage	
Long service life	
Low sludge production; the sludge is stabilised	
Moderate area requirement (can be built underground)	

Table 10: Pros and cons of an ABR

4.3.3.2 Anaerobic Filter (AF)

Findings from M&E activities 2017
- see Page 38

Removal Rate:
SS 61.4%; COD 44.0%
TSS 66.7%
(5 Systems)

An AF is a fixed-bed reactor in an anaerobic contact process, with one or more filtration chambers in series. As wastewater flows through the filter, particles are trapped and organic matter is degraded by the active biomass that is attached to the surface of the filter material. Filter material can be gravel, rocks or specially formed plastic pellets. To reduce costs, locally available material shall be used. For example, in Tanzania coconut husk can be used or in Indonesia volcanic rock might be a good solution. Good filter material provides 90m² to 300m² surface area per m³. With this technology, TSS and BOD removal can be as high as 90%, but typically ranges between 50% and 80%. Nitrogen removal is limited and normally does not exceed 15% in terms of total nitrogen (TN).

This technology is easily adaptable and can be applied at the household level, in small neighbourhoods or in bigger catchment areas. It is most appropriate where a relatively constant amount of blackwater and greywater is generated. The AF can be used for secondary treatment, to reduce the organic loading rate for a subsequent aerobic treatment step, or for polishing. This technology is suitable for areas where land may be limited, as the tank is most commonly installed underground and requires a small area. Accessibility by

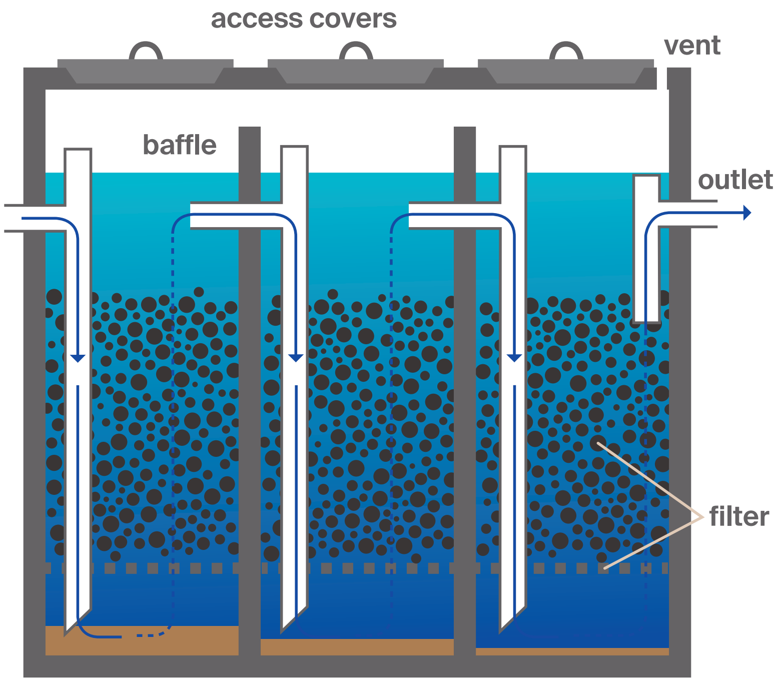


Figure 15: Section view of an anaerobic filter (AF) (adapted from Tilley, et al., 2014)

vacuum truck is important for desludging. AFs are not efficient at removing nutrients and pathogens. Depending on the filter material, however, complete removal of worm eggs may be achieved. The effluent usually requires further treatment. When the bacterial film on the filter material becomes too thick, it must be removed. This may be done either by back-washing or by removing the filter mass for cleaning outside the reactor.

An important design criterion is the equal distribution of wastewater across the filter area. The HRT is about 1.5–2 days. For domestic wastewater the total volume can be estimated by assuming 0.5m3/cap - 1m3/cap. A head loss of 30cm-50cm must be taken into account.

Pros	Cons
✓ No electrical energy is required	⊗ Requires expert design and construction
✓ Low operating costs	⊗ Low reduction of pathogens and nutrients
✓ Long service life	⊗ Effluent and sludge require further treatment and/or appropriate discharge
✓ High reduction of BOD and solids	⊗ Risk of clogging, depending on pre- and primary treatment
✓ Low sludge production; the sludge is stabilised	⊗ Removing and cleaning the clogged filter media is cumbersome
✓ Moderate area requirement (can be built underground)	⊗ Filter material can be costly and difficult to obtain locally

Table 11: Pros and cons of anaerobic filters

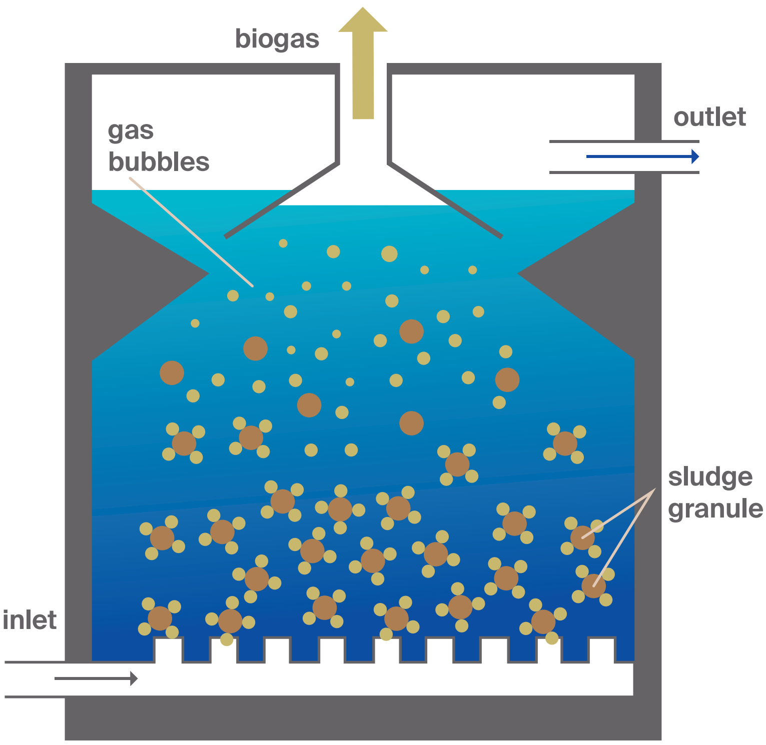


Figure 16: Section view of an up-flow anaerobic sludge blanket reactor (UASB) (adapted from Tilley, et al., 2014)

4.3.3.3 Up-flow Anaerobic Sludge Blanket Reactor (UwwASB)

The UASB is a single-tank process. Wastewater enters the reactor from the bottom and flows upward. A suspended sludge blanket filters and treats the wastewater as the wastewater flows through it.

A UASB is not a typical component of a DEWATS, mainly because it requires increased operational skills and capacity. A UASB is not appropriate for small or rural communities without a constant water supply or electricity. The technology is relatively simple to design and build, but developing the granulated sludge may take several months. The UASB has the potential to produce higher quality effluent than septic tanks and Biogas Settler and can do so in a smaller reactor volume. Although it is a well-established process for large-scale industrial wastewater treatment and high organic loading rates up to 10 kg BOD/m3/d, its application to domestic sewage is still relatively new.

UASBs are often used for wastewater from breweries, distilleries and food processing as well as pulp and paper waste since the process typically removes 80 to 90% of COD. General treatment capacities of 55% to 75% COD reduction were observed at average HRTs of 5 to 6 h when treating communal wastewater. Where the influent is low-strength or where it contains too many solids, proteins or fats, the reactor may not work properly.

Findings from M&E activities 2017 - see Page 38

Removal Rate:
SS 93.3%; COD 47.0%
TSS 37.9%; BOD 37.3%
(1 System)

Pros	Cons
✓ High reduction of BOD	⊗ Requires frequent discharge of excess sludge (up to a weekly basis)
✓ Can withstand high organic and hydraulic loading rates	⊗ Treatment may be unstable with variable hydraulic and organic loads
✓ Low sludge production (and thus, infrequent desludging required)	⊗ Requires O&M by skilled personnel; difficult to maintain proper hydraulic conditions (up-flow and settling rates must be balanced)
✓ Biogas can be used for energy (but usually first requires scrubbing)	⊗ Long start-up time
	⊗ A constant source of electricity is required
	⊗ Not all parts and materials may be locally available
	⊗ Requires expert design and construction
	⊗ Effluent and sludge require further treatment and/or appropriate discharge

Table 12: Pros and cons of up-flow anaerobic sludge blanket reactors

4.3.4 Advanced Secondary Treatment

Though primary and secondary treatment units are capable of removing over 90% of enteric microbial load, organic matter and total phosphorus, the effluent from the secondary treatment units may not meet the requirements for water reuse or wastewater discharge in terms of pathogen and nutrient concentrations. Hence, it is important to polish the secondary effluent to improve its hygienic quality and meet the requirements set for wastewater discharge or reuse (Ministry of Urban Development - Government of India, 2012).

Typically, tertiary treatment units are provided to polish the secondary effluent and remove residual contaminants. A tertiary treatment process can consist of coagulation, solid/liquid separation and disinfection units for the removal of residual TSS, colour, organic matter, offensive odour and microorganisms. Solid/liquid separation is normally achieved by filtration, floatation and adsorption. Disinfection of the pathogenic organisms is achieved by chlorination or ozonation or UV disinfection or some combination thereof.

To prevent clogging of the below described filters with fine soil, stormwater should neither be mixed with the wastewater before the treatment step, nor should outside stormwater be allowed to overflow the filter bed. Erosion trenches around the filter bed should always be kept in proper functioning condition.

4.3.4.1 Constructed Wetlands (CW)

CWs can be distinguished by:

3. The direction of their flow: horizontal or vertical
4. Their filter material: coarse (e.g. gravel) or fine (e.g. sand)
5. Their vegetation: planted or unplanted

Findings from M&E activities 2017 - see Page 38
Removal Rate:
SS 75.2%; COD 46.1%
TSS 50.0%; BOD 73.6%
(16 System)

Horizontal Subsurface Flow Constructed Wetland or Planted Gravel Filter (PGF)

A horizontal subsurface flow constructed wetland is a large gravel and sand-filled basin that is planted with wetland vegetation. As wastewater flows horizontally through the basin, the filter material filters out particles and microorganisms degrade the organics. The filter media acts simultaneously as a filter for removing solids, a fixed surface upon which bacteria can attach, and a base for the vegetation. Although facultative and anaerobic bacteria degrade most organics, the vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonise the area and degrade organics there as well. The plant roots play an important role in maintaining the permeability of the filter.

Clogging is a common problem and, therefore, the influent should be well settled with primary and secondary treatment before flowing into the wetland. This technology is not appropriate for untreated domestic wastewater (i.e. blackwater). It is a good treatment option for communities that have primary treatment (e.g. septic tanks), but are looking to achieve a higher quality effluent. The horizontal subsurface flow constructed wetland is a good option where land is cheap and available. Depending on the volume of the water and the corresponding area requirement of the wetland, it can be appropriate for small sections of urban areas, as well as for peri-urban and rural communities. It can also be designed for single households. If the effluent is to be reused, the losses due to high evapotranspiration rates could be a drawback of this technology, depending on the climate.

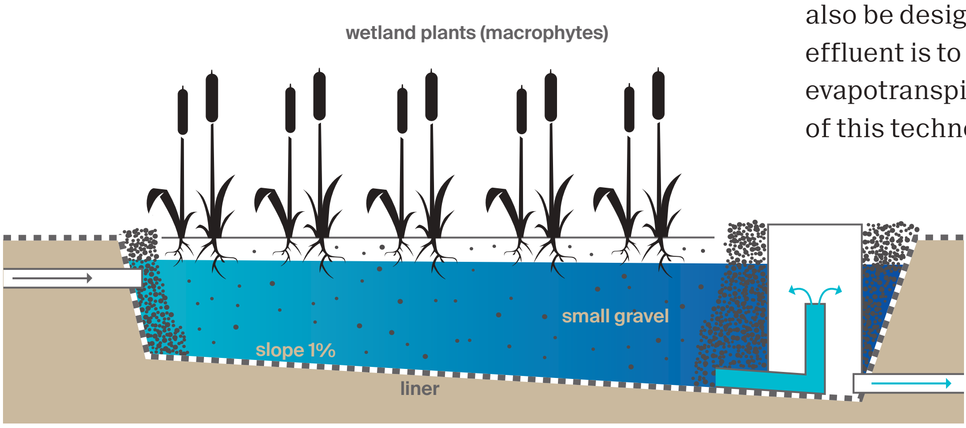


Figure 17: Section view of a horizontal subsurface flow constructed wetland (adapted from Tilley, et al., 2014)

Pros	Cons
High reduction of BOD, TSS and pathogens	Requires a large land area
Pleasant landscaping possible	Little nutrient removal
Does not have the mosquito problems of the free-water surface constructed wetland	Risk of clogging, depending on pre- and primary treatment
No nuisance from odours	Long start-up time to work at full capacity
No electrical energy is required	Costly if the right quality of gravel is not available
Low operating costs	Requires expert design and construction

Table 13: Pros and cons of horizontal subsurface flow constructed wetlands

Vertical Subsurface Flow Constructed Wetland

A vertical flow constructed wetland is a planted filter bed that is drained at the bottom. Wastewater is poured or dosed onto the surface from above using a mechanical dosing system. The water flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe. The key distinction between a vertical and horizontal wetland is not simply the direction of the flow path, but rather the aerobic conditions.

