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Development of a Conceptual Framework for Decision Support Systems for Emergency Sanitation

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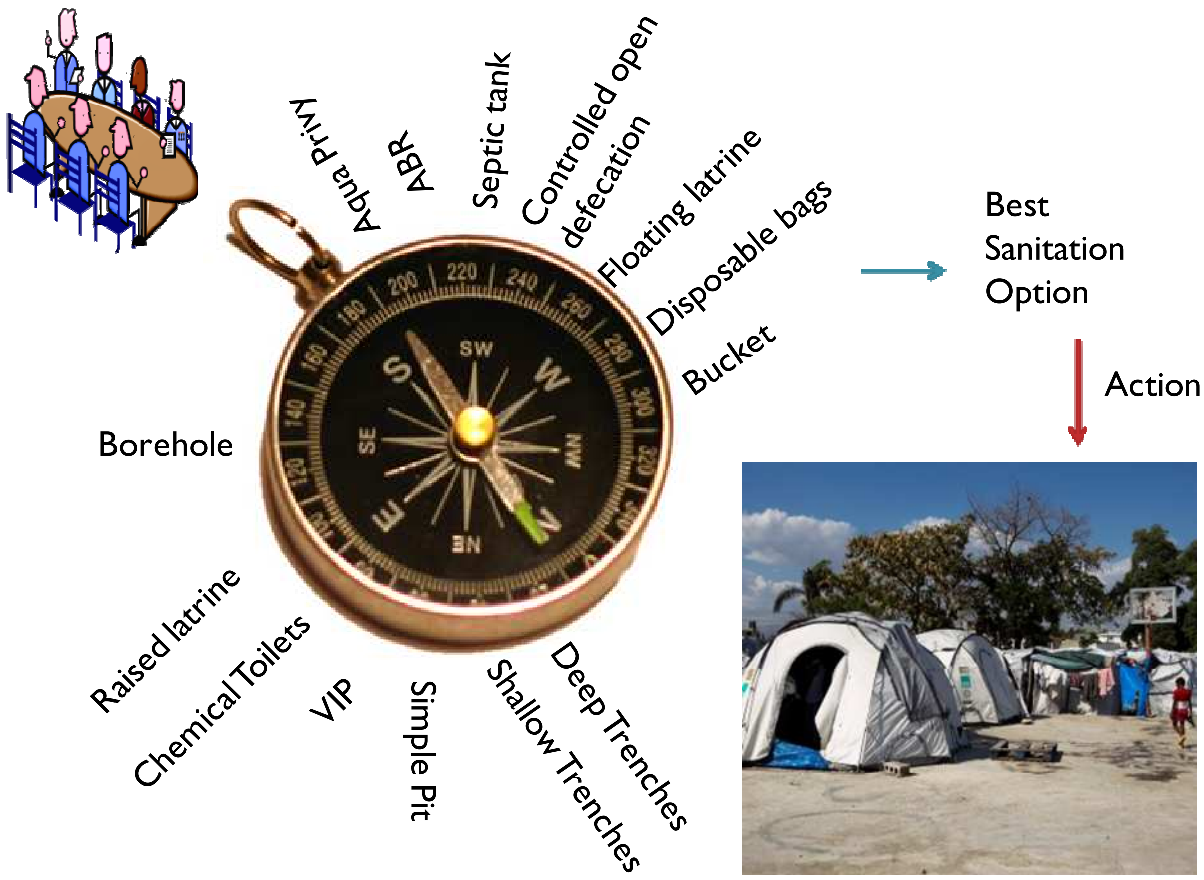

Development of a Conceptual Framework for Decision Support Systems for Emergency Sanitation

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To
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Abstract

When a disaster happens, people seek refuge to a safer place; often gather themselves in temporary shelters e.g. displaced camps. In these camps, due to the high population the provision of safe sanitation can be challenging which may result into disease outbreaks such as diarrhoea. Therefore to prevent disease outbreak, proper emergency sanitation is required. Emergency Sanitation is the provision of facilities and services for the safe disposal of human urine and faeces in the case of emergency. Sanitation provision in emergency requires a quick response. Due to the time constraints, to come up with the most feasible technology is not always possible in an emergency. Different emergency sanitation technologies are available, but to decide on the appropriate one is complicated. Therefore, a decision tool for emergency situations is needed to assist decision makers in selecting the appropriate technology.

Literature indicates that, there are different formats, guidelines, and tools used in the selection process of sanitation technologies. These include decision tables, flow diagrams, matrices and computer based tools. Many selection tools in water and sanitation have been developed such as SANEX, WAWWTAR, SETNAWWAT, SANCHIS, but in the context of emergency sanitation, no computerised selection tool has been developed yet. Thus, a decision support tool is required to serve for technology selection in emergency situations universally.

The research study aims at addressing the need for Decision Support Systems (DSS) in emergency situations. Decision support systems (DSS) for emergency conditions are computerised tools or systems that will be used in the case of disaster situation for technologies selection. Such a tool can be used by relief providers in selecting the best option based on different criteria proposed. Because the emergency conditions are challenging, having this kind of tool will contribute in providing a suitable solution to sanitation. The tool will incorporate the sanitation chain, i.e. wastes are managed from a point of generation to the point of use or ultimate disposal.

In order to have a computer based DSS, a conceptual framework is constructed. A conceptual framework is a step by step analysis based on screening and evaluation criteria narrowing down to the best sanitation option. The framework integrates all the necessary technological sanitation solutions based on the sanitation chain concept. In the conceptual framework, the first screening is achieved through screening criteria, whereby a user is prompted to feed information that is necessary to screen the appropriate technologies for the particular disaster scenario. Furthermore, after the first screening a second screening is done by assessing the compatibility of the sanitation chain based on the collection and storage. Moreover, evaluation of the screened option is done. Evaluation is achieved by multi criteria analysis approach (MCA). A MCA is a pre-defined process. Five evaluation criteria were developed which were used to analyse the effect of sanitation chain. For every part of sanitation chain these criteria were introduced.

From the conceptual framework which was developed, a computer based DSS model is built using Microsoft Excel 2007 interface and visual basic application (VBA) programme. The model is easy to use as it requires no technical background. The model can be applied in the emergency context for selecting an appropriate technology to be applied for the particular disaster scenario.

Keywords: Conceptual framework, Decision Support System, Emergency Sanitation

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Abbreviations

DSS	Decision Support System
IDP	Internally Displaced People
NGOs	Non Governmental Organisations
SANCHIS	SANitation CHoice Involving Stakeholders
SETNAWWAT	Selection Tool for Natural Wastewater Treatment Systems
UNICEF	United Nations International Children's Emergency Fund
WAWWTAR	Water and WasteWater Technology and Reuse
WHO	World Health Organisation
GWT	Groundwater Table
MBR	Membrane Bioreactor
CAS	Conventional Activated Sludge
UASB	Upflow Activated Sludge Blanket
SMARTS	Simple Multi Attribute Rating Technique Swings
UDDT	Urine Diversion Dehydrated Toilet
TSS	Total Suspended Solid
BOD	Biodegradable Oxygen Demand
AF	Anaerobic Filter
ABR	Anaerobic Baffled Reactor
CWs	Constructed Wetlands
HSFCW	Horizontal Surface Flow Constructed Wetlands
SAT	Soil Aquifer Treatment
WASH	Water and Sanitation Hygiene
VIP	Ventilated Improved Pit latrine
VBA	Visual Basic Application
MCA	Multi Criteria Analysis

CHAPTER 1

Introduction

Literally, the word "emergency" refers to an unexpected and dangerous situation that must be dealt with immediately. In the context of humanitarian relief, what referred to as an unexpected and dangerous situation can be man-made and/or caused by a (natural) disaster such as flooding, famine, earthquakes, landslide, political instability and wars that happen suddenly and results in public health problems (Harvey, et al., 2002). One of the consequences of disasters is the displacement of a large population. A refugee is a person who is outside his/her country of origin or habitual residence because he/she has suffered persecution on account of race, religion, nationality, political opinion, or because he/she is a member of a persecuted 'social group'. The United Nations report, *Guiding Principles on Internal Displacement* presented by Deng (2004) defines IDPs as "persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence in particular as a result of or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognized State border". Displaced population is most affected in complex emergency, since they need to adapt to new environment.

In addition to adapting to a new environment, the affected population is suffering from sanitation problems. According to the World Health Organisation (WHO), sanitation refers to the provision of facilities and services for the safe disposal of human urine and faeces. The number of disasters is increasing as a result of climate change, consequently making the provision of clean water and sanitation a great challenge in emergency (Fenner, et al., 2007, IPCC, 2008).
During emergency a quick response is required. Amongst relief assistance delivered by humanitarian agencies is provision of sanitation facilities. In providing safe sanitation, different sanitation technologies for emergency are available. However, the humanitarian agencies face a challenge in selecting which sanitation technology is suitable for the specific emergency scenario that happened.