By intermittently dosing the wetland (4 to 10 times a day), the filter goes through stages of being saturated and unsaturated, with the correspondingly different phases of aerobic and anaerobic conditions. During a flush phase, the wastewater percolates down through the unsaturated bed. As the bed drains, air is drawn into it and the oxygen has time to diffuse through the porous media. The filter media acts simultaneously as a filter for removing solids, a fixed surface upon which bacteria can attach and a base for the vegetation. The top layer can be planted. In this case, the vegetation is allowed to develop deep, wide roots, which permeate the filter media. Nutrients and organic material are absorbed and degraded by the dense microbial populations. By forcing the organisms into a starvation state between dosing phases, excessive biomass growth can be decreased and porosity increased.

The vertical flow constructed wetland is a good treatment option for communities that have primary treatment (e.g. septic tanks), but are looking to achieve a higher quality effluent. Because of the mechanical dosing system, this technology is most appropriate where trained maintenance staff, constant power supply, and spare parts are available. Since vertical flow constructed wetlands are able to nitrify, they can be an appropriate component of the treatment process for wastewater with high ammonium concentrations.

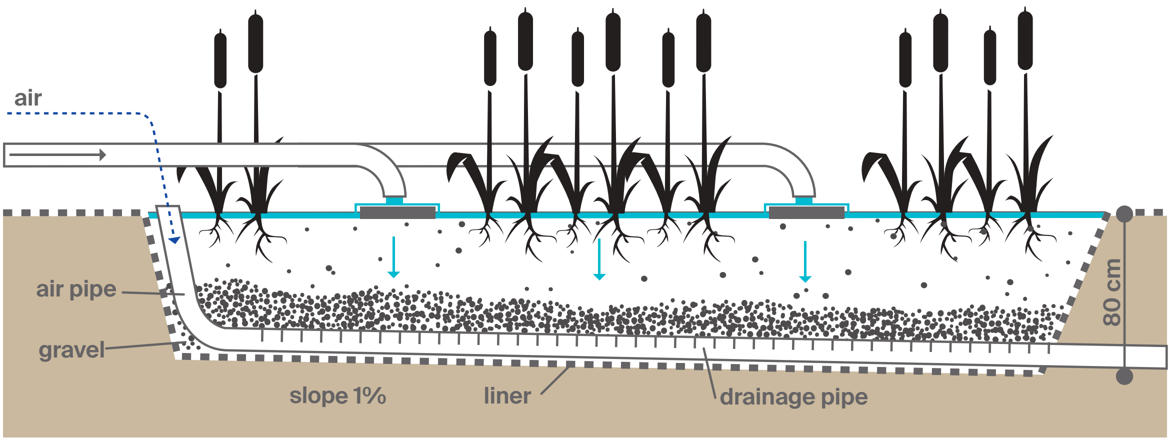


Figure 18: Section view of a vertical subsurface flow constructed wetland (adapted from Tilley, et al., 2014)

Pros	Cons
High reduction of BOD, TSS and pathogens	Requires expert design and construction, particularly for the dosing system
Ability to nitrify due to good oxygen transfer	Requires more frequent maintenance than a horizontal subsurface flow constructed wetland
Does not have the mosquito problems of the free-water surface constructed wetland	A constant source of electrical energy may be required
Less clogging than in a horizontal subsurface flow constructed wetland	Long start-up time to work at full capacity
Requires less space than a free-water surface or horizontal flow wetland	Not all parts and materials may be locally available
Low operating costs	

Table 14: Pros and cons of vertical subsurface flow constructed wetlands

Findings from M&E activities 2017
- see Page 38

Removal Rate:

SS 100%; COD 61.2%

TSS 0%; BOD 61.3%

(1 System)

Vertical Sand Filter

Vertical sand filtration in a DEWATS is comparable with the vertical constructed wetland, only that the filter material is sand. Compared to the horizontal filter, it is the more efficient and reliable treatment system from a technical and scientific point of view. One challenge of vertical sand filtration is the equal distribution of water on the surface of the filter, which is realised by feeding in doses. Doses must be large enough to temporarily flood the entire filter, but small enough to allow oxygen to enter before the next flooding. The sand, therefore, must be fine enough to allow flooding and porous enough to allow quick percolation. In addition, resting times of one to two weeks are needed so that oxygen can enter the filter after wastewater has percolated.

Vertical sand filters are normally 1-1.2m deep. However, if there is enough natural slope and good ventilation, they can be constructed up to three meters high. The filters may or may not be covered by vegetation. In the absence of vegetation, the surface must be scraped regularly, in order to allow enough oxygen to enter. With dense vegetation, the stems of the plants ensure sufficient open pores in the filter surface.

The vertical sand filter is not a typical component of the DEWATS approach. Dosing of flow can be challenging, but is typically performed with self-acting siphons, automated pumps or tipping buckets. The latter is most suitable to the DEWATS approach, because its basic operating principle is easily understood and the hardware can be manufactured locally.

While vertical filters can bear a hydraulic load up to 100l/m²xd, it is better to restrict loading to 50l/m²xd. The organic load may reach up to 20g BOD/m²xd and in the case of re-circulation, 40gBOD/m²xd is possible.

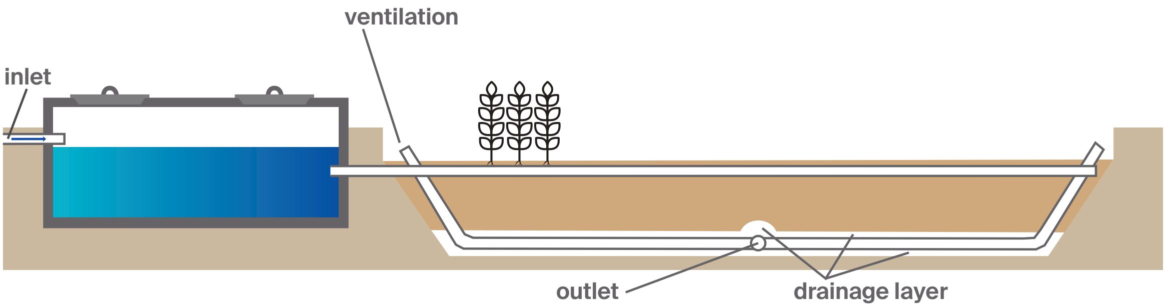


Figure 19: Section view of a vertical sand filter

Pros	Cons
High reduction of contaminants	Necessity of permanent operational control
	Necessity of a dosing device and a strict adherence to charging intervals
	Needs resting periods of one to two weeks
	Bad odour might occur during the charging times

Table 14: Pros and cons of vertical subsurface flow constructed wetlands

4.3.4.2 Polishing Ponds

Wastewater treatment ponds are artificial lakes. They provide wastewater treatment through natural processes. Different treatment processes can be utilised, depending on the design of the pond. A series of ponds can be used to combine different treatment effects. Ponds may be classified into:

- Sedimentation ponds (pre-treatment with anaerobic sludge stabilisation)
- Anaerobic ponds (anaerobic stabilisation ponds)
- Oxidation ponds (aerobic cum facultative stabilisation ponds)
- Polishing ponds (fully aerobic post-treatment ponds)

In a DEWATS, it is recommended to employ ponds only as a polishing step, as other uses of ponds often come into conflict with high demand for land and produce large amounts of methane. In addition, ponds are frequently overloaded or misused as dumpsites. Polishing ponds are shallow and used only for the final sedimentation of TSS and the reduction of nutrients. Artificially aerated ponds are not considered to be part of the DEWATS approach. DEWATS polishing ponds receive their oxygen via the water surface and from algae via photosynthesis. This provides sufficient oxygen for a loading rate of approximately 4gBOD/m^{2}xd. Polishing ponds can also be used to grow fish. The fish can feed on algae and other organisms that grow in the nutrient-rich water, removing nutrients from the wastewater until they are eventually harvested for consumption. Simultaneously, the fish assist in controlling mosquitos.

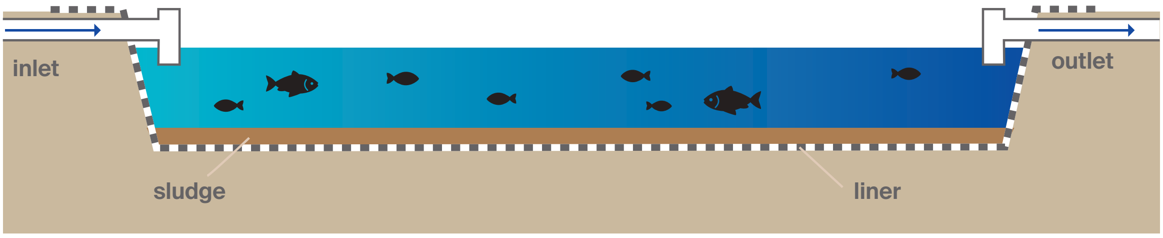


Figure 20: Section view of a polishing/fish pond (adapted from Tilley, et al., 2014)

Pros	Cons
✓ Can be used for the combined treatment and disposal/reuse of effluent	⊗ Requires expert design and construction
✓ Has a long lifespan (depending on local conditions)	⊗ Requires a large area
✓ Low maintenance requirements	⊗ Can lead to nuisance like bad odours and mosquito breeding
✓ Relatively low capital costs; low operating costs	⊗ Primary treatment is required
	⊗ May negatively affect soil and groundwater properties
	⊗ Fish may pose a health risk if improperly prepared or cooked

Table 15: Pros and cons of polishing/fish ponds

4.3.5 Treatment of Sludge from DEWATS

After desludging a Biogas Settler or ABR, the sludge should be treated in drying beds where pathogens are killed off through exposure to oxygen and UV-radiation. In addition, dewatering (or “thickening”) of sludge is an important treatment objective, as sludge contains a high proportion of liquid, and the reduction in this volume will simplify and greatly reduce the costs of subsequent treatment steps. Environmental and public health treatment objectives are achieved through pathogen reduction, stabilisation of organic matter and nutrients, and the safe end use or disposal of treatment end-products.

4.3.5.1 Unplanted Sludge Drying Beds

An unplanted drying bed is a simple, permeable bed that, when loaded with sludge, collects percolated leachate and allows the sludge to dry by evaporation. Approximately 50% to 80% of the sludge volume drains off as liquid or evaporates. The bottom of the drying bed is lined with perforated pipes to drain away the leachate that percolates through the bed. On top of the pipes are layers of gravel and sand that support the sludge and allow the liquid to infiltrate and collect in the pipe. These layers should not be too thick (maximum 20 cm), or the sludge will not dry effectively. The final moisture content after 10 to 15 days of drying should be approximately 60%. When the sludge is dried, it must be separated from the sand layer and transported for further treatment, end-use or final disposal. The leachate that is collected in the drainage pipes must also be treated properly, depending on where it is discharged.

Sludge drying is an effective way to decrease the volume of sludge, which is especially important when it has to be transported elsewhere for further treatment, end-use or disposal. The technology is not effective at stabilising the organic component of the sludge or decreasing the pathogenic content. Further storage or treatment of the dried sludge might be required. Unplanted drying beds are best suited for rural and peri-urban areas where there is inexpensive, available space situated far from homes and businesses. If designed to service urban areas, unplanted drying beds should be at the edge of the community, but within economically feasible reach for operators of motorised emptying services. This is a low-cost option that can be installed in most hot and temperate climates. Excessive rain may prevent the sludge from properly drying.