1.1. Background

Previously, the World has experienced many disaster situations like war (Sudan, 2003) tsunami (South East Asia, 2004), earthquake (Pakistan, 2005, Haiti, 2010, Japan, 2011), floods (Pakistan, 2010, Thailand, 2011). These disasters resulted into a huge number of refugees and Internally Displaced Persons (IDPs) who need shelter and basic needs on the spur of the moment. The evacuation process to new habitats needs to be ascertained by safe drinking water as well as good sanitation practise. Despite that an emergency occurs unexpectedly, a quick response is required. Moreover the emergency situation can last from days to years depending on the nature of the disaster. The provision of safe sanitation is done mainly by local authorities and non-governmental organisations (NGOs). Humanitarian relief agencies working in emergency situations include Oxfam, Red Cross, UNICEF, etc. Provision of sanitation in complex emergencies has been proven to be challenging (Adams, 1995). The problem is partially attributed to the use of non-appropriate sanitation technology.

Different support resources are used to aid the selection process under emergency conditions. The support resources include process guides/documents, decision-making support tools, evaluation tools, technical briefs, technical references, and policy briefs. A Decision Support System (DSS) as defined by Palaniappan, et al. (2008) "*is a product that combines information on a user's given situation with information on available technologies and approaches, and then helps a practitioner select the best technology or approach*". It compares and contrasts different technologies and approaches, including their construction, operation and management, costs, financing, scalability, and institutional requirements. It also incorporates the special needs of different geographic locations as well as the need for community involvement. There have been many selection tools developed in the field of water and sanitation, including computer programs such as SANEX (Loetscher and Keller, 2002), WAWWTAR (Finney and Gearheart, 2004), SETNAWAT (Sah, et al., 2010), SANCHIS (Van Buuren, 2010), but in the context of emergency sanitation, no computerised selection tool has been developed yet. For example Reed (2010) designed a sanitation options selection tool in the form of manual and flow chart for Haiti. Thus, it is necessary to have a decision support tool to select emergency sanitation options that can be flexibly used for emergency scenario anywhere.

Despite the available sanitation technologies, the selection of the appropriate one is complicated. As mentioned earlier, an emergency scenario varies from one event to another and depends where the event happened. The selection process is highly influenced by site specific criteria as well as technology specific requirements. To come up with the best solution these requirements need to be considered. These considerations can then be translated as selection criteria during the decision making process. All these criteria need to be incorporated in a systematic manner. An effective decision support system is the one that could successfully integrate the sanitation technologies with selection criteria. The decision support tool will incorporate the sanitation chain, i.e. wastes are managed from a point of generation to the point of use or ultimate disposal (Tilley, et al., 2005).

For the case of emergency, a universal decision support tool is needed which can assist in selecting the appropriate technology regardless of location. Currently, such a tool is lacking. Computer program DSS is considered attractive to be used in emergency for its user friendliness, time-saving aspects, and independency from internet connection. For a computer based selection tool to be developed, a conceptual framework has to be constructed. A conceptual framework is a step by step analysis based on site specific criteria and technology specific criteria narrowing down to the best sanitation option.

1.2. Problem Statement

It is generally accepted that in most emergencies, water supply and sanitation are among the most important interventions for improving public health and controlling disease (Adams, 1995). Emergency sanitation intervention promotes a safer environment and preventing the spread of diseases in disaster - affected areas. Consequently, it is important to select appropriate sanitation options for specific emergency scenarios. Although different sanitation technologies exist ranging from "dry" to "wet" solutions, there is no single technological solution that can universally address sanitation issues in all emergencies. Each emergency scenario calls for different approaches in the technological choice. The choice of a particular technology will be affected by specific factors such as geological, geographical, political, legislative, technical, social and cultural variables. To select the appropriate technology, a decision support tool is required. However, whilst different decision support tools for sanitation exist, this is not the case for sanitation in an emergency. Therefore, due to these variations and uniqueness of emergency scenarios, a selection tool is required that can be used by any country regardless of its development status in selecting the appropriate technology for specific emergency situation.

1.3. Significance of Proposed Work

Technology selection tools are lacking for emergency sanitation conditions. In addition, there is no decision support tool that acts as a general tool applicable for all disaster situations. Since the disaster happens in a short notice, it can lead to provision of inappropriate technologies which e.g. led to non cost effective provision. Therefore; a selection tool (DSS) needs to be developed to assist in the provision of an effective emergency response. The decision support tool will save time as well as funding. This study will benefit humanitarian relief agencies providing emergency sanitation facilities, in selecting the appropriate technology.

1.4. Research Question

How to create a logical sequence from a set of selection criteria, that incorporate a range of emergency sanitation technical options, to result in effective decision support system to select sanitation options in emergency situations?

1.5. Research Objectives

1.5.1. General objectives

To develop a Conceptual Framework decision support tool for emergency sanitation that could be translated into a computer program.

1.5.2. Specific Objectives

The general objective is further narrow down into the following specific objectives;

- To identify potential sanitation technologies applicable in emergency relief.
- To develop a work flow for the selection of sanitation technologies in emergency relief.
- To develop and validate software to aid in the selection of sanitation technologies chain in emergency relief

CHAPTER 2

Literature Review

Previously in CHAPTER 1, it has been observed that there is a lack of a decision support system (DSS) for the condition of emergency. In order to develop one, it is important to understand the available sanitation technology options that are applicable in case of emergency. This chapter gives an overview of what has been done in the previous emergencies in providing safe sanitation. Moreover, it analyses the existing DSS state of art with regards to emergency sanitation DSS.

2.1. Emergency Sanitation

Emergency sanitation refers to the provision of safe sanitation system in order to prevent diseases outbreaks following a disaster. It is part of relief efforts to assist disaster affected people, mainly involving displaced people. When a disaster situation occurs, people will move to a secure place. Both refugees and displaced people will be grouped in this area, which makes provision of safe drinking water and sanitation more challenging (Fernando, et al., 2009).

During these challenges, an emergency sanitation response is required. Initially sanitation response may seem to be simple i.e., but the manner in which they are provided can have influential consequences to the affected society (Davis and Lambert, 2002).

Study cases from the past emergencies explain the challenges faced on provision of safe sanitation in emergency as well as the importance of emergency sanitation. Different case studies presented below entails the importance.

2.1.1. Haiti case study

In 2010, an earthquake of 7.0 magnitude struck Haiti which resulted in over 900 informal settlements in the Port au Prince area (Reed, 2010)) following displacement of a large population that lost their houses during that earthquake. The earthquake damaged the existing water and sanitation systems. Moreover, the water and sanitation systems near to the located IDPs camp sites could not cater the additional load due to the displacement.

Different humanitarian agencies with the government of Haiti worked together in the provision of water and sanitation services. In displacement camps, there was a great concern that lack of sanitation would lead to the outbreak of excreta related diseases (Reed, 2010). Due to inadequate sanitation services which were threatening the life of the affected community, further steps were taken to improve the situation including a Water and Sanitation Hygiene (WASH) cluster (Reed, 2010) .

The provision of sanitation services in Haiti was very challenging due to many factors. The displaced people were placed in camps which were situated in privately owned land making service provision limited due to unwillingness of the owner to allow his/her land to be used for sanitation services (Reed, 2010). Also owners worried that their land would be depreciated when used for sanitation. Furthermore, in Haiti it was not possible to dig due to ground conditions i.e. a high water table. Also the disposal of garbage and toilet waste was restricted due to environmental reasons (Reed, 2010). In the camp sites, no piped water was available; therefore sanitation had to be waterless (Cocking and Bastable, 2010). According to Cocking and Bastable (2010), composting latrines were built in five camps by Oxfam. The Haiti situation made humanitarian agencies to come up with different emergency sanitation solutions including trench latrines, composting latrines, disposable bags, raised latrines, de-sludging equipments etc. The Haiti disaster indicates the importance of good sanitation during emergency.

Temporary camps in Haiti [Source: OCH -Ozarks Community Hospital]

Red Cross toilets in Haiti [source: BBC]

Figure 2.1 Raised Toilets in emergency camps -Haiti

2.1.2. Pakistan case study

In 2010 Pakistan experienced flooding whereby the existing wastewater infrastructure were submerged and destroyed. The damaged wastewater systems led to contamination of the flood water. The contaminated stagnant flood water, standing for months, contributed to a dangerous sanitation situation which could lead to waterborne diseases like cholera and malaria (Yousaf, 2012). To rescue the situation, provision of safe sanitation was required.

Safe sanitation provision faces many challenges during the Pakistan flood emergency including field conditions, and social acceptance. Amongst the challenges were high groundwater table in the region which gave a limitation on the provision of safe sanitation. In this emergency situation internally displaced people (IDPs) continued with their previous sanitation practices; including lack of proper sanitation and open defecation practice (Johannessen, 2011). Therefore, to improve the sanitation practice in the camps, programs to create demand for sanitation were introduced as well as preventing open defecation practice. Programs to encourage people to use toilets like Community Led Toilet Sanitation (CLTS) were introduced (Johannessen, 2011). Different relief agencies like Oxfam GB came up with different excreta disposal technologies.

The most common excreta disposal technology was a trench latrine (oxfam, 2011). UN-HABITAT (2011) introduced in Pakistan a trial use of peepoo, which was easily accepted and well received by the affected communities. Furthermore, to improve the situation, other sanitation technologies including emergency Pit latrines and Ventilated Improved Latrines (VIP) with different superstructures were introduced (oxfam, 2011, UN-HABITAT, 2011).

When dealing with sanitation it is not only about engineering solutions but rather about socio cultural aspects also. The Pakistan people were used to open defecation habits, therefore it was a challenge for relief agencies to change people's mind towards the use of latrines. The diarrheal outbreak due to lack of safe sanitation in Pakistan flood shows how crucial sanitation is, during emergency.

Pakistan Flood Source: Oxfam international photo gallery

The use of peepoo bag training Source: (UN-HABITAT, 2011)

Figure 2.2 Pakistan flood and the use of biodegradable bags

2.1.3. Bangladesh case study

Despite the fact that flood in Bangladesh is a yearly event; the 1998 flood was devastating due to its longer duration. The flood lasted for about 69 days (Ahmed and Ashfaque, 2002). Although Dhaka City has flood protected areas like the area of west and Pragoti Sarani, the city was flooded. All sanitation facilities were not functional except for one Sewage Treatment Plant (STP) situated at Pagla. The flood caused massive destruction to the infrastructure resulting to backflow of sewage hence environmental pollution. To rescue the situation, different sanitation practices were adopted by flood-affected people. During the flood, the ground was inundated; therefore, the use of temporary erected toilets on the roof was adopted. The residents of the ground floor of multi story houses were compelled to use toilets of the upper floors. People, who were using latrines in low income areas, decided on erecting elevated platform for defecation thus releasing the faecal matter directly in floodwater. Moreover, this practice resulted in environmental problems on water bodies especially for downstream usage. In order to prevent water pollution due to sanitation practice mentioned above, safe sanitation practice should be aimed at high. The Bangladesh flood case study show how important it is to plan for emergency sanitation prior to disaster occurrence in highly disaster affected areas.

UDL Floating Emergency Latrine [Source: Oxfam]

IDPs using the multi-story building toilets [Source: UN News Centre]

Figure 2.3 Emergency latrines provided in Bangladesh flooding

2.2. Sanitation Technologies during emergency

2.2.1. Known and or Potential Sanitation Technologies

Tilley, et al. (2005) refer to sanitation as a multistep process in which wastes are managed from the point of generation to the point of use or ultimate disposal. The consecutive different steps in the sanitation process will be referred to as 'sanitation chain'. The sanitation chain includes excreta disposal (user-interface and containment), conveyance (collection, desludging and transport), treatment, and disposal or reuse (See **Figure 2.4**). Different sanitation technologies for emergency exist. Known sanitation technologies in emergency include; simple pit latrines, borehole, trench latrines, ventilated pit, composting toilets (Urine diversion dehydrated toilets (UDDT), fossa alterna, Arboloo, Terra Pretta), chemical toilets, raised toilets, plastic bags, biodegradable bags, buckets/commode, septic tank, anaerobic filters, anaerobic baffled reactor, and aqua privies. Moreover; there are other technologies that have potential to be used in emergencies. These include Membrane Bioreactor (MBR), Conventional Activated Sludge, Upflow anaerobic sludge banket (UASB), Trickling filters, waste stabilisation ponds (WSP), Constructed wetlands, Co-composting, and drying beds.

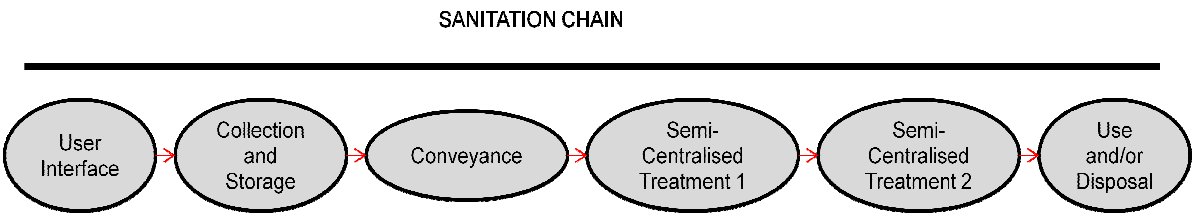


Figure 2.4 Sanitation chain

2.3. Decision Support System (DSS)

2.3.1. Sanitation Decision Support System: The State of Art

In the selection process of sanitation technologies during emergency, decision support systems are very essential in identifying, evaluating, and choosing a technology or approach that best suits the conditions and needs of their community (Palaniappan, et al., 2008). In the emergency sanitation context, a decision support system (DSS) is a tool that assist relief provider in evaluating the appropriateness of different sanitation options during emergency. Loetscher and Keller (2002) define decision tools in the form of descriptive systems, checklists, decision tables, flow diagrams, and computerised systems. Basically the DSS links the existing scenario with the available technologies and approaches by critically comparing and contrasting the available technologies. The comparison and evaluation of different options may be carried out with regard to technical social, institutional, legal, and financial criteria (Palaniappan, et al., 2008). However, there is a limitation on existing tools. A review of previously developed sanitation decision support tools is presented below.

Van Buuren (2010) introduced SANCHIS, an appropriate technology selection tool for sustainable drainage and sanitation systems. It uses a method of participatory multi-criteria analysis whereby stakeholders compose performance matrices based on a list of system options and criteria for the assessment of the appropriateness and sustainability of these options. It formulates the entries to the assessment matrix as a numerical value instead of qualitative judgements. SANCHIS uses Simple Multi Attribute Rating Technique Swings (SMARTS) to trade-off the disadvantages with respect to some criteria against the advantages with regard to other criteria. The author claimed that stakeholders can subsequently use these matrices to reach a rational decision. A set of criteria and indicators for the assessment were selected and used as a guideline for the description and comparison of technologies and technology chains.

Finney (2004) developed a computerised decision making tool for water and wastewater to assist in the selection process and decision making. The computer program was named Water and Wastewater Treatment Technologies Appropriate for Reuse (WAWTTAR). This program is a platform developed to assist in the selection of suitable water and wastewater treatment processes appropriate to the material and manpower resource capabilities of particular countries at particular times (Finney and Gearheart, 2004). WAWTTAR's interface requires someone with a sufficient technical background to screen and research possible water and wastewater treatment options. The program has been designed to incorporate wastewater reuse as an equal criterion in the selection of feasible solutions. It also assists in addressing a community's public health, water resource, and ecological condition. Furthermore, the program can estimate the cost of huge number of possible system depending on the local conditions for which the problem is solved.

Another computer program DSS is SANEX. SANEX is a computerised decision support tool in sanitation suitable for developing countries. Loetscher and Keller (2002) describe SANEX as the DSS that covers low-cost technologies such as latrines and pour-flush toilets and simplified sewerage. The purpose of SANEX is to guide users in assessing the suitability of alternatives with regard to community situation and preferences. The tool uses multi criteria analysis for rating the available alternatives with respect to different criteria. SANEX uses numerous technical and socio-cultural criteria to evaluate 83 sanitation alternatives. Each alternative is a train of several of the following components: collection, treatment, disposal and reuse; off-site conveyance, off-site treatment, disposal and reuse. SANEX also contains a costing module that gives cost estimates in local currency units in order of magnitude. The capital cost, recurrent cost, and total annual cost are calculated based on cost -capacity relationships.

Another DSS for selection of natural system for wastewater treatment was developed in 2010. Sah, et al. (2010) describe SETNAWWAT as a decision support platform for selection of natural systems for wastewater treatment by screening the best option possible. This system is best suited for planners who are exploring the possibility of implementation of natural system for wastewater treatment. This support system is simple, and has been developed in Excel and Visual Basic Application (VBA) (Sah, et al., 2010). It has user friendly interface whereby inputs information are fed in the spreadsheet. Based on these inputs, the model evaluates the treatment trains depending upon defined set of criteria ranging from technical, economic and social criteria and ranks them in the order of preference. The selection process is done from a pre defined treatment trains.