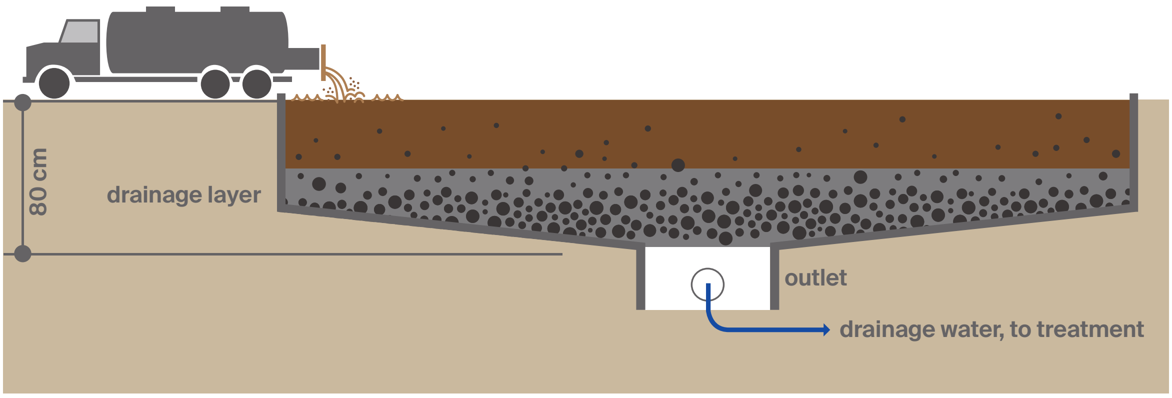


Figure 21: Section view of an unplanted sludge drying bed (adapted from Tilley, et al., 2014)

Pros	Cons
✓ Good dewatering efficiency, especially in dry and hot climates	⊗ Requires a large land area
✓ Can be built and repaired with locally available materials	⊗ Odours and flies are normally noticeable
✓ Relatively low capital costs; low operating costs	⊗ Labour intensive removal
✓ Simple operation, only infrequent attention required	⊗ Limited stabilization and pathogen reduction
✓ No electrical energy is required	⊗ Requires expert design and construction
	⊗ Leachate requires further treatment

Table 16: Pros and cons of unplanted sludge drying beds

4.3.5.2 Planted Sludge Drying Beds

A planted drying bed is similar to an unplanted drying bed, with the plants bringing the added benefits of transpiration and enhanced sludge treatment. The key improvement of the planted bed over the unplanted bed is that the filters do not need to be desludged after each feeding/drying cycle. Fresh sludge can be directly applied onto the previous layer; the plants and their root systems maintain the porosity of the filter. This technology has the benefit of dewatering and stabilising the sludge. Also, the roots of the plants create pathways through the thickening sludge that allow water to easily escape. The appearance of the bed is similar to a vertical flow constructed wetland. The beds are filled with sand and gravel to support the vegetation. Instead of effluent, sludge is applied to the surface and the filtrate flows down through the subsurface where it is collected in drains. This technology is effective at decreasing the sludge volume (down to 50%) through decomposition and drying, which is especially important when the sludge needs to be transported elsewhere for end-use or disposal. If designed to service urban areas, planted drying beds should be at the edge of the community, but within economically feasible reach for operators of motorised emptying services.

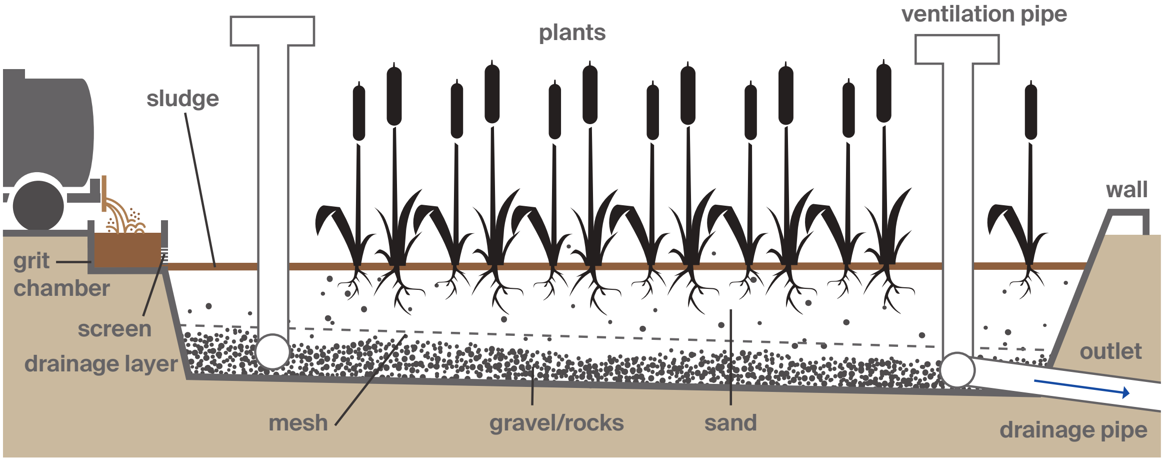


Figure 22: Section view of a planted sludge drying bed (adapted from Tilley, et al., 2014)

Pros	Cons
✓ Can handle high loading	⊗ Requires a large land area
✓ Better sludge treatment than in unplanted drying beds	⊗ Odours and flies may be noticeable
✓ Can be built and repaired with locally available materials	⊗ Long storage times
✓ Relatively low capital costs; low operating costs	⊗ Labour intensive removal
✓ Fruit or forage growing in the beds can generate income	⊗ Requires expert design and construction
✓ No electrical energy required	⊗ Leachate requires further treatment

Table 17: Pros and cons of planted sludge drying beds

4.4 Disposal/Reuse

Disposal or reuse is the last step in the sanitation value chain. At this stage the treated wastewater and sludge have to meet the stipulated treatment requirements. When market demand can be ensured and the technical feasibility is proven, reuse is favoured over disposal. Different reuse options and applications exist for the different by-products, namely:

- Treated wastewater (effluent)
- Dried and hygienised sludge
- Biogas

Requirements and restrictions for reuse are described in the paragraphs below. The World Health Organisation (WHO) in its "Guidelines for the safe use of wastewater, excreta and greywater" gives further reliable orientation on the use of wastewater, which can be downloaded using the following link:
www.who.int/water_sanitation_health/publications/gsuweg4

With the implementation of resource recovery, it is important to evaluate sludge components that may impact both humans and the environment. These include pathogens and heavy metals. Social factors such as acceptance of using products from wastewater treatment and level of market demand also need to be taken into account in order to ensure uptake of the intended end use.

Pathogens

Wastewater contains large amounts of microorganisms, mainly originating from the faeces. The microorganisms can be pathogenic, and exposure to untreated wastewater constitutes a significant health risk to humans, either through direct contact or through indirect exposure. Pathogens are transmitted and spread through an infection cycle, which includes different stages and hosts. This cycle can be interrupted by putting barriers in place to block transmission paths and prevent cycle completion.

Wastewater needs to be treated to an adequate hygienic level depending on the end use or disposal option. The recent 2006 WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture places less emphasis on treatment thresholds, but rather highlights a multi-barrier approach where lower levels of treatment may be acceptable when combined with other post-treatment barriers along the sanitation value chain.

The first barrier for beneficial use is provided by the level of pathogen reduction achieved through treatment of wastewater. A selection of further post-treatment barriers may include a usage restriction on crops that are eaten raw, withholding periods between application and harvest to allow pathogen die-off, drip or subsurface irrigation methods, restricting worker and public access during application, use of personal protective equipment and safe food preparation methods such as thorough cooking, washing or peeling. When considering the risk of infection, all potential exposure groups should be accounted for. These can be broadly categorised as workers and their families, surrounding communities, and product consumers.

Heavy Metals

Heavy metals are a concern due to their toxicity and long-term negative effects on soils. Heavy metals should be evaluated on a case by case basis, but are only a major concern if wastewater includes industrial effluents or stormwater from roads that are not adequately pre-treated. Heavy metals can also enter the system at the household level through the relatively common practice of improper disposal of wastes containing heavy metals (e.g. batteries, solvents, paints) into the system. The total metals concentrations in the sludge differs from the bioavailable metals concentrations, as the organic matter in sludge can bind metals in a form that is not biologically available.

Social Factors

Different societies and cultures have different reactions and approaches to the management of human excreta that have to be taken into consideration when evaluating the best end use for wastewater treatment products. Some cultures reject the use of excreta altogether, whereas others have a long history of excreta use in agriculture. The use of treated wastewater is typically perceived differently from that of excreta, and has a higher acceptance based on its appearance, smell and health impacts. This highlights the need for evaluating the market demand of potential products prior to deciding on a treatment and end use scheme.

4.4.1 Treated Wastewater

4.4.1.1 Irrigation: distribution systems

To reduce dependence on freshwater and to maintain a constant source of water for irrigation throughout the year, wastewater of varying quality can be used in agriculture. However, to limit the risk of crop contamination and health risks to workers, only water that has had secondary treatment (i.e., physical and biological treatment) should be used. Examples of types of irrigation technologies appropriate for treated wastewater are:

1. Drip irrigation above or below ground, where the water is slowly dripped on or near the root area
2. Surface irrigation where water is routed overland in a series of dug channels or furrows
3. Sub-surface irrigation where water is distributed by an underground network of perforated pipes

To minimise evaporation and contact with pathogens, spray irrigation should be avoided. Properly treated wastewater can significantly reduce dependence on fresh water, and/or improve crop yields by supplying more water and nutrients to plants. Raw sewage or untreated blackwater should not be used, and even well-treated water should be used with caution. Long-term use of poorly or improperly treated water may cause long-term damage to the soil structure and its ability to hold water.

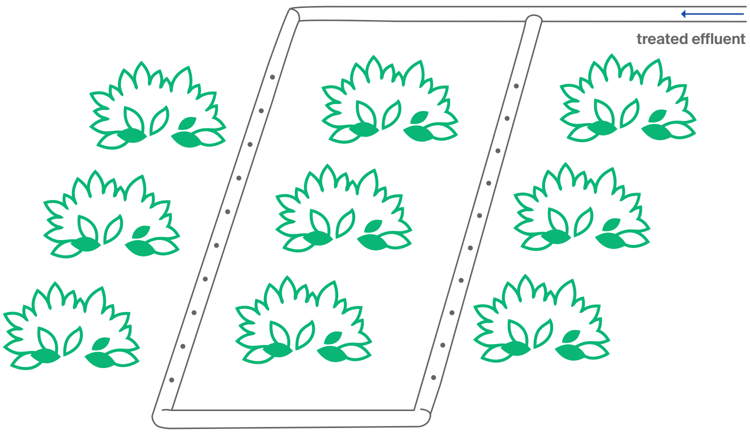


Figure 23: Sketch of a drip irrigation system with treated wastewater

Generally, drip irrigation is the most appropriate irrigation method; it is especially good for arid and drought-prone areas. Surface irrigation is prone to large losses from evaporation but requires little or no infrastructure and may be appropriate in some situations. Crops such as maize, alfalfa (and other feed), fibres (e.g. cotton), trees, tobacco, fruit trees (e.g. bananas or mangos) and foods requiring processing (e.g., sugarcane for sugar production) can be grown safely with treated effluent. More care should be taken with fruits and vegetables that may be eaten raw (e.g. tomatoes, salad or cucumbers), as they could come in contact with the water. Energy crops like eucalyptus, poplar, willow, or ash trees can be grown in short rotation and harvested for biofuel production. Since the trees are not for consumption, this is a safe, efficient way of using lower-quality effluent. Soil quality can degrade over time (e.g. due to the accumulation of salts) if poorly treated wastewater is applied.

Pros	Cons
✓ Reduces depletion of groundwater and improves the availability of drinking water	⊗ May require expert design and installation
✓ Reduces the need for fertiliser	⊗ Not all parts and materials may be locally available
✓ Potential for local job creation and income generation	⊗ Drip irrigation is very sensitive to clogging, i.e., the water must be free from TSS
✓ Low risk of pathogen transmission if water is properly treated	⊗ Risk of soil salinisation if the soil is prone to the accumulation of salts
✓ Low capital and operating costs depending on the design	⊗ Social acceptance may be low in some areas

Table 18: Pros and cons of irrigation with treated wastewater

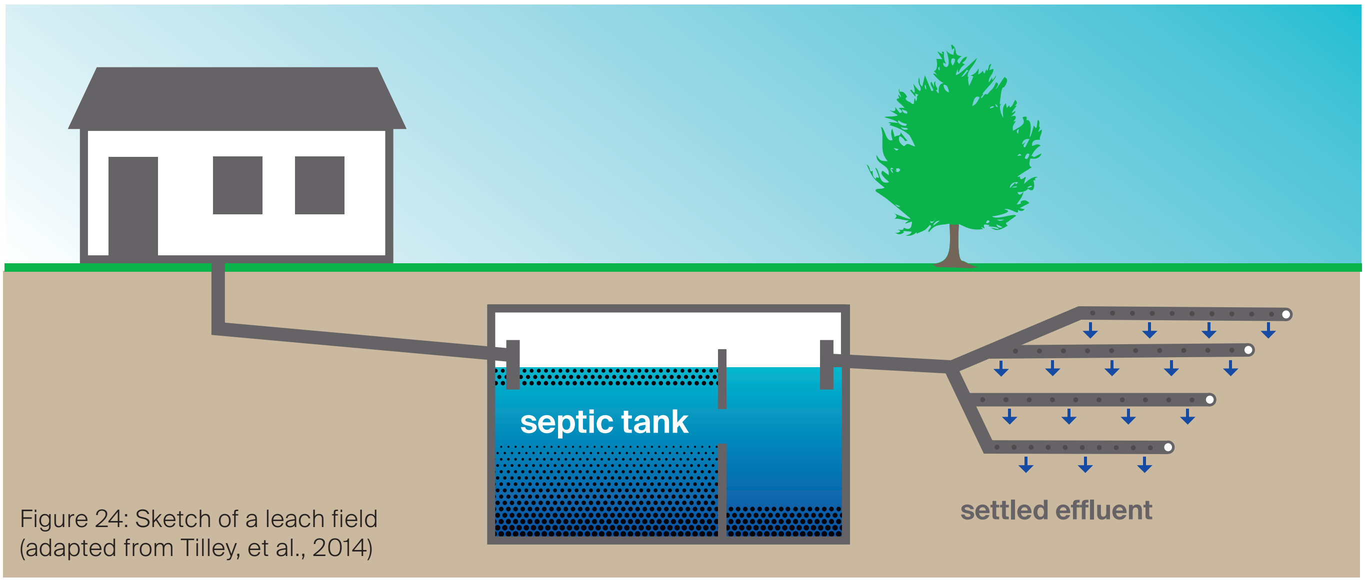


Figure 24: Sketch of a leach field (adapted from Tilley, et al., 2014)

4.4.1.2 Discharge to the ground: Leach fields using French Drains

Water can be discharged into the ground. Groundwater recharge is increasing in popularity as groundwater resources deplete and as saltwater intrusion becomes a greater threat to coastal communities. Although the soil is known to act as a filter for a variety of contaminants, groundwater recharge should not be viewed as a treatment method. Once an aquifer is contaminated, it is next to impossible to reclaim it. Groundwater recharge is most appropriate for areas that are at risk of saltwater intrusion or aquifers that have a long retention time.

A leach field, or drainage field, is a network of perforated pipes (French Drains) that are laid in underground gravel-filled trenches to dissipate the effluent from a water-based small-scale wastewater treatment system used to infiltrate water. Each trench is 0.3 to 1.5m deep and 0.3 to 1m wide. The bottom of each trench is filled with about 15cm of clean rock and a perforated distribution pipe is laid on top. More rock is placed to cover the pipe. A layer of geotextile fabric is placed on the rock layer to prevent small particles from plugging the pipe. A final layer of sand and/or topsoil covers the fabric and fills the trench to the ground level. The pipe should be placed at least 15cm beneath the surface to prevent effluent from surfacing. The trenches should be dug no longer than 20m in length and at least 1 to 2m apart. A leach field should be laid out such that it will not lead to contamination of freshwater sources and not interfere with a future sewer connection.

Leach fields require a large area and unsaturated soil with good absorptive capacity to effectively dissipate the effluent. Due to potential oversaturation of the soil, leach fields are not appropriate for dense urban areas. Trees and deep-rooted plants should be kept away from the leach field as their roots can crack and disturb the tile bed. Nevertheless, if well designed a French Drain can also be applied as a distribution system for irrigation (see Chapter 4.4.1.1).

Since the technology is underground and requires little attention, users will rarely come in contact with the effluent and, therefore, it has no health risk. The leach field must be kept as far away as possible (at least 30 m) from any potential potable water source to avoid contamination.

Pros	Cons
✓ Can be used for the combined treatment and disposal/reuse of effluent	⊗ Requires expert design and construction
✓ Has a long lifespan (depending on local conditions)	⊗ Requires a large area
✓ Low maintenance requirements	⊗ Primary treatment is required to prevent clogging
✓ Relatively low capital costs; low operating costs	⊗ May negatively affect soil and groundwater properties

Table 19: Pros and cons of discharging treated wastewater using French Drains

4.4.1.3 Discharge to the ground: Soak Pits

A soak pit, also known as a soak-away or a leach pit, is a covered, porous-walled chamber that allows water to slowly soak into the ground. Effluent from a collection and storage/treatment or (semi-) centralised treatment technology is discharged to the underground chamber from which it infiltrates into the surrounding soil. As wastewater (greywater or blackwater after primary treatment) percolates through the soil from the soak pit, small particles are filtered out by the soil matrix and organics are digested by microorganisms. Thus, soak pits are best suited for soil with good absorptive properties; clay, hard-packed or rocky soil is not appropriate.

A soak pit does not provide adequate treatment for raw wastewater, and the pit will quickly clog. It should only be used for discharging blackwater or greywater that has been through at least primary treatment. Soak pits are appropriate for rural and peri-urban settlements. They depend on soil with a sufficient absorptive capacity. They are not appropriate for areas prone to flooding or that have high groundwater tables.

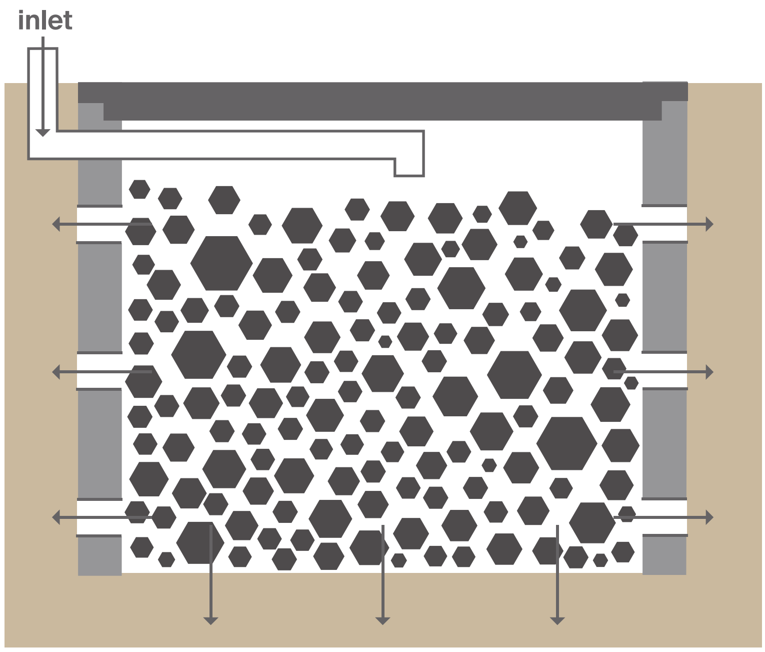


Figure 25: Section view of a soak pit
(Tilley, et al., 2014)

Pros	Cons
✓ Can be built and repaired with locally available materials	⊗ Primary treatment is required to prevent clogging
✓ Technique is simple to apply for all users	⊗ May negatively affect soil and groundwater properties
✓ Small land area required	
✓ Low capital and operating costs	

Table 20: Pros and cons of soak pits

4.4.1.4 Discharge into surface waterbodies

Treated effluent and/or stormwater can be directly discharged into receiving surface waterbodies such as rivers, oceans, lakes and ponds. The use of the surface waterbody, whether it is for industry, recreation or natural ecosystems, will determine the quality and quantity of treated wastewater that can be introduced without harmful effects.

The adequacy of discharge into a waterbody will entirely depend on the local environmental conditions and regulations. Generally, discharge to a waterbody is only appropriate when there is a safe distance between the discharge point and the next closest point of use. A permit must be required for water discharge into any waterbody (surface or groundwater).

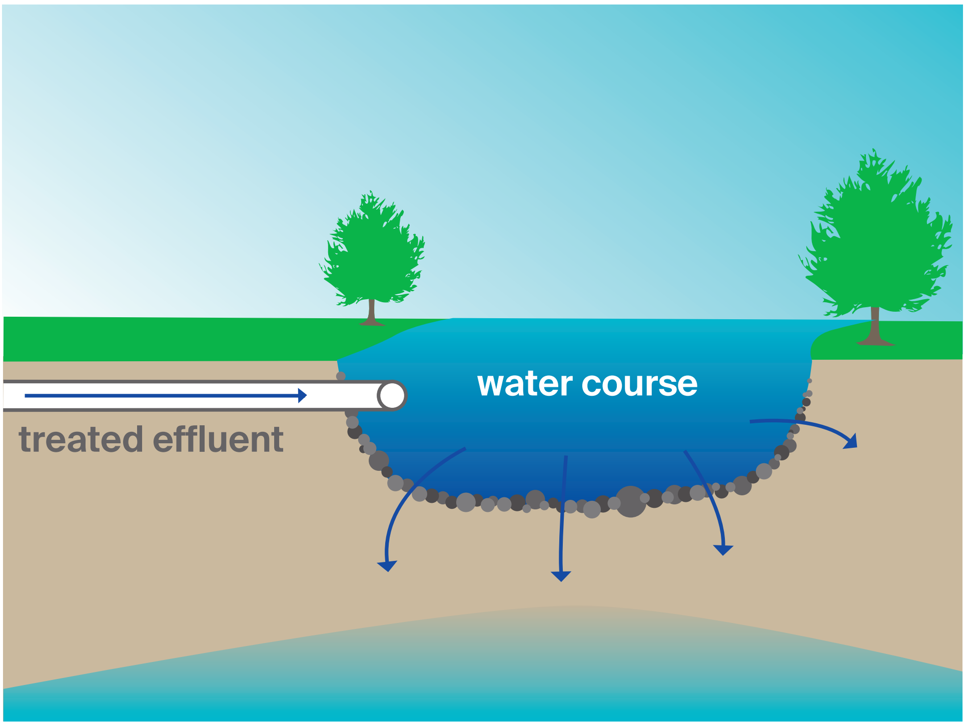


Figure 26: Sketch of treated water discharge into a waterbody (adapted from Tilley, et al., 2014)

Pros	Cons
May provide a 'drought-proof' water supply (from groundwater) due to infiltration from the surface waterbody	Discharge of nutrients and micro-pollutants may affect natural waterbodies and/or drinking water
May increase productivity of waterbodies by maintaining constant water levels	Introduction of pollutants may have long-term impacts
	May negatively affect soil and groundwater properties

Table 21: Pros and cons of discharge of treated wastewater into surface waterbodies

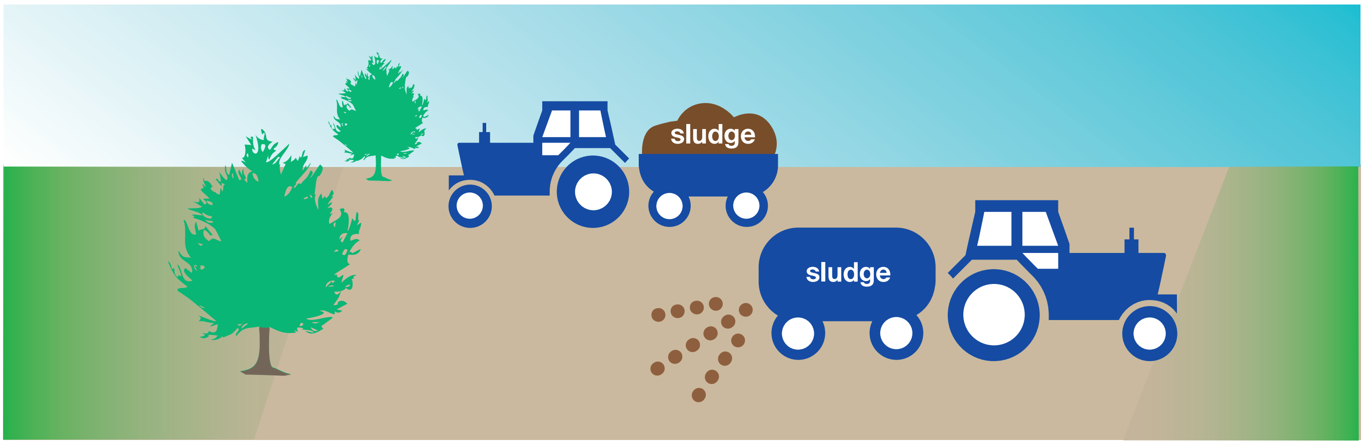


Figure 27: Application of treated sludge in agriculture (adapted from Tilley, et al., 2014)

4.4.2 Treated Sludge

Depending on the treatment type and quality, digested or stabilised sludge can be applied to public or private lands for landscaping or agriculture. Sludge that has been treated can be used in agriculture, home gardening, forestry, sod and turf growing, landscaping, parks, golf courses, mine reclamation, as a dump cover, or for erosion control. Although sludge has lower nitrogen, phosphorus and potassium levels than commercial fertilisers, it can be an effective substitute for a significant portion of chemical fertiliser. Additionally, treated sludge has been found to have properties superior to those of commercial fertilisers, such as bulking and water retention properties, and the slow, steady release of nutrients.

Although sludge is sometimes criticised for containing potentially high levels of metals or contaminants, commercial fertilisers are also contaminated to varying degrees, most likely with cadmium or other heavy metals. Sludge that originates at large-scale wastewater treatment plants is more likely to be contaminated since it receives industrial and domestic chemicals as well as surface water run-off which may contain hydrocarbons and metals. Application of sludge on land may be less expensive than disposal. Depending on the source of the sludge and on the treatment method, sludge can be treated to a level where it is generally safe and no longer generates significant odour or vector problems.