WASTE has recently developed a Sanitation Decision Support Tool which can be used on the level of individual. The tool ascertains in the selection process between different options on sanitation. Currently, the tool is available in paper form showing various types of technologies a total of 54 in different phases of the sanitation management and a manual on how to use the tool (Castellano, 2011). Furthermore WASTE is working with AKVO into making the tool available online for use (www.akvo.org). For the selection process, the tool integrates six different aspects including technical aspects, environmental or health aspects, financial/economic aspects, social cultural aspects, institutional aspects and legal aspects. With respect to this different aspect integration, the WASTE tool covers all stakeholders for sanitation. It uses the concepts presented by (Tilley, et al., 2005) in the compendium sanitation systems and technologies.

2.3.2. Decision Support System

To address the complex emergency sanitation challenge, there is a need to identify, evaluate and choose To address the complex emergency sanitation challenge, there is a need to identify, evaluate and choose technologies that can best deal with the emergency scenario (Palaniappan, et al., 2008). The sanitation providers are still facing a challenge to have the adequate sanitation system. Different sanitation systems for emergency are available but to understand one that is suitable and feasible to the emergency area in an immediate response is complicated.

In many cases pit latrine has been the popular choice; however it can be difficult to be applied in some areas due to a high water table, floods, and land ownership complication. Among all available sanitation technologies, the relief providers encounter the dilemma of which path to choose. The challenge remains in the selection and implementation of the appropriate technologies in a way that can solve the environmental and health problems of the affected community. Many decision support tools have been developed so far to address the sanitation problem but not in the context of emergency.

This research study aims in developing a conceptual framework that will help in the selection process of technologies during emergency. The framework will be translated into a computer based DSS model that is independent of internet access. The model will aid relief providers in selecting an appropriate technology to be deployed.

CHAPTER 3

Methodology

In CHAPTER 2 it was clearly indicated that a relief provider needs help to select a most suitable technology to implement when a disaster happens. Despite of the available sanitation technologies to be used in emergency, selecting the appropriate technologies remains a challenge. In order to aid relief agencies in the process of decision making, this study tried to capture all the considerations into one decision support system - DSS model. This chapter focus on, identifying the potential sanitation technologies that can be used in emergency relief (Section 3.2) and to develop selection criteria for the selection the above technologies (Section 3.3).

3.1. Introduction

This is a desk study research which includes a substantial literature study as well as contacts with different stakeholders involved in dealing with emergency sanitation worldwide. The study compares existing international practices and uses as much as possible data from real life emergency events that occurred in the past.

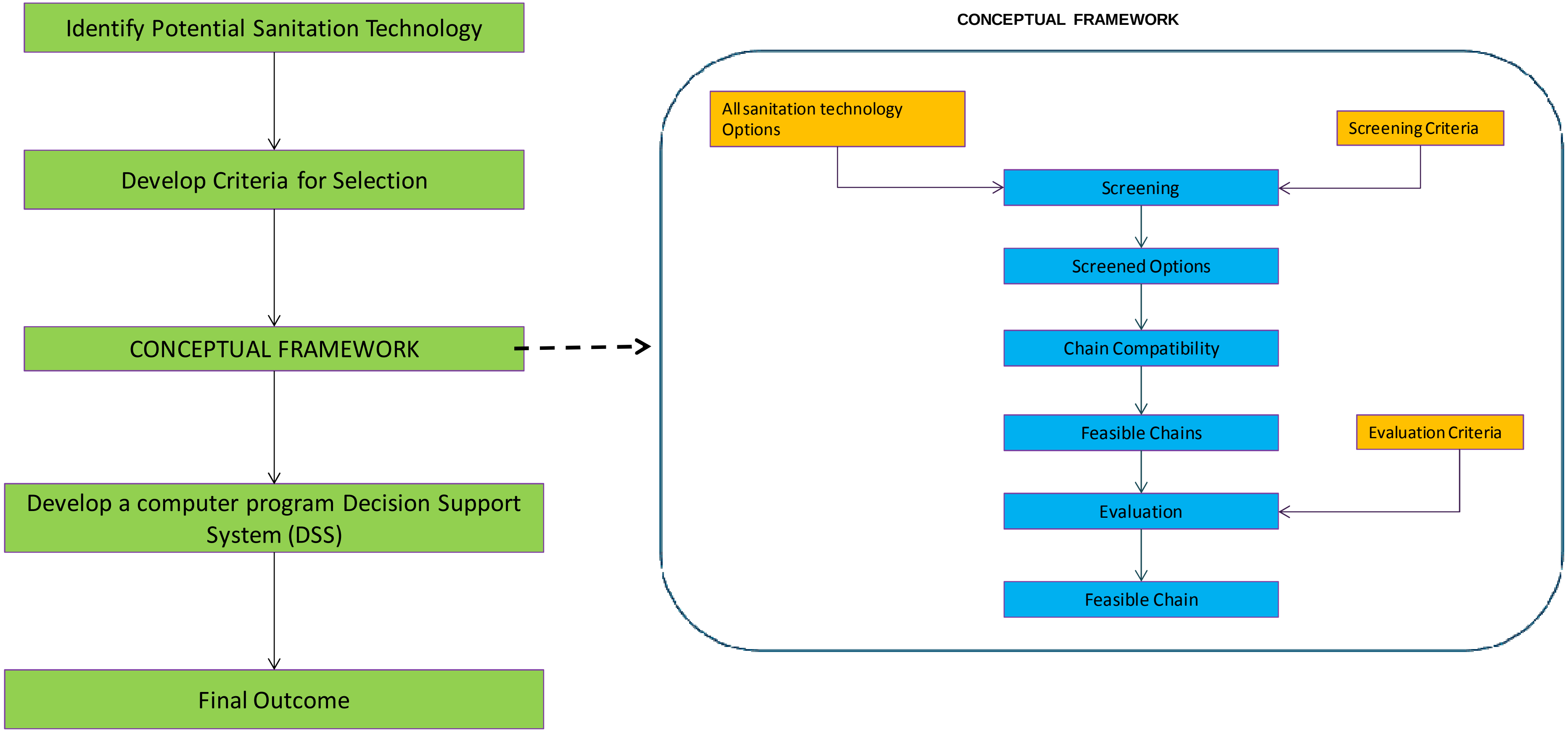


Figure 3.1 Methodology for seleting sanitation technology chain in emergency relief

3.2. Potential Sanitation Technologies Chain in Emergency Relief

This section identifies the emergency sanitation technologies to be included in the DSS. The identification of the sanitation technologies depends on two criteria: firstly, whether a technology has been used in the emergency and secondly, whether the technology has a potential to be used in emergency i.e. likeliness. Moreover, the sanitation technologies proposed should be environmentally friendly.

Using the sanitation chain concept, the identified sanitation options are grouped according to their position in the chain. The sanitation chain consists of a multistep process of excreta management from the point of generation to the point of use or disposal. In this paper, the chain consists of processes of how excreta is collected (User Interface - Collection), transported (Conveyance), treated (Treatment) and disposed of (Disposal).

User Interface refers to drop hole, urine diversion, and pour flush. Collection ways to which excreta is collected include biodegradable bags, pit non water tight, pit water tight, storage latrine, composting, and chemical toilet. The Conveyance and Transport include manual emptying and transport, motorised emptying and transport, and sewerage. Furthermore; Semi Centralised Treatment options include co-composting, drying beds, sedimentation/thickening, WSP, constructed wetlands, trickling, UASB, MBR, and conventional Activated Sludge (CAS). Succeeding the semi treatment technologies, two products are formed i.e. faecal sludge or effluent. For this research, only sludge line is taekn into account for the final disposal ways. It is assumed that the effluent from the treatment systems will further be used for irrigation or water disposal. The final disposal point for faecal sludge includes burying onsite or offsite, open dumping, sludge or dried faecal matter fertilizer, and urine fertilizer.

Observing the practices in emergency and technology-specific requirements, the treatment chain is divided into two i.e. Semi Centralized Treatment 1 and Semi-Centralized Treatment 2. To every chain component, there are different sanitation technologies to be used. (Section 3.2.1 to Section 3.2.6 below entails).
See **Table 3.2** for the inventory of sanitation technologies and its position in the chain. The following sections i.e. Section 3.2.1to Section 3.2.6 explain the details of listed sanitation technologies and compatibility with other sanitation technologies in the succeeded chain.

In general; waste are generated from human activities and its environment. Waste generated directly by humans includes urine and faeces. Other kinds of waste are due to the functioning of technologies (e.g. flush water to move excreta through sewers) and some are generated as a function of storage or treatment (e.g. faecal sludge) (Tilley, et al., 2005). For the design of a robust sanitation system, it is necessary to define all of the waste that is flowing into (Inputs) and out (Outputs) of each of the sanitation technologies in the system (Tilley, et al., 2005).