Pros	Cons
✓ Can reduce the use of chemical fertilisers and improve the water-holding capacity of soil	⊗ Odours may be noticeable, depending on prior treatment
✓ Can accelerate reforestation	⊗ May require special spreading equipment
✓ Can reduce erosion	⊗ May pose public health risks, depending on its quality and application
✓ Low costs	⊗ Micro-pollutants may accumulate in the soil and contaminate groundwater
	⊗ Social acceptance may be low in some areas

Table 22: Pros and cons of the application of treated sludge in agriculture

4.4.3 Biogas

In principal, biogas can be used like other fuel gas. When produced in household-level Biogas Settler, it is most suitable for cooking. Additionally, electricity generation is a valuable option, but only when the biogas is produced in large anaerobic settlers.

The biogas is trapped, pressurised and distributed to the consumer. Household energy demand varies greatly and is influenced by cooking and eating habits (i.e. hard grains and maize may require substantial cooking times and therefore more energy compared to cooking fresh vegetables and meat). Biogas has an average methane content of 55-75%. As a rule of thumb, 1m^3 biogas is equivalent to approximately 6kWh of electric energy and can substitute about 5kg of firewood or 0.6l of diesel fuel.

The calorific efficiency of using biogas is 55% in stoves, 24% in engines, but only 3% in lamps. Thus, the best use of biogas is heat production: for cooking in homes and canteens or for drying and heating as part of industrial processes. Biogas burners can be made from converted LPG burners. The minimum amount of biogas required for a household kitchen (~5-8 people) is approximately 1m^3/d. Producing this amount of biogas requires domestic wastewater from about 8-10 households or 15kg of organic waste or the manure from 5 pigs or 1-2 cows. These numbers give only a rough approximation of what is needed to provide a household with cooking energy and can widely differ depending on many parameters.

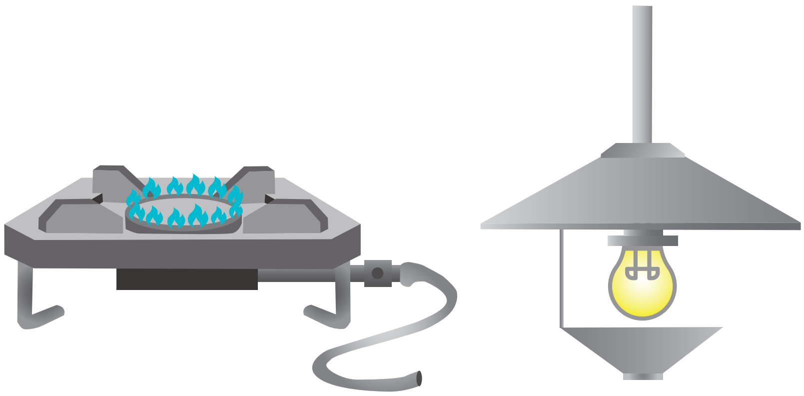


Figure 28: Examples of biogas appliances (adapted from Tilley, et al., 2014)

Findings from M&E activities 2017 - see Page 38

Only 2 of 7 systems with a Biogas Settler had functioning appliances. None burned off unused biogas.

Pros	Cons
✓ Free, renewable and off-grid source of energy	⊗ May not fulfil total energy requirements
✓ Reduction of indoor air pollution and deforestation (if firewood or coal was previously used)	⊗ Cannot replace all types of energy
	⊗ Cannot be easily stored (low energy density per volume) and thus needs to be continuously used
	⊗ M&E results show that a significant percentage of systems is not operational, or the produced biogas is not utilised
	⊗ The emission of unburned biogas has a negative impact on the climate

Table 23: Pros and cons of biogas combustion

4.5 DEWATS Module Combinations

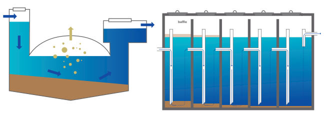
This chapter aims to provide examples of possible combinations and configurations of DEWATS modules, including their treatment performance and basic requirements (e.g. land area, capital costs and operation costs). Globally, 70% of DEWATS include a settler, 38% a Biogas Settler, 38% an ABR, 25% an AF and 18% a PGF. The most popular combination of modules includes a settler and an ABR, in some cases also followed by an AF. All of the treatment performances and requirements mentioned below are approximations, dependent on the context. Therefore, any information provided below shall not be used for detailed project planning.

Findings from M&E activities 2017
- see Page 38

Average treatment performance of a modular combination of ABR, AF and CW:

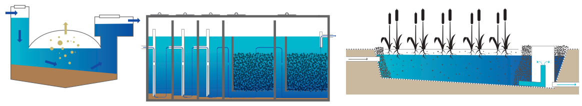
	Inlet	Outlet
SS [mg/l]	3.6	0.1
COD [mg/l]	382.8	87.5
BOD [mg/l]	160	75.5
TSS [mg/l]	35	20
	(6 Systems)	

Biogas Settler and ABR



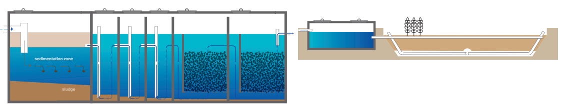
	Inlet	Outlet	Requirement
TSS [mg/l]	350	250	Area: 0.1m²/cap
COD [mg/l]	1,400	350	CAPEX: 20USD/cap.
PO_4-P [mg/l]	15	15	OPEX: 5USD/cap*a
NH_4-N [mg/l]	20	85	
FC [No/100ml]	10^{12}	10^{7}	

Biogas Settler, ABR, AF and PGF



	Inlet	Outlet	Requirement
TSS [mg/l]	350	30	Area: 0.25-0.6m²/cap.
COD [mg/l]	1,400	100	CAPEX: 80-120USD/cap.
PO_4-P [mg/l]	15	10	OPEX: 5-10USD/cap*a
NH_4-N [mg/l]	20	70	
FC [No/100ml]	10^{12}	10^{5}	

Septic tank, ABR, AF, Vertical Sand Filter and UV



	Inlet	Outlet	Requirement
TSS [mg/l]	350	25	Area: 1.0m²/cap.
COD [mg/l]	1,400	60	CAPEX: 150-200USD/cap.
PO_4-P [mg/l]	15	6	OPEX: 8-15USD/cap*a
NH_4-N [mg/l]	20	10	
FC [No/100ml]	10^{12}	10^{3}	

BORDA Tanzania Office DEWATS, Mikocheni, Dar es Salaam.
On-site wastewater management system (designed by BORDA Tanzania) with Biogas Settler, ABR, PGF, polishing pond, and french-drain. The system produces biogas for cooking purposes, and treated wastewater is used to irrigate the office compound.

5 Phases of a DEWATS Project

The activities conducted in the process of implementing and operating a DEWATS are laid out in the QMS. The QMS include Standard Operating Procedures (SOPs). A general overview of the DEWATS implementation and operation process is presented in the flowchart below (Figure 28). The SOPs distinguish between projects for single household connections, institutional systems, and cluster or community systems.

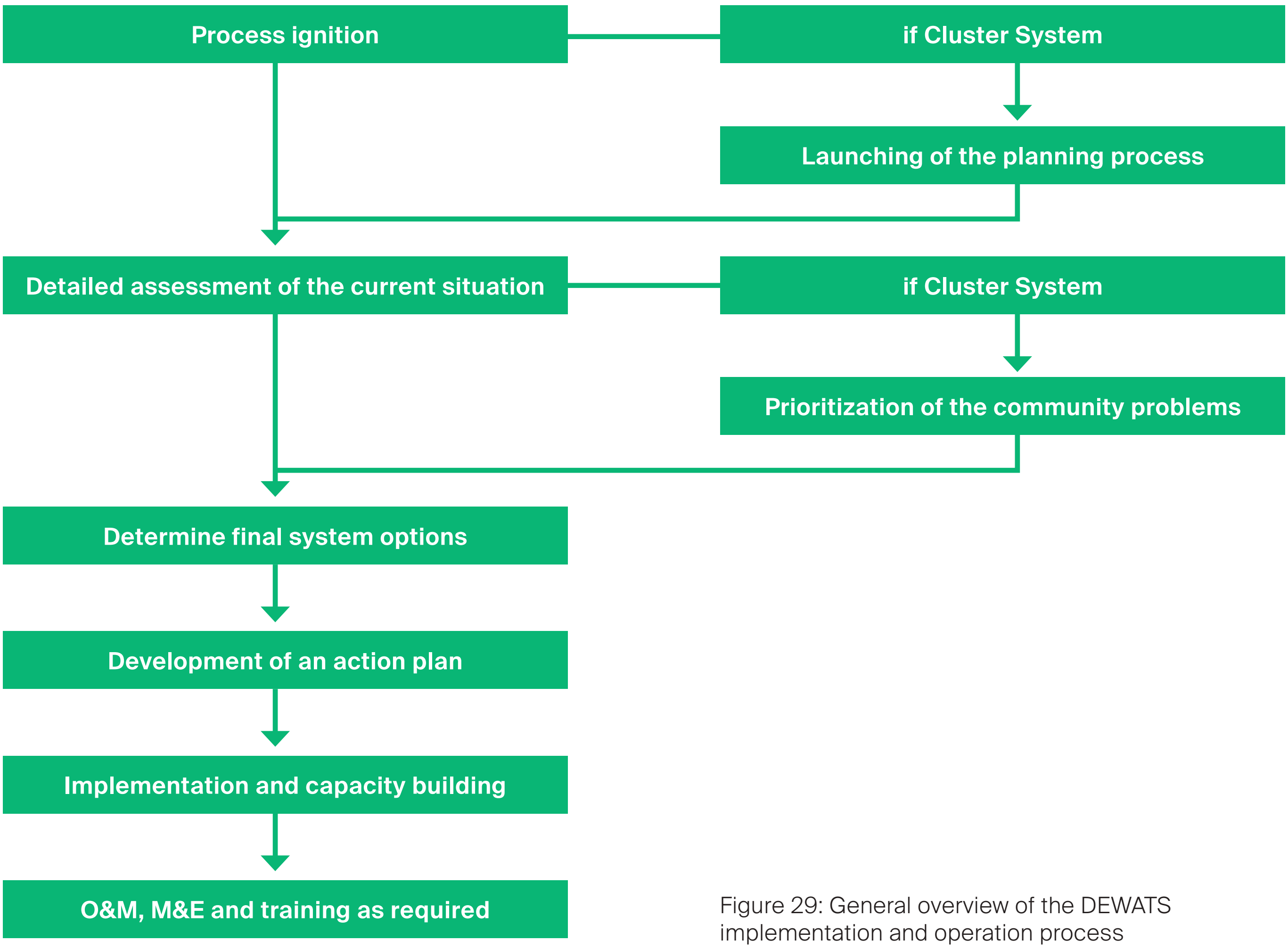


Figure 29: General overview of the DEWATS implementation and operation process

For detailed information on the planning and implementation procedures of DEWATS – in addition to the abstracts mentioned below – the following documents should be consulted (see Chapter 4 for references on DEWATS design, which are not repeated here):

1. Parkinson, J., Lüthi, C., & Walther, D. (2014). Sanitation 21: A Planning Framework for Improving City-Wide Sanitation Services. IWA; Eawag-Sandec; GIZ.
2. Lüthi, C., Morel, A., Tilley, E., & Ulrich, L. (2011). Community-Led Urban Environmental Sanitation Planning (CLUES). Eawag-Sandec, WSSCC, UN-HABITAT.
3. Strande, L., Ronteltap, M., & Brdjanovic, D. (Eds.) (2014). Faecal sludge management: Systems approach for implementation and operation, Faecal Sludge Management: Systems Approach for Implementation and Operation. IWA.
4. ESCAP; UN-Habitat; AIT. (2015). Policy Guidance Manual On Wastewater Management: With A Special Emphasis On Decentralized Wastewater Treatment Systems .
5. Policy Guidance Manual On Wastewater Management: With A Special Emphasis On Decentralized Wastewater Treatment Systems; ESCAP, UN-Habitat & AIT; 2015
6. McConville, J. (2010). Unpacking Sanitation Planning - Comparing Theory and Practice. Chalmers University of Technology.

Sanitation planning requires understanding and matching stakeholders' interests, needs and constraints in an enabling environment. Common reasons for failure of sanitation projects are the implementation of infrastructure without:

- Consulting the main stakeholders
- Planning adequate O&M and financial schemes
- The availability of adequate skills
- Sufficient organisational capacity

Demand for sanitation is often minimal, particularly in low- and middle-income countries, so fostering a demand for wastewater treatment can be seen as the first step in the chain of implementing sanitation services. Interventions to increase household and community demand for sanitation typically include:

- Promotion of the benefits of sanitation
- Marketing of specific sanitation products
- Hygiene promotion
- Social development
- Mobilisation (often linked to the formation of community groups in urban areas)
- Community triggering

Several approaches have been developed to help planners in defining appropriate management strategies, which differ according to the scale and location of implementation (e.g. households with single connections, institutions, communities with 'cluster' systems or whole cities), the planning perspective (bottom-up vs. top-down) and the funding source (development partner or national resources). The planning model needs to encompass the entire system and all project phases, including participatory planning stages. Integrated planning needs to link different levels, as the management needs to be organised city-wide – by the Local Government Authority (LGA) in a close relationship with the users and operators.

The City Sanitation Planning (CSP) approach for Dar es Salaam was created in response to the need for a simple, fast and flexible tool for determining "which sanitation solutions go where". All information related to this can be found here: www.citysanitationplanning.org

5.1.1 Launching of the planning process

Groundwork should start with the identification and preliminary characterisation of the stakeholders and the relationships between them. To initiate the planning process, it is recommended that key stakeholders are invited to a launch workshop, where all participants can develop a common understanding of the situation in the intervention area, as well as agree on the process of how to solve the problems. This common understanding, which encompasses particular group dynamics and stakeholders' interests, is very important and can never be assumed. Experience shows that many stakeholders, especially local authorities, are usually not aware of the situation on the ground. For this reason, it is recommended that a field visit for all stakeholders is included as part of the launch workshop in order to raise awareness.

Government and utility representatives should be involved in the launch workshop, in order to avoid potential conflicts with existing policies, regulations and municipal by-laws. Their participation will also help clarify the available support and skills at municipal or district levels. This workshop should also aim at:

- Creating awareness amongst decision-makers of legal requirements, required resources and institutional backing
- Developing an enabling environment, and getting different stakeholders and authorities to offer their competencies
- Launching a process for the provision of financial and human resources at different government levels

Once all stakeholders are sensitised to the sanitation reality and aware of the project objectives, it will be much easier to collect information for the feasibility studies. It is often not easy to access data, especially where 'information is power', and it is important to make key contacts and build trust through transparency. At the end of this phase, the process leaders should have a clear idea of feasible options and key stakeholders.

The detailed assessment of the local context and the current situation shall include the following:

- Detailed stakeholder map
- Status of the enabling environment (institutional setup, government support, financial arrangements, socio-cultural acceptance, legal framework, skills and capacities)
- Sanitation practices, needs and reuse interests
- Identification of potential sites
- SWOT analysis of the project

The launching activities are especially relevant for the implementation of community wastewater treatment solutions as clusters systems.

5.1.2 Feasibility Study

The main result of the feasibility study is the identification of viable system options. This phase starts with an in-depth analysis of the current situation, such as the quantification and characterisation of wastewater flows, as a prerequisite for the selection and design of technical options. A characterisation and selection of sites should also be made as this may influence the viability of different technical options. The concept development and detailed analysis conducted during the feasibility study includes:

- Characterisation and quantification of wastewater
- Site selection
- Technology selection
- Institutional setups and financial flow models
- Cost-recovery mechanisms and cost-benefit analysis for the system's lifecycle
- Several system scenarios
- Iterative optimisation loops of scenarios with stakeholders

Based on this and the information collected during the launching of the planning process, technical, organisational and financial options can be preselected, studied in depth, and discussed in a participatory manner. It is crucial to recognise that sanitation planning is not about single 'stand-alone' technologies. Rather, it is about the combination of services and how different factors correlate. Each scenario should be evaluated in detail as follows:

- Requirements for technology combinations, and their pros and cons (e.g. O&M requirements)
- Management and institutional setups,

roles and responsibilities, and contractual arrangements
- Capital and operation costs, financial mechanisms and estimated budget
- Capacity building and training needs
- Environmental impact

Each scenario should be examined in conjunction with the requirements for an enabling environment. If an aspect of the scenario does not meet the requirements, it should be either adapted or activities should be carried out to create the missing conditions. The strengths, limitations and implications of the preselected systems should be assessed. It is important to involve the key stakeholders in the evaluation, as they will have to take over the roles and responsibilities of the system. It is also important that stakeholders are properly informed.

At the end of the phase, it is recommended to organise a validation workshop with all the key stakeholders, in order to publicly and officially present and validate the decisions taken. Any disagreement from important and/or influential stakeholders should be cleared before the public workshop. The feasibility study report should state clearly who the main stakeholders for the next phase will be. For this reason, it is recommended at this point to reassess the interest and influence of the key stakeholders according to the validated options.

5.1.3 Site and Technology Selection

The first step in the technical planning of small-scale DEWATS is the site selection. The wrong site location is likely to impact adversely on the long-term sustainability of the service. Politicians, landowners, town planners, residents, operators and users are all likely to have differing priorities and requirements as to where the infrastructure should be located. Decisions may be heavily biased. Political pressure for available space may override what is considered appropriate for the users and host community. Potential and existing sites need to be identified through discussions and site visits with key stakeholders.

As such, the most appropriate technology is the technology that is economically affordable, environmentally sustainable and socially acceptable. The decision regarding the wastewater treatment process to be adopted should be derived from a balance of:

- Technical feasibility (adequate to treatment objective)
- Economic viability/affordability for communities
- Social and cultural acceptance
- Legal aspects
- Environmental sustainability

There are no generalised formulas for the optimal solution to site and technology selection. To structure the decision-making process, criteria and weightings can be attributed to the various factors and analysed in a Multiple Criteria Decision Analysis (MCDA), so that the selection really leads to the most appropriate alternatives. Experience and common sense when attributing the relative importance of each technical aspect are essential. While the economic side is fundamental, it needs to be remembered that the best option is not always the one that simply presents the lowest cost in economic–financial studies. Table 22 lists the main factors that influence the site and technology selection.

5.1.4 Flood Protection

The planning and design (including the site and technology selection) of DEWATS should take into account protection against flooding. Every treatment plant must be positioned so that it is not subject to flooding or is otherwise protected from flooding, and has all-weather road access. The treatment process units should be located at an elevation higher than the 100-year flood level or otherwise be adequately protected against 100-year flood damage. Newly constructed plants should remain fully operational during a 100-year flood event.

Influencing Factor	S	T	Influencing Factor	S	T
Land			Social / Cultural		
Availability of space / land	✓	✓	User preferences / social and cultural acceptance	✓	✓
Soil and groundwater characteristics	✓	✓	Community's willingness and ability to pay and connect to wastewater treatment system	✓	✓
Distance between place of wastewater generation and treatment plant	✓	✓	Skills and capacity for implementation and operation	✓	✓
Topography	✓	✓	Nuisance control	✓	✓
Flooding risk	✓	✓	Process Related		
Technology / Material / Infrastructure Available			Desired output products	✓	✓
Availability and condition of existing sanitation technology: sewer connections and current wastewater management systems	✓	✓	Management considerations	✓	✓
Local availability and cost of materials	✓	✓	Environment and public health impact	✓	✓
Robustness of technology that is needed and available	✓	✓	Sludge generation and quality	✓	✓
Construction requirements	✓	✓	O&M requirements	✓	✓
Road access	✓	✓	Health and safety	✓	✓
Availability of electricity	✓	✓	Government / NGO support		
Finance			Programmes or strategies related to sanitation	✓	✓
Financial resources	✓	✓	Acts, regulations and standards	✓	✓
O&M costs	✓	✓	Availability of Data		
Capital costs	✓	✓	Maps, statistics, surveys, etc.	✓	✓
Expenses for wastewater (tariffs)	✓	✓	Water and Wastewater		
Population			Wastewater characteristics: Volume and quality	✓	✓
Population and households in coverage area	✓	✓	Water availability, reliability of supply and usage patterns	✓	✓
Number of enterprises and institutions in coverage area	✓	✓	Effluent standards for discharge and reuse	✓	✓

Table 24: Factors influencing the selection of the site (S) and the technologies (T)

5.1.5 Detailed Project Development – Action Planning

Based on the options validated in the previous phases, an action plan can be developed. This action plan should include the following items:

- Detailed design and drawings of the treatment system
- Bills of quantities (BOQs) and procurement plans
- Detailed definition of roles and responsibilities in the new system and terms of references
- O&M management plan with a clear allocation of costs, responsibilities and training needs
- Written agreement between stakeholders, securing financial and institutional mechanisms
- Strategy for control (M&E) and enforcement, including the frequency of control, the means needed and sanctions
- Planning of capacity building and identification of human resource needs and options for job creation
- Definition of contracts and bidding processes
- M&E strategy for the implementation phase
- Timeline for implementation with distinct phases, milestones and an itemised implementation budget

Unsatisfactory O&M is often a cause of failure in wastewater treatment projects and thus the O&M management plan is particularly important. The whole action plan should be presented, discussed and validated in a workshop with all the key stakeholders. Key stakeholders should be reassessed according to the definition of roles and responsibilities. Several workshops may be needed until a consensus is reached.

During this project phase all legally required permits need to be obtained. In addition, an environmental impact assessment should be conducted at this stage, if required.

5.2 Implementation

This phase is mainly about translating the action plan into work packages that will ultimately become contracts for implementing the DEWATS. Several arrangements are applicable for the implementation of the plans, the most common being through private sector contractors based on competitive tendering and bidding procedures.

In parallel to this process, stakeholders should be organised according to the action plan. If needed, the legal and regulatory framework should be adapted or appended with by-laws. According to the identified needs, capacity building should be provided for a smooth transfer of roles and responsibilities. The public should also be properly informed about or even involved in the intervention and the improvements being carried out in their municipality. This will increase awareness and a sense of ownership shared by the public and the authorities. Before the inauguration of the treatment plant, the strengths, weaknesses and training needs of key stakeholders should be reassessed. At this point there is still time to organise further training and adapt the capacity-building strategy.

5.3 Handover and start-up

After finalising the construction work and ensuring all modules are watertight, the whole system–including infrastructure and stakeholders–requires a start-up phase for acclimatisation. During this phase, all responsibilities are handed over from the contractors and planners to the owner of the system. The management and the operator take over all tasks and start the operation. The stakeholders will need some time to get used to their new roles and responsibilities, and some adjustments will certainly be needed over the first few months of operations. Support from the project team is of particular importance during this phase. During this period all relevant documents are handed over to the owner of the plant. Although the system is operational, the consultant is still present to assist in the start-up processes and to respond to challenges. Within the first 6 months of operation, the contractors are generally responsible for damages (defect liability period). Finally, an inauguration ceremony can be organised. Such an event can generate public interest and increase awareness, and can also have a positive influence on institutional decision makers.

Effluent concentrations will be high during the start-up phase of the reactors. The average start-up period (defined as the period before stable effluent concentrations can be

During M&E activities, it was observed that only 8 of 21 operators had received adequate training, and in most cases there were insufficient tools for O&M. Due to these findings, the following is suggested:

- Improved and more frequent training should be provided for operators
- O&M tools must be provided on-site and activities like removing blockages and repairing broken toilets must be carried out regularly to ensure an adequate service for the users

expected) of DEWATS reactors is estimated at three to six months. The treatment performance depends on the availability of active bacterial mass in the reactors. Inoculation of the Biogas Settler, the ABR and the AF with old sludge (e.g. from septic tanks) shortens the start-up period. In principle, it is advantageous to start with only a quarter of the daily flow and with slightly stronger wastewater. The loading rate should increase slowly over three months. This provides bacteria with enough time to multiply before solids are washed out. Starting with the full hydraulic load from the beginning will severely delay maturation.

In CWs and PGFs, young plant seedlings may not grow on wastewater. Therefore, it is advisable to start feeding the system with plenty of fresh water and to let the pollution load increase parallel to plant growth. When plants are under full load, the outlet level is adjusted according to flow. Water should not stand on the surface of the PGF near the inlet. If this happens, the swivel arm at the outlet should be lowered.

5.4 Operation and Maintenance (O&M)

Challenges in O&M are one of the main reasons for the failure of DEWATS. The feasibility of an adequate O&M is an effect of the quality of planning, design and implementation. “Operation” refers to all the activities that are required to ensure that a DEWATS delivers treatment services as designed and “maintenance” refers to all the activities that ensure long-term operation of equipment and infrastructure. Having skilled workers perform these tasks in a timely manner and in accordance with best practices will maximise the efficiency of the DEWATS and ensure its long-term performance.

Financial, technical and managerial inputs are needed to ensure the continuous operation of even the simplest of DEWATS. The procedures that establish how the treatment facility and equipment should be utilised are documented in several O&M plans, monitoring programmes, reports, log books, and health and safety plans, which outline the step-by-step tasks that employees are required to carry out in order to ensure the long-term functioning of the DEWATS. The O&M management plan that is developed during the detailed project planning phase—and that must be carefully followed—should include:

- O&M tasks encompassing routine operations, preventive maintenance (inspection and periodic maintenance) and reactive maintenance (repairs)
- Tools and equipment lists, with descriptions
- Safety procedures, rules and equipment
- O&M costs
- Administrative tasks including bookkeeping, collecting fees, annual budgeting, paying employees and dealing with complaints
- Monitoring and sampling procedures
- Reporting procedures
- Responsibilities of all parties concerned
- Training activities for responsible persons

This chapter is based on content extracted from the publications listed below. For further detailed information on the O&M of DEWATS, these documents should be consulted:

1. Simwambi, A., Tembo, M., & Wolter, D. (2016). DEWATS Engineers Operations, Maintenance & Management Manual. WAZASA; BORDA.
2. BORDA. (2008). Operational Tasks for the Upkeep of Decentralised Wastewater Treatment System (DEWATS). Bangalore, India: CDD Society.
3. Leitao, R., van Haandel, A., Zeeman, G., & Lettinga, G. (2006). 3. The effects of operational and environmental variations on anaerobic wastewater treatment systems: A review. Bioresource Technology, 1105 – 1118.