Urine is the liquid waste produced by the body to rid itself of urea and other waste products where as Faeces refers to (semi-solid) excrement without urine or water (Tilley, et al., 2005). Excreta consist of urine and faeces that is not mixed with any flushing water. In practice, excreta also include anal cleansing material like water, bulk or hard material, and soft paper. Sewage refers to all water used in domestic activities i.e. greywater and blackwater. Faecal sludge is undigested or partially digested slurry resulting from the storage and treatment of sewage, black water, brown water and excreta (Van Buuren, 2010). There are two types of faecal sludge: high strength (originating from latrines and unsewered public toilets) and low strength (originating from septic tanks, also called septage). Digestate is called the sludge formed in anaerobic digesters that process human excreta.

Different waste streams can be generated through human activities. Yellowwater is a mixture of urine and toilet flushing water. Blackwater is the mixture of urine, faeces and flush-water along with anal cleansing water (if anal cleansing is practiced) and/or dry cleansing material (e.g. toilet paper). Greywater is the domestic wastewater generated by the use of drinking water for personal hygiene, laundry, food preparation and other non-toilet uses. Brown water is toilet wastewater which consists of flush water, toilet paper and faeces originating from urine-diverting flush toilets. In practice brown water is not free from urine, since complete source separation of urine is unattainable (Van Buuren, 2010).

There are different waste streams in the context of sanitation. Definition of different waste streams is summarised in **Table 3.1**. This research, four waste streams which are most likely to be produced in the case of emergency. The four waste streams are excreta, blackwater, yellowwater, and brownwater. Moreover, this research does not focus on greywater as well as solid waste produced in IDPs camps

Table 3.1 Summary of waste stream

Waste stream	Definition
Urine	liquid waste produced by the body to rid itself of urea and other waste Products ion
Faeces	semi-solid excrement without urine or water
Excreta	urine + faeces
Yellowwater	urine + toilet flush water
Blackwater	faeces + yellowwater + anal cleansing water/material
Greywater	the domestic wastewater generated by the use of drinking water for personal hygiene, laundry, food preparation and other non-toilet uses
Brownwater	toilet wastewater which consists of flush water, toilet paper and faeces originating from urine-diverting flush toilets (blackwater without urine)
Sewage	greywater + blackwater
Faecal sludge	undigested or partially digested slurry resulting from the storage and treatment of sewage, blackwater, brown water and excreta

Table 3.2 Potential Sanitation technologies applicable in emergency

User Interface	Collection and storage / Treatment	Conveyance	Semi centralised treatment 1	Semi centralised treatment 2	Use and/or Disposal
No User Interface	Collection bags/ Container (Biodegradable bags, Bucket/container)	No emptying and transport	No treatment	No treatment	Sludge fertilizer
Drop Hole	Pit non water tight (deep/shallow latrines, controlled open defecation, borehole, pit latrines, and Arborloo)	Manual emptying and transport	Co-composting	Trickling filters	Urine fertilizer
Pour Flush	Pit water tight (septic tank toilet, Anaerobic Filters AF, Anaerobic baffled reactor ABR, Aqua privies, and fossa alterna)	Human Powered emptying/ Collection and Motorised transport	Unplanted Drying beds	Upflow Anaerobic Sludge Blanket (UASB)	Burying/ fill and cover onsite
Urine Diversion (UD)	Storage latrine (Floating latrine, raised/storage latrine)	Motorised emptying and transport	Planted Drying beds	Membrane bioreactor	Burying/ fill and cover offsite
Urinal	Composting Toilet (UDDT, UDT, Urine jerrycans, Urine bladder)	Sewerage	Sedimentation/Thickening	Conventional activated sludge	Surface Disposal/ Open dumping
	Chemical Toilet		Waste Stabilization Ponds (WSP)		
			Sub Surface Constructed wetlands		

3.2.1. User interface

User interface refers to toilet facility that a user come into contact with when using a sanitation system. This include drop hole, pour flush, urine diversion, and urinals. In some cases, no user interface is required for instance in controlled open defecation sanitation technology.

3.2.1.1 Drop hole

Drop hole interface in a toilet/latrine refers to a latrine where human excreta is dropped directly into a pit or other types of collection tank. This is mostly used together with collection systems that are onsite sanitation like shallow pits, trench latrines, and borehole systems. This interface has been used a lot in emergency because it can be fixed to many collection systems that are appropriate in emergency.

Advantages

Drop hole interface is easy to construct. It can be combined with many sanitation collection systems that are applied onsite.

Limitations

The interface is limited to technologies that are applicable onsite.

Costs

Since the interface is built together with collection system preferred, the cost will be varying depending on the collection technology to be used.

3.2.1.2 Pour flush latrine

A pour flush user interface toilet is a toilet basin with a water trap at the bottom and a pipe to convey blackwater to a septic tank or direct to a sewerage system. It has a shallower U-bend to allow manual flushing by pouring small amounts of water in the toilet pan compared to cistern-flush toilet (Harvey, et al., 2002), Paterson et al., 2007). It relies on water to create a hygienic water seal and flush the excreta to the containment. The hygienic water seal prevents smell and ingress of flies. In emergency the pour-flush toilets are applicable where water for flushing is available as well as where anal cleansing with water is practiced.

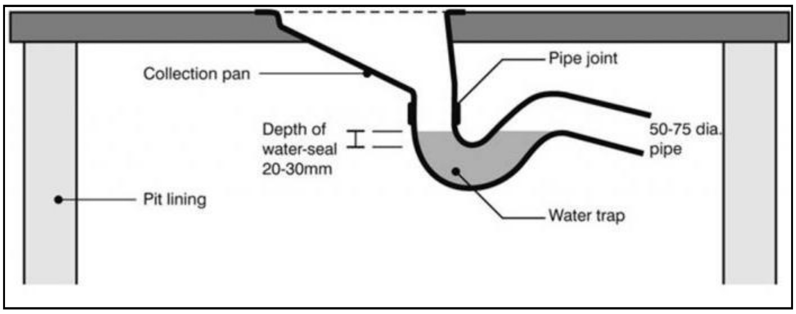


Figure 3.2 Pour Flush Interface (Source: (Harvey, et al., 2002))

Advantages

Pour flush systems have a great advantage when water for flushing is applicable, it can be connected direct to sewerage systems. It has a hygienic water seal that prevents smell and ingress of flies.

Limitations

The pour flush systems applicability is limited to areas with water availability. Therefore in water scarce areas pour flush systems will not be feasible. However, the flush water demand may be met by using grey water collected in buckets, and latrine users use a small jug to scoop up the grey water and flush (Harvey, et al., 2002).

Costs

Since the interface is built together with a collection system preferred, the costs will be varying depending on the collection technology to be used.

3.2.1.3 Urine Diversion (UD)

Urine diversion (UD) user interface in a toilet are toilet bowl that collect urine separately from faeces and from water. UD toilet contains two outlets for collecting urine and faeces separately, and sometimes a third outlet is introduced when anal cleansing is practiced. UD result in two waste streams i.e. yellowwater from urine or excreta from dried faecal matter. In UD systems two collection systems are introduced. For urine, jerry cans or urine bladders can be used for collection while for dried faecal matter the single/ double vaults are used. UD systems have been applied in emergency due to the fact that they result in low volume of faecal matter compared to other systems that receive blackwater. UD do not mix water and faeces, but it is possible to mix urine with water as well as faeces with water (Von Münch and Winker, 2011).

Figure 3.3 Urine Diversion Interface (Source: Sustainable Sanitation - SuSanA)

Advantages

UD systems end products have potential for reuse in crop production as fertilisers. UD systems have little odour production due to urine faeces separation. The UD systems are water tight; therefore there is no groundwater pollution.

Limitations

The uses of UD systems end products are limited due to social acceptance as well as prevailing norms regarding the reuse of human excreta

Costs

UD system is generally low in costs. Since the interface is built together with the collection system preferred, the cost will be varying depending on the collection technology to be used.

3.2.1.4 Urinal

Urinals are user interface for urination both for men and woman. Urinal for women consists of raised foot-steps and a sloped channel directing urine to a collection technology while for men, urinals can either be wall-mounted units that are vertical or squat slabs that the user squats over (Tilley, et al., 2005). Urinals can be waterless or water flush urinal. However, in emergency, low cost waterless urinals have more potential to be used.

Figure 3.4 Low cost waterless urinal (Source: www.sswm.info)

Advantages
The urine collected is undiluted, therefore has a high potential for reuse as fertilizer. Waterless urinals produce fewer odours compared to water flush urinals. The urinal can be self built by local materials. In some cases, the provision of a urinal is useful to prevent the misuse of dry systems (e.g. UDDT). Urinals are appropriate for every climate.
Limitations
Urinals collect urine only and therefore they cannot be applied for excreta collection.
Costs
Generally, an urinal has low capital and operating costs. The costs vary depending on the materials used, whether it is a flush system, whether it is waterless or not, and on the disposal system (piping). The waterless urinal cost is low as it uses local materials like jerry cans. A study in South Africa show the prefabricated plastic urinals cost around 30 Euro per bowl without a stench strap (www.sswm.info/urinal).

3.2.2. Collection and Storage/ Treatment
In line with the requirements of emergency response, all selected technologies under collection-chain can be used immediately after its instalment or construction. Those technologies are described in the following sections.

3.2.2.1 Collection bags/ container

i. Biodegradable bags
Biodegradable bags refer to self sanitising personal single use toilet bags made from biodegradable water sealed materials, for example biodegradable plastics. They are similar to the common plastic bags in appearance; however, they contain enzymes which aid in the breakdown of excreta (Harvey, et al., 2002). An example of biodegradable bags is the peepoo bag, which is a biodegradable plastic bag with a liner coated on the inside by a thin film of urea. An enzymatic breakdown, aided by the naturally occurring enzymes in the faeces, starts when the urea comes into contact with the urine and faeces. The breakdown yields ammonia and carbonates which increase the pH of the contents to start a hygienisation process which kills pathogens.

In emergency, the biodegradable bags were introduced in two IDP camps by Oxfam GB after the earthquake in Port-au-Prince, Haiti, 2010 as a trial study (Patel, et al., 2011). Similarly, UN-HABITAT (2011) introduced peepoo bags trial study in Pakistan flood emergency camps. Both studies demonstrated packet toilet using standard and peepoo bags as a possible option for excreta disposal in emergencies (Patel, et al., 2011, UN-HABITAT, 2011). However, a proper collection and removal plan for the bags is inevitable for the success of the packet latrines. In the two IDP camps where the trial was conducted, a reduction in ‘flying toilets’, open defecations, and user reports on diarrhoea was observed (Patel, et al., 2011).

Advantages
Biodegradable bags are lightweight, thus can be deployed and distributed to a disaster affected population in a short time period. It can be used in various situations because it does not require any excavation or upper-structure construction, and it can be used where space is limited. Moreover, water and electricity is not required in the operation. It can be used as fertilizers when stored for 2 up to 4 weeks in at least 20°C (Gur, 2012). Also, they do not require operation and maintenance.

Limitations
The biodegradable bags should be utilized with good supervision and a good collection and disposal plan. A final disposal site must be identified, and the method may not be acceptable to all people in affected population.

Figure 3.5 Biodegradable bag [Source: www.peepoople.com]

Costs

Biodegradable toilets are very low cost. In the urban slum of Kibera in the outskirts of Nairobi, Kenya, the average cost for users is estimated to be about 10 USD per person per year (Gur, 2012). The calculation includes a drop point system where the users are refunded for handing in their used biodegradable bags, that later can be used as valuable fertilisers. Moreover the trial study in Pakistan carried by UN-HABITAT in a duration of three months indicates that the peepoo bags cost USD 16 per person (UN-HABITAT, 2011).

ii. Buckets/Container

Bucket or container latrines are comprised of buckets or containers with tight fitting lids that are provided for defecation, especially in situations where space is limited. The containers should be emptied at least daily for treatment. Disinfectants may also be used to minimize contamination and odour. Bucket or container latrines should be adopted only when other immediate measures are not available and the users find the method acceptable (Harvey, et al., 2002).

Advantages

The advantages of the bucket or container latrines include the ease of procurement and transportation of the containers. It's easy to clean and reusable. It has a low risk of pathogens transmission. In addition the latrines do not require water and electricity to operate, and requires less space thus are suitable where space is limited.

Limitations

The limitations for bucket or container latrines are that the containers may be put into different uses, the method may not be acceptable to many people, and their use requires extensive hygiene education to ensure safe final disposal. In addition a lot of disinfectant as well and a big number of containers are required, and the faecal sludge require treatment prior to final disposal.

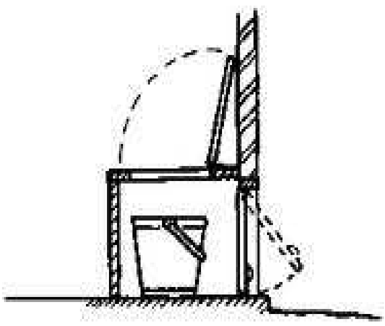


Figure 3.6 Buckets [Source: http://helid.digicollection.org]

Costs
Monvois, et al. (2010) gave the investment cost and operating cost for buckets and cart to be 300 -1000 Euros and 50 - 150 Euros respectively (equivalent to 392 - 1308 and 65 - 196 USD based on the exchange rate of 1Euro equivalent to 1.31 USD on 9th January 2013).

3.2.2.2 Pit non water tight
Single pit excavation non water tight are sanitation technology chain that includes the sanitation technologies that require pit excavation for excreta containment and the excavated pit is not water tight. This classification includes deep or shallow trench latrines, controlled open defecation, borehole latrines, pit latrines, and Arboloo. These sanitation technologies require deep/shallow excavation. In order to prevent flies from breeding, it's advisable after defecation to spread a thin layer of soil to cover the excreta. Clearly geophysical investigation on groundwater table should be done when a borehole latrine is introduced.

i. Controlled open defecation
Controlled open defecation areas of fields are open with strips for defecation situated far from water sources or food chain in order to avoid contamination. Controlled open defecation has a size of about 1.5m wide with screening sheets (Harvey, et al., 2002). One strip should be used at a time and marked well. In wet humid climates, it would be necessary to cover the faeces with soil or lime to reduce smell nuisance and flies, while in hot and dry climates faeces can be left uncovered to dry under the sun (Davis and Lambert, 2002). Moreover, Controlled open fields have been used in difficult non-excavation conditions in Zaire (Adams, 1999) at the influx of the Rwandan Refugees in 1994.
Advantages
Controlled open defecation fields are easy to construct and put in use within a very short time. In addition, the open fields do not require water or energy to operate, are easily understood, and can accommodate a large number of the affected population providing there is enough land.
Limitations
Controlled open defecation fields requires large land area, do not provide adequate privacy, can only be applied where people are accustomed to open defecation, and are not suitable in overcrowded conditions. The practice presents high chances of faecal contamination, have a short life-span, and the fields require intensive operation and maintenance.

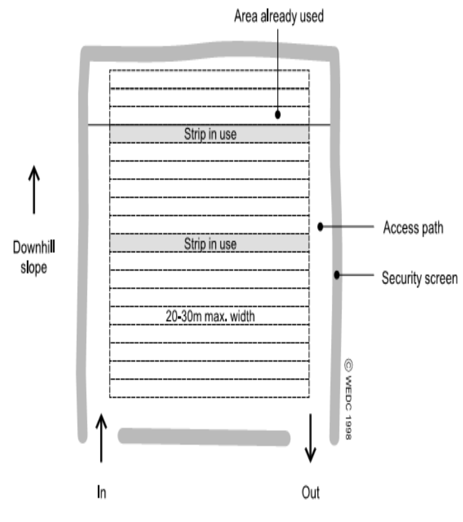


Figure 3.7 Open defecation field [Source: (Harvey, et al., 2002)]

Costs

The cost of controlled open defecation is relatively low provided land is available. It only requires labour for excavation work, and the fill materials are locally available.

ii. Trench latrines

Trench latrines can be excavated as shallow trench latrines or deep trench latrines.

Shallow trench latrines are 15cm deep, 20 to 30cm, and 4m long narrow trenches for defecation. The practice is similar as in controlled open defecation. Users defecate on trenches and cover with soil in order to prevent flies from breeding in the trench (Davis and Lambert, 2002, Harvey, et al., 2002).

Deep trench latrines are trenches of about 6m long, 0.8m wide and 2m deep with six cubicles above it with wooden board or logs placed across the trench for users to squat over while defecating. Furthermore, for partitioning of the cubicles the plastic sheeting or local material can be used in order to create privacy. Upon use, faeces are covered with soil reduce odour and prevent flies from breeding (Davis and Lambert, 2002, Harvey, et al., 2002).

Advantages

Trench latrines can be installed easily and rapidly, and odour and flies can easily be reduced simply by covering faeces with soil (Davis and Lambert, 2002, Harvey, et al., 2002). In addition, trench latrines have simple construction, operation and maintenance requirement, are easily understood, provide adequate privacy, and do not require water or energy to operate, and can be constructed with locally available materials. Furthermore, the faecal sludge is buried in situ and does not require handling and treatment.