5.4.1 Operation

DEWATS require clear operational procedures. The operational procedures should take all context-dependent variables (e.g. wastewater characteristics, local legislation, climate) into account. The O&M plans should include a customised operation manual containing the following information:

- The engineering drawings and DEWATS specifications
- The responsible person for each task
- The frequency of each activity
- The operational procedures and tools required to perform each task
- The chemicals and other consumables required, along with their suppliers, storage and application
- The safety measures required
- The organisational structure, distribution and management of administrative responsibilities
- The information that is to be monitored and recorded
- Emergency and non-routine operational requirements

All procedures provided in the operation manual must be adapted in order to ensure conformance with local laws and standards. The performance and service lifespan of the DEWATS also largely relies on basic operational tasks done at household facilities such as toilets, sewer lines, manholes and biogas stoves. Operation of the DEWATS also includes tasks such as proper toilet and biogas use. A summary of the operational tasks and their frequencies is presented in Table 23.

Operational tasks

Table 25: Operational tasks

Facility	Task	Frequency
Multiple Modules	Removal of solid waste from all manholes, reactors, inlets, outlets and sewers	Monthly, and more frequently when large quantities are observed
	Removal of scum and grease from all manholes, reactors, grease traps, inlets and outlets	Monthly, and when large quantities are observed, depending on wastewater characteristics
	Further treatment and disposal of solid wastes	Whenever removed from the treatment units
	Oiling of movable parts such as locks, doors and handles of manhole covers	Monthly
	Cleaning and care of the site (e.g. management of vegetation)	Weekly
	Extraction and further treatment and/or disposal/reuse of end products	Depends on reuse/disposal
	Management and documentation of material stock	Weekly
	Washing particle filter	Once in 6 months, depending on wastewater characteristics
Screens, Grit Chamber and Grease Trap	Cleaning of solid waste screens	Daily
	Removal of grit	Daily
	Removal of oil, grease and other floatables	Daily
	Treatment and/or disposal of screening material and other removed material	With removal (daily)
Biogas Settler and Applications	Poking and stirring the floating organic material into the water	Weekly, and depending on feeding material
	In case of feeding with organic solid waste, poke and stir	Each feeding time
	Releasing water from water trap(s)	Weekly
	Cleaning of biogas burners	Monthly
	Gas utilisation or disposal (combustion)	Continuously (daily)
CW / PGF	Management of vegetation	Monthly
	Removing leaves, soil and solid waste accumulated at the surface of the filter	Monthly
Vertical Sand Filter	Removing leaves, soil and solid waste accumulated at the surface of the filter	Monthly
Pond System	Weeding, removal of leaves and other litter	Monthly
Effluent distribution system	Control of water flow through control chambers	Monthly
Sludge Drying Bed	Preparation of drying beds and channels	With desludging
	Management of vegetation	Monthly
	Filling the bed(s) with sludge	As desludging
	Control sludge flow to and the distribution of sludge in the drying bed	As desludging
	Cleaning of sludge flow channels	As desludging
	Monitoring of drying process	Weekly
	Packaging the dried soil conditioner, transportation and storage	On demand
	Direct utilisation of soil conditioner, organisation of transport to municipal landfill site or sale to private company for reuse	On demand

5.4.2 Maintenance

There are two main types of maintenance activities: preventative maintenance and reactive maintenance. Preventive maintenance includes all routine or scheduled work activities required to keep the installations in conditions so that the operations can be done successfully. Reactive maintenance includes all work activities aimed to restore the installations or equipment to its normal operating conditions after occurred failures or breakdowns. Maintenance tasks can be performed by operators or specialised personnel, depending on the capacities of the operator and the O&M strategy. It is important that the tasks and the people in charge are clearly defined and documented for each wastewater treatment system. Well-planned preventative maintenance programmes can often minimise reactive interventions to emergency situations, which are frequently costlier and more complex. Component breakdowns at DEWATS can result in wider system failure. Therefore, each component at the DEWATS has specific preventative maintenance requirements that need to be described in detail in a maintenance plan including the tasks, frequency of actions, and step-by-step procedures for accomplishing the tasks, also including inspections. Physical inspections conducted at scheduled intervals are important, where specific indicators such as water flow in control chambers, cracked wires, broken concrete, and discoloured and brittle pipes are checked in order to identify preventative maintenance needs. A list of regular inspection tasks is provided in Table 24.

The maintenance plan should be guided by the local context and the asset-specific monitoring information. Coastal DEWATS, for example, may require more frequent painting and corrosion control due to the higher salt content of the air compared to the same plant located inland. Maintenance task details include the equipment, tools, supplies and time needed to accomplish the task. Once completed, the task details should be entered into the equipment maintenance log book or database, along with any difficulties encountered. A list of regular maintenance tasks is provided in Table 25.

If a DEWATS is well operated and preventive maintenance measures are diligently executed, the likelihood of system malfunctions decreases to a minimum. However, since malfunctions occur in every operational system, they can also occur in DEWATS. Once they are noticed, malfunctions or indications of failures should never be neglected or considered insignificant. Systematic troubleshooting shall be conducted to locate and evaluate the causes and permanently resolve failures as quickly as possible to restore the system to a well-functioning condition. Typical malfunctions of DEWATS and their causes are listed in Table 26.

Regular inspection tasks

Table 26: Regular inspection tasks

Facility	Task	Frequency
Multiple Modules	Visual monitoring of the influent and effluent water quality (e.g. turbidity, colour, smell)	Weekly
	Inspect treatment modules for structural damages	Annually
	Inspect and open manhole covers, keep them accessible at all times	Monthly
	Inspect water levels in reactors	Weekly
	Inspect for free wastewater flow in sewer system, inlet, outlet and at distribution channels of all DEWATS Modules	Monthly
	Inspect pumps, remove accumulated leaves, sludge or other solids	Weekly
Biogas Settler	Inspect the gas pipelines for leakage	Once in 3 months
	Check the gas volume and pressure	Once in 3 months

Regular maintenance tasks

Table 27: Regular maintenance tasks

Facility	Task	Frequency
Multiple Modules	Repair manhole covers	Damaged
	Repair doors, gates and locks	Damaged
	Repair electricity supply and lights	Damaged
	Repair drinking water supply valves and tabs	Leaking, blocked, severely corroded, etc.
Settler	Control sludge level, and desludge if needed	Annually
Septic Tank	Control sludge level, and desludge if needed	Annually
Biogas Settler	Control sediment sludge consistency and level, and desludge if needed	Annually
ABR	Control sludge level, and desludge if needed	Annually
AF	Control sludge level, and desludge if needed	Annually
	Clean and backwash the filter material	Clogged
CW / PGF	Optimise/control the water distribution and level, check the position of the swivel pipe	Monthly
	Clean the filter material	Clogged

Table 28: Typical malfunctions of DEWATS and their causes

Malfunction	Possible cause
Insufficient treatment of wastewater	Wrong loading: too-high concentration of contaminants or excessive inflow
	Low HRT due to excessive sludge accumulation
	Re-pollution of treated wastewater due to heavy scum accumulation in Biogas Settler or ABR
	Short-circuiting due to broken separation walls or vertical pipes in ABR or AF
	Low HRT due to excessive accumulation of matter on the filter material of the AF
	Low HRT due to excessive plant growth or low water level in PGF
	Low nutrient uptake in PGF due to inappropriate plant growth
Extrusion of water at unforeseen places (e.g. flooded PGF)	Backlogging of water due to excessive inflow
	Backlogging of water due to blockages, e.g. by solid waste
	Broken sewer line
	Brocken structure
Biogas stove mechanically damaged	Damaged fixed part (stand or burner)
	Valve too hard to turn
	Loose valve (valve turning too easy)
Insufficient biogas flame quality or odour by biogas	Excessive primary air intake
	Leakages in the piping system, stove or valves
	Clogged parts in the stove (jet, burner, nozzles or valves)
	No or little biogas production in the Biogas Settler
	Clogged piping system (water trap, pipe, gas outlet)
	Burner ports too small
	Jet too big

5.5 Management

An essential part of a well-functioning system is proper management. Since management tasks are needed during all project phases, management cannot be seen as a single project phase that is performed at one specific time. DEWATS management begins even before the plant is taken into operation. A successful implementation of a project starts with making sure that all participants accept DEWATS and consider it to be a good and useful approach. When stakeholders identify more strongly with the project, they bring a higher recognition of personal responsibility for a well-functioning system, and designated tasks are carried out as a matter of course and with more reliability.

5.5.1 Monitoring and Evaluation (M&E)

Any wastewater treatment plant should be closely monitored and evaluated on a regular basis. The results of the M&E shall be used for adjustments and continuous improvements even after commissioning. In addition, the dissemination of lessons learnt is important for supporting future developments and improvements. Monitoring of system performance should be conducted to ensure:

- Technical stability
- Satisfaction of stakeholders
- Regulation and licensing conformity
- Cost recovery and financial viability

In line with these, the following aspects shall be monitored:

- Planning and design: approval by local authorities and procurement of all legal permits (e.g. construction permit and EIA)
- Implementation: construction supervision
- Treatment performance: by the operator to control and optimise the treatment process
- Monitoring of the operator: by the management or owner of the DEWATS
- Effluent quality: by an independent monitoring body to enforce effluent standards
- The whole DEWATS project: to evaluate the effectiveness and efficiency of the project

The O&M of a DEWATS requires a detailed understanding of the treatment processes and performance requirements. This understanding should not only be based on the theoretical information concerning the treatment mechanisms and the design of the technology, but also on a treatment performance monitoring procedure that requires specific planning, infrastructure (e.g. laboratory), employees and financing. This monitoring programme should be structured to provide the operators with adequate information for continuously optimising the plant performance and to provide control over the effluent quality. In addition, an independent monitoring body shall monitor the effluent quality to enforce the effluent standards. These monitoring programmes may include a range of different methods such as:

- Visual or sensory inputs: includes visual observations of DEWATS conditions such as blockage and damage, leakages, smell and cleanness of the environment around the DEWATS
- Measurement of DEWATS effluent: includes test strips or kits that can be utilised in the field (on-site) for measuring pH, dissolved oxygen or temperature
- Laboratory testing of samples (either on-site or off-site): includes the measurement of COD, BOD, TSS, ammonia, nitrates, phosphates and FC

Monitoring is expensive and time consuming. A written monitoring plan is essential. It assists operators and other responsible persons in the collection and organisation of required, relevant and accurate data. This plan is based on the following questions:

- Why is the information required?
- What information is to be obtained?
- How and when are the data or samples collected in the field?
- Who collects them?

In addition to monitoring the treatment performance, the overall project shall also be monitored and evaluated. The tool developed for the M&E of DEWATS projects incorporate the criteria listed below, which are referred to as Statements of Change (SoC). The SoC enable holistic monitoring of all relevant aspects of a DEWATS project, not restricted to the effluent quality but rather in addition to water parameters. The following SoC, in addition to planning, design and construction considerations, are used in the current DEWATS monitoring tool:

- The sanitation service maintains or improves environmental health.
- The sanitation service improves the living conditions of communities.
- Functioning technology: The system is operating as intended.
- Functioning maintenance: The systems is maintained as intended.
- Sustaining demand: The system is available, used to capacity and acceptable.
- Effective management: There is an active and accountable management entity and operator.
- Sustainable financing: There is sufficient ongoing income to cover all short and long-term costs.

5.5.2 Documentation and Recordkeeping

All documents produced during the planning, design and implementation of the small-scale wastewater treatment system need to be properly filed and easily accessible to system managers. Effective O&M programmes for DEWATS require that accurate records are kept of all O&M activities, monitoring, and malfunctions. Operators frequently refer to records in order to identify previous operational fluctuations and periodically recurring operational problems, to review the effectiveness of mitigation measures that may have been used to correct past operating problems, and to optimise O&M procedures. These records should therefore be easily accessible to DEWATS operators.

Some examples of recordkeeping that are useful for DEWATS include:

- Information on the operation of the DEWATS including daily operating records, the operator log book, the manifest reports and the treatment unit operating data sheet
- Disaster response and emergency recovery records
- Preventative and corrective maintenance records including the equipment maintenance log books and store room supply reports
- Compliance reports including field and analytical data and correspondence from regulatory officials
- Employee records such as employee schedules, time sheets and injury reports

The type of records and the length of time for which they will be retained for a particular facility will be determined by the size of the DEWATS, the applicable regulatory requirements, and the technologies that are used. Since these records are tools that can be used by employees to assist in the day to day operation of the facility, a summary of the information should be used to optimise the O&M plan, and also in the planning of any expansion of the DEWATS or in the design of new DEWATS.