Limitations

Trench latrines have limitations such as large space requirements, and a short lifespan (Harvey, et al., 2002). Moreover, trench latrines can be difficult to install in difficult conditions like high water tables areas, unstable soils and rocky grounds. The facilities present odour problems in hot climates (WHO, 2009), poor cleaning and maintenance, and have a relatively high land area requirement.

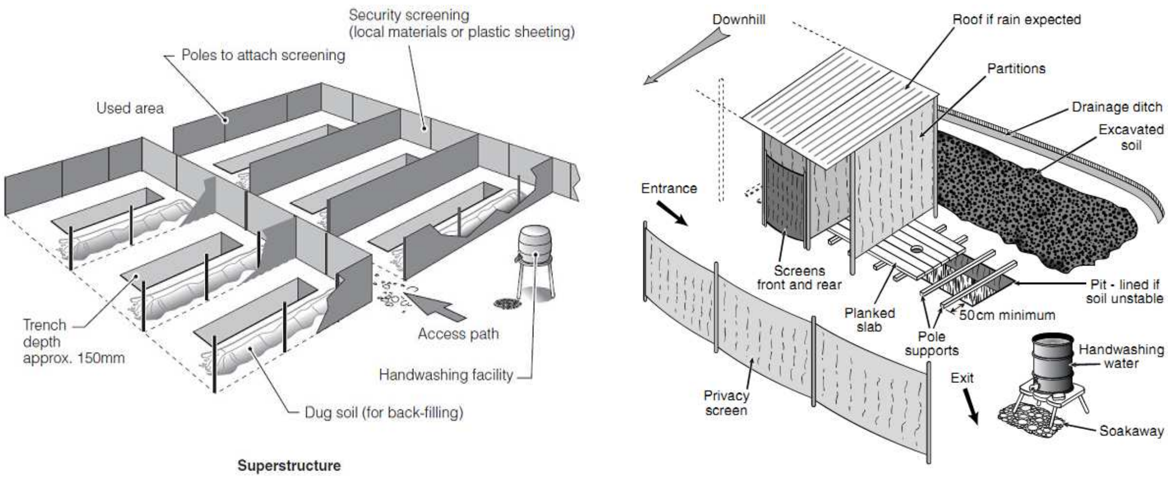


Figure 3.8 Shallow (L) and deep (R) Trench Latrine [Source: (Fernando, et al., 2009, PEN., 2010)]

Costs

Trench latrines cost is relatively low when land for excavation is available. It only requires labour for excavation work, and the fill materials are locally available. The cost can vary depending on the cost of land.

iii. Borehole Latrine

A borehole latrine is a drilled hole, either by hand or by machinery. These latrines are possible in emergency in areas with either high a groundwater table (GWT) or rocky areas. In rocky areas the machinery drilling is more applicable. In high GWT areas, the borehole should be lined and packed with gravel to prevent it from collapse as well as water piezometric level from rising. Moreover, the borehole is also applicable in either site condition. According to Harvey et al., (2002), a typical borehole latrine should be 4-8m deep with a diameter of about 40 cm. Also a diameters of up to 50cm can also be achieved in favourable soils (Davis and Lambert, 2002). The depth of borehole latrine is limited to GWT conditions which should be 2m below the bottom of the pit to avoid contamination (Davis and Lambert, 2002). In emergency, during heavy usage the borehole latrine lifespan can be reduced and installation of many units may be required to carter the population

Advantages

Borehole latrines are fast to install provided drilling equipment is available. They can be constructed in some difficult sites especially the hard ground conditions, and use minimal workforce (Harvey, et al., 2002). Moreover, borehole latrines are highly reliable, do not require water or electricity to operate, can use local materials for construction of the superstructure, and have simple operation and maintenance requirements. The borehole latrines do not require de-sludging and sludge handling as the content is left in the pit once it fills up.

Limitations

Very deep borehole latrine can result in risk of GWT contamination. Borehole latrine with small diameter has a chance of its hole being blocked.

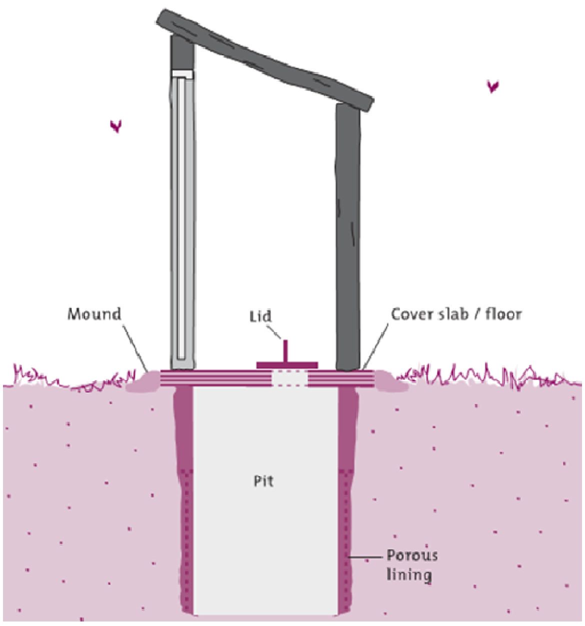


Figure 3.9 Borehole latrine [Source:(Brikké and Bredero, 2003)]

Costs

Borehole latrines costs are quite expensive due to sophisticated technology and machines required for drilling. Drill work depends on the type of soil, which have impact on cost. The drilling machine requires fuel to run which is expensive.

iv. Pit latrines

Pit latrines are rectangular or circular excavated pits covered by a hygienic cover slab, with a hole through which excreta fall into the pit. A superstructure is built on top of it. Hardcore/big stones are placed at the bottom of the pit. These hardcore cannot act as a seal since seepage can occur. Pit latrines can be one pit or a double pit depending on the collection volume required as well as when UD techniques are introduced. Moreover, the pit vault can be raised in areas where digging is difficult. In order to improve performance, the pit latrine technology is modified into other forms of pit latrines including *Simple pit latrine, Ventilated Improved latrine (VIP), Arboloo, and Fossa Alterna.*

Simple pit latrine

A simple pit latrine is comprised of a pit of 2m deep or more covered by a slab with a seat or squatting hole through which excreta falls directly into the pit (Harvey, et al., 2002). A superstructure can be made from locally available materials such as wood, mud and grass. Bricks and mortar can also be used to make a more permanent structure. The lifespan of the pit or the frequency of de-sludging will depend on the rate of sludge accumulation and the infiltration characteristics of the soil. The bottom of the pit should be 1.5 m above the water table and the horizontal distance should be at least 30m away from water sources (The Sphere Project, 2011). The latrine can be built in twin pits where it is not possible to dig a deep pit. The pits are dug side by side and a superstructure built over both pits with each pit having its own drop-hole.

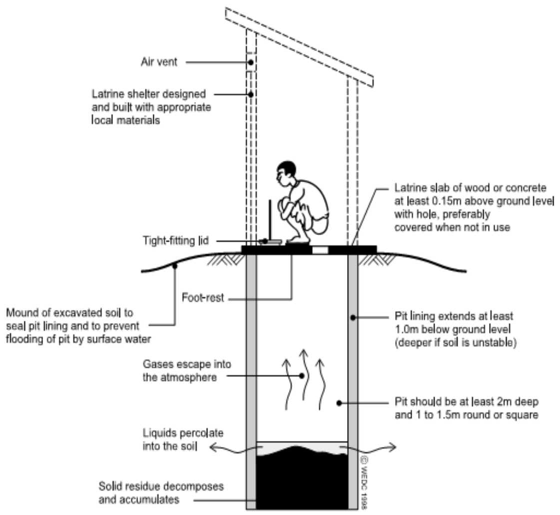


Figure 3.10 Simple pit latrine [Source: (Harvey, et al., 2002)]

Advantages

Simple pit latrines are fast to install (easy deployment), cheap since they can be built and repaired with locally available materials, have low operation and maintenance costs, are easily understood, and operate without water (Franceys, et al., 1992, Harvey, et al., 2002, Katukiza, et al., 2012). Simple pit latrines offer a reliable performance and service, and do not always require energy to operate except when de-sludging operations are necessary. Pit latrines can be used immediately after construction (Tilley, et al., 2005).

Limitations

Simple pit latrines are difficult to construct in situations such as areas with high water tables, rocky, compacted or unstable soils (Harvey, et al., 2002). They are likely to have odour and flies problems which may spread pathogens if they land on food or utensils (Cairncross, 1987, Harvey, et al., 2002). Pit latrines can also impact negatively on the environment as overflows and infiltration from pit latrines can pollute water sources (Katukiza, et al., 2012).