5.5.3 Plant Security and Safety

DEWATS are critical infrastructures and must therefore be secured from unauthorised entry and vandalism by fencing off facilities and employing security staff. Managers of DEWATS can also create a culture of security by enacting the following guidelines:

- Include security as a topic in employees' meetings and discussions
- Appoint a Plant Security Officer or assign the duties to a responsible employee
- Enforce security policies and procedures consistently and equitably
- Provide security training for all employees

There are many specific health and safety concerns associated with the conveyance, treatment and reuse/disposal of wastewater. As a result of poor management of wastewater, operators and local communities are at a high risk of exposure to physical, chemical and biological hazards. Health and safety guidelines should therefore form an integral part of the O&M plan, but are quite often not given adequate attention. Health and safety regulations must be enforced by the management of a DEWATS.
Preventative measures for mitigating health and safety risks can be adopted voluntarily or, assuming effective enforcement measures are in place, through the introduction of regulation. The first and best line of defence for mitigating risks is by limiting exposure to known hazards. This includes:

- Providing and using the appropriate personal protective equipment (PPE) to prevent direct and indirect exposure to wastewater (e.g. gloves, coveralls, rubber boots with a metal sole, safety glasses and safety masks)
- Developing and providing training on the use of tools customised for local conditions

Further details and recommendations can be found on the Occupational Safety and Health Administration (OSHA) website: www.osha.gov

in order to prevent direct contact with wastewater

- Providing a training programme on Standard Operating Procedures (SOPs) including the proper use of PPE, tools and equipment

Preventative measures related to personal health care are recommended, including immunisation and a deworming programme. The latter is recommended particularly for operators transitioning from unsafe to safe practices.

The "Health and Safety Plan" specifies the procedures, practices and equipment that should be used by DEWATS employees in order to conduct their activities in a safe manner. Health and safety plans are prepared specifically for each DEWATS but also contain aspects that are common to all DEWATS. The following topics should be included in health and safety plans:

- PPE and safety measures for O&M activities: This includes head, eye, hand, foot and face protection, breathing safety devices (e.g. dust masks), and coveralls.
- Infection control and hygiene measures: This includes proper immunisations (e.g. hepatitis A, tetanus) and following hygienic procedures at all times when handling equipment that might have come into contact with faecal matter. More specifically, this includes regular use of washing facilities, refraining from eating, drinking or smoking in areas where wastewater or chemicals are stored or processed, and immediately reporting illness to the plant supervisor.
- Emergency contact procedures: This includes a contact list and emergency procedure which is posted in a common area and thus can be easily consulted by employees in the event of an emergency. First aid materials and equipment must also be provided.
- Protection against falling and drowning: This includes a drowning prevention programme that provides safety equipment, signage and training.
- Confined space entry protection: This concerns all spaces which are enclosed and have limited access, such as tanks and dry wells, where the breathable atmosphere may become compromised. In order to prevent confined space accidents, a "Confined Space Entry Permit" programme is implemented at DEWATS facilities.
- Electrical safety and the use of the lockout/tagout (LOTO) procedure: This keeps workers safe when performing O&M activities on powered devices. The lockout/tagout procedure ensures that the breaker to the power source for the equipment that is to be repaired is turned off and locked in the off position.

5.5.4 Asset Management

Asset management is a holistic approach to DEWATS maintenance that maximises the long-term effectiveness of the facility at the lowest possible cost. The full lifecycle costs of an asset include:

- Capital cost of purchasing and installation
- Labour required for O&M
- Spare parts for repairs
- Essential consumables such as grease or chemicals
- Replacement costs once the component has reached the end of its useful life

Integral to the full lifecycle costs are the stocks of tools and supplies that are required for long-term operational needs. These should ideally be available at each DEWATS location. If several DEWATS rely on the same technology or equipment, centralised stocks can be organised.

Asset management is crucial for large DEWATS. The following information should be included in the maintenance plan:

- The current state of the assets
- The required 'sustainable' level of service

- The assets which are critical to sustained performance
- The minimum lifecycle costs
- The long-term funding strategy

Without an asset inventory, no comparison can be made on the cost of equipment or the importance of the asset. Components that are crucial for the operation of the DEWATS should be highlighted, and replenished immediately after use. It is therefore important to have a reputable provider with agreements drawn up to ensure swift service.

Findings from M&E activities 2017 - see Page 38

In 40% of the systems, the operator or management entity cannot give any details about the responsibilities of the operator. Only 33% have a written document describing responsibilities. Generally, project documents such as O&M manuals, drawings, and project reports were missing.

5.5.5 Administrative Management

Since different parties are involved in running a DEWATS, responsibilities have to be described, clearly defined and shared from the beginning. Since the performance of a system is only as good as its stakeholders, it is of utmost importance that participant's tasks are carried out attentively. Mismanagement can lead, for example, to poor operational skills among employees, misunderstanding of technical priorities by administrative employees, poor communication or poor financial performance. All responsibilities should be recorded in a written form so that:

- Participants know / are aware of their specific responsibilities
- Tasks and measures can be delegated and executed quickly

Generally administrative management includes:

- Financial procedures: Financial procedures must be clearly defined based on operational needs. The operating costs should be made available and monitored, and the budget adjusted based on actual expenses. Special provisions and administrative mechanisms should be in place regarding DEWATS damage and failures. The procedures for the acquisition of light tools and safety equipment must be rapid, and special funds should be available for small repair work in order to ensure continuous operation. In a sustainable wastewater treatment system, the community should be able to finance the implementation of the system, the O&M, the capital improvement needed in the future, and the necessary long-term repairs and replacements.
- Human resource management (HR): This is a major element of the successful operation of any DEWATS. Clear financial mechanisms must be defined to ensure that sufficient and appropriate staff is available to operate the DEWATS. HR requirements can be defined based on the specifications of the design consultants, and the operational requirements observed during the start-up period. In some cases, where O&M activities may involve very specific skills or resources which are not available in-house, external services can be hired. Irrespective of the size of the DEWATS, employees should have defined roles and responsibilities in order to ensure their complete understanding of specific job requirements.
- Staffing, roles and responsibilities: DEWATS can have a broad range of staffing requirements depending on the size of the plant, the treatment volume and the required skill level. An organisational chart that clearly specifies the roles and responsibilities of each employee as well as the lines of communication is a useful management and training tool which should be defined during the design and planning phase. Smaller DEWATS may combine various job titles and responsibilities.

Findings from M&E activities 2017 - see Page 38

Most of the projects visited had financial challenges, such as a lack of funding for O&M activities.

- Coordination: Effective communication should be encouraged between the O&M and monitoring staff of different DEWATS in the same jurisdiction, as well as with the decision makers. An effective vertical communication ensures that administrative employees understand the constraints and needs of O&M employees, and results in more rapid acquisition of the parts and repairs that are needed to ensure continuous operation of the DEWATS. Horizontal communication between the DEWATS staff at different locations allows the exchange of experiences and therefore assists in the optimisation of the procedures. Frequent (weekly or monthly) meetings should be held in order to facilitate discussions between operating, monitoring and administrative employees on the difficulties experienced and possible solutions. If the operating company is in charge of several DEWATS, one person can be designated to ensure quality control and harmonisation of the O&M procedures across all the facilities. This would result in the experience-based adjustment of procedures and guidelines as well as their subsequent standardisation for all similar DEWATS, ensuring the uniform implementation of safety rules and O&M procedures.

Findings from M&E activities 2017 - see Page 38

Active clubs or committees which take responsibility for sanitation issues were non-existent

Faecal Sludge Treatment Plant, Mburahati, Dar es Salaam. Faecal Sludge Treatment Plant (designed by BORDA Tanzania, financed by UKAID) with Biogas Settler, ABR, AF and sub-surface water distribution system. The FSTP produces biogas for cooking purposes, and treated wastewater is used to irrigate the surrounding vegetation.

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7 Appendix

<table>
<tr><th></th><th colspan="2">On-Site Systems</th><th>Off-Site Systems</th></tr>
<tr><th></th><th>Wastewater - Single Household Connection</th><th>Wastewater - Institution System</th><th>Wastewater - Community or Cluster System</th></tr>
<tr><th>Step</th><th colspan="3">Activity</th></tr>
<tr><td></td><td colspan="3">SOP01: Planning</td></tr>
<tr><td rowspan="2">Process ignition</td><td colspan="3">Project acquisition (client approach)</td></tr>
<tr><td colspan="3">Pre-agreement (including agreement on payments for feasibility study)</td></tr>
<tr><td>Launching the planning process</td><td></td><td></td><td>– Identification and characterization of stakeholders
– Launching workshop: Initiation of planning process
– Sensitisation of stakeholders and awareness creation
– Assessment of local context and current situation</td></tr>
<tr><td>Detailed assessment of the current situation</td><td colspan="3">Identification of viable system options:
- development and detailed analysis of system options
- pre-selection of options
- in-depth analysis of pre-selected options</td></tr>
<tr><td>Prioritization of community needs and validation</td><td></td><td></td><td>– Meeting with the selected communities
– Need, Stakeholder and Community Participation Assessment
– Preparation of Community Action Approach
– Identification of land
– Determining the steering committee, signing MoU with local Authority and Utility</td></tr>
<tr><td rowspan="7">Determine the final system option</td><td colspan="3">Identification of cost recovery models</td></tr>
<tr><td colspan="3">Quotation (proposal/options)</td></tr>
<tr><td colspan="3">Acceptance by client (proposal presentation)</td></tr>
<tr><td colspan="3">Contract drafting & signing</td></tr>
<tr><td colspan="3">Land approval</td></tr>
<tr><td colspan="3">Legal approvals (the type of legal approval needed depends on several variables, such as the size or the location of the system)
– Approval of EIA
– Project acceptance approval</td></tr>
<tr><td colspan="3">Finalize cost recovery model</td></tr>
</table>

Table 29: Activity list for wastewater treatment projects (adapted from Lüthi, et al., 2011)

<table>
<tr><th rowspan="2">Step</th><th colspan="2">On-Site Systems</th><th>Off-Site Systems</th></tr>
<tr><th>Wastewater - Single Household Connection</th><th>Wastewater - Institution System</th><th>Wastewater - Community or Cluster System</th></tr>
<tr><td></td><td colspan="3">Activity</td></tr>
<tr><td></td><td></td><td>SOP02: Design</td><td></td></tr>
<tr><td rowspan="9">Development of an action plan</td><td colspan="3">Gathering further data if needed</td></tr>
<tr><td colspan="3">Site layout / locality plan if none exists</td></tr>
<tr><td colspan="3">Preparation of DED and BOQ</td></tr>
<tr><td colspan="3">Detailed description of the construction
– Project brief</td></tr>
<tr><td colspan="3">Define implementation plan</td></tr>
<tr><td colspan="3">Preparation of O&M plan and manual</td></tr>
<tr><td colspan="3">Final approval by the client
– Finalize written agreement</td></tr>
<tr><td colspan="3">Design approvals and construction permit (responsible authorities)</td></tr>
<tr><td></td><td colspan="2">Construction tender (If tendering required)</td></tr>
<tr><td></td><td></td><td>SOP03: Construction, Handover & Start-Up</td><td></td></tr>
<tr><td rowspan="15">Implementation and capacity building</td><td>Coordination meeting
– meeting with client before construction starts</td><td colspan="2">Coordination meeting
– meeting with client/community before construction starts</td></tr>
<tr><td colspan="3">Labour and material mobilisation</td></tr>
<tr><td colspan="3">Construction briefing:
– Health and safety briefing</td></tr>
<tr><td></td><td colspan="2">Identify operator</td></tr>
<tr><td></td><td colspan="2">O&M training</td></tr>
<tr><td></td><td></td><td>Community education & mobilization
– Capacity development
– Public awareness creation</td></tr>
<tr><td></td><td colspan="2">Health & hygiene education for users</td></tr>
<tr><td colspan="3">Execution of work instructions / construction methodology</td></tr>
<tr><td colspan="3">Construction supervision and step by step approvals</td></tr>
<tr><td colspan="3">Post-construction testing and verification (e.g. water-tightness, gas-tightness, free flow, etc.)</td></tr>
<tr><td colspan="3">Procure O&M equipment</td></tr>
<tr><td colspan="3">Commissioning</td></tr>
<tr><td colspan="3">Start-up phase</td></tr>
<tr><td colspan="3">Training of users</td></tr>
<tr><td colspan="3">Handover:
– Inauguration ceremony
– Handover of responsibility to the system management / owner</td></tr>
<tr><td></td><td></td><td>SOP04: O&M, M&E</td><td></td></tr>
<tr><td rowspan="3">Post-implementation activities</td><td colspan="3">O&M according to O&M plan</td></tr>
<tr><td colspan="3">Regular M&E</td></tr>
<tr><td colspan="3">Trainings as required</td></tr>
</table>

Monitoring and Evaluation (M&E) activities conducted on selected decentralised wastewater treatment projects throughout Tanzania

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