Costs

Pit latrines can be made of locally available material, and hence costs become relatively low. In Pakistan, pit latrine cost 18 USD per person in a trial study of three months (UN-HABITAT, 2011). Moreover, the manual on low cost sanitation technologies in Mongolia present the capital cost of a pit latrine to be 90 - 220 USD (Lahiri. S, 2006). Monvois, et al. (2010) gave the investment cost and operating cost for pit latrines to be 40-100 Euros and 5-15 Euros respectively (equivalent to 52- 130and 6- 19USD based on the exchange rate of 1Euro equivalent to 1.31 USD on 9th January 2013).

Ventilated Improved Pit latrine (VIP)

The ventilated improved pit latrine (VIP) is a pit latrine with ventilation that is fitted to the pit to overcome the simple pit latrine drawbacks of flies nuisance and unpleasant odour. The ventilation is usually a pipe screened with a gauze mesh or fly-screen at the top outlet(Davis and Lambert, 2002, Harvey, et al., 2002). The smell is carried upwards by the chimney effect and flies are prevented from leaving the pit and spreading disease. Similarly with the simple pit latrines, VIPs can be built in twin pits where it is not possible to dig a deep pit. The pits are dug side by side and a superstructure built over both pits with each pit having its own drop-hole.

Advantages

The VIPs reduce flies and odour nuisance, provide quality long-term solution, require small land space, do not need a constant source of water, can be constructed and repaired with locally available materials, and is suitable for all types of users like squatters, sitters, wipers and washers (Harvey, et al., 2002, Tilley, et al., 2005). Like the simple pit latrines, the VIPs have a short start up time (can be used immediately after construction), low operation and maintenance costs, and are easily understood. VIPs offer reliable performance and service, and do not always require energy to operate except when de-sludging operations are necessary.

Limitations

VIPs have the same limitations as simple pit latrines. VIPs are more costly than simple pit latrines, may take longer time to construct (not easily deployed)(Davis and Lambert, 2002) , and their dark interior may limit their usage by children (Harvey, et al., 2002).

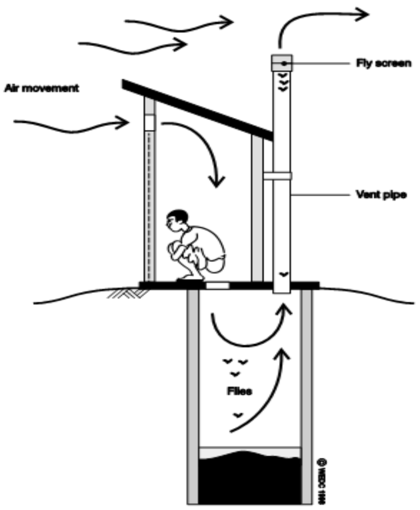


Figure 3.11 VIP [Source: (Harvey, et al., 2002]

Costs

Moreover, the manual on low cost sanitation technologies in Mongolia present the capital cost of a VIP to be 110 - 220 USD (Lahiri. S, 2006). Monvois, et al. (2010) gave the investment cost and operating cost for VIP to be 100-300 Euros and 5-15 Euros respectively (equivalent to 130 - 392 and 6 - 19 USD based on the exchange rate of 1Euro equivalent to 1.31 USD on 9th January 2013).

v. Arborloo

The arboloo is a shallow pit (1.0 to 1.5 m deep) and a toilet, both temporary (Gensch and Sacher, 2012). When the pit is full, it is filled with soil and covered and left to compost. Then, the toilet (consisting of a ring beam, slab and structure) moves from one site to the next at 6 to 12 month intervals(Gensch and Sacher, 2012). Although there is no benefit recovered, the full pit poses no immediate health risk. A tree is planted on top and will grow vigorously in the nutrient-rich pit.

Advantages

The arborloo is a simple technique for all users. It has low capital and operating costs. An arborloo has a low risk of pathogen transmission. Furthermore, it may encourage income generation i.e. tree planting and fruit production.

Limitations
Arborloo is requires relatively labour intensive (a new pit needs to be dug every 6 to 12 month) (Gensch and Sacher, 2012). It is not suitable in areas with a high groundwater table because it results in ground water contamination. Is only possible where there is enough space.
Costs
Arborloo are cost effective technologies cost about 7-20 USD (Leech 2010).

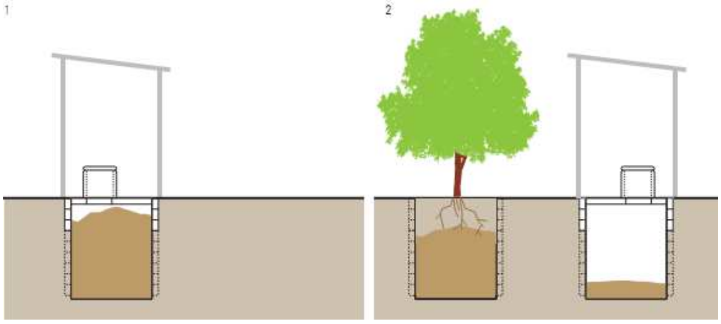


Figure 3.12 Arborloo [Source: (Tilley, et al., 2005)]

3.2.2.3 Pit water tight

Single pit excavations water tight is a group of sanitation technologies which include the excavation of water tight pits. This sanitation technology includes septic tank toilets (also plastic made septic tanks) and its modification technologies like Anaerobic Filters (AF), Anaerobic Baffled Reactors (ABR), Aqua privies as well as fossa alterna. These sanitation technologies collect excreta and wastewater in the sealed pit storage in order to reduce ground water contamination. Also the excreta in the storage chamber undergo anaerobic biodegradation treatment which later results in stabilised sludge and effluent. The sludge can be emptied manually or by motorised equipments. Overflowed partially treated effluent can be disposed through sewerage system, water disposal or soakaway system. Pit water tight sanitation technologies fall into the following sanitation chain. Figure below entails. The study refers to design specifications of these technologies for common used technologies to household level. Furthermore exceptions can be made for septic tanks to serve to a community level.

i. Septic tank toilet

A septic tank is watertight settling tank usually installed underground into which raw wastewater is delivered through a short sewer receiving the waste from plumbing fixtures inside a building. The septic systems in emergency receive black water. A septic tank is appropriate where wastewater is generated in relatively large amounts that may not be possible to dispose of in pit latrines, and where sewerage is unaffordable or uneconomical. Septic tanks may also be applied in areas where water is used for anal cleansing (Harvey, et al., 2002). Moreover, the system has relatively good performance achieving removal efficiencies of 60 % for BOD and 80% for TSS with an estimated 25% of nitrogen removal by sludge settlement (Fenner et al., 2007). Septic tanks have potential in emergencies because it can serve a big number of populations.

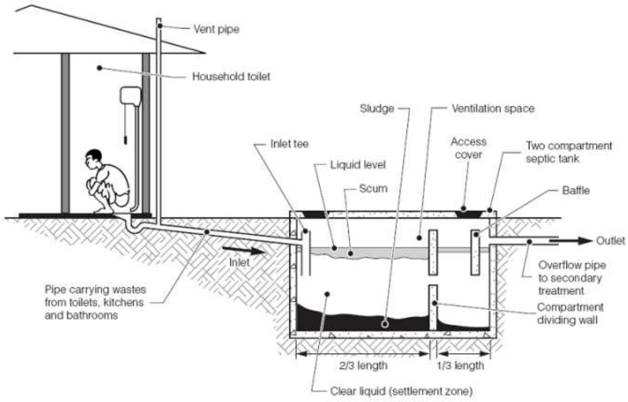


Figure 3.13 Septic Tank [Source: (Harvey, et al., 2002)]

Advantages

Septic tanks have as advantages that they can be raised and used in difficult situations including rocky and flood prone areas where pit latrines and other technologies requiring excavation are not suitable, they can be constructed with locally available materials, have long life of service, can reduce odour and flies nuisance, and require small space. Septic tanks do not require electricity.

Limitations

The application of septic tank technology is limited by the fact that it requires constant supply of water, the effluent and sludge require secondary treatment for further reduction in pathogens and organics. Moreover, septic tanks are not suitable in some difficult conditions especially in areas with high water table and frequent flooding (Tilley, et al., 2005).

Costs

Septic tanks are attractive as they have low capital and operation costs (Tilley, et al., 2005). Moreover, the manual on low cost sanitation technologies in Mongolia present the capital cost of a septic tank to be 90 - 375 USD (Lahiri. S, 2006). Monvois, et al. (2010) gave the investment cost and operating cost for septic tank to be 500-800 Euros and 5-10 Euros respectively (equivalent to 654 - 1046 and 6 - 13 USD based on the exchange rate of 1Euro equivalent to 1.31 USD on 9th January 2013).

ii. Anaerobic Filters (AF)

An anaerobic filter (AF) is an anaerobic system consisting of a sedimentation tank followed by chambers or columns filled with filter media that supports growth of biomass. The filter media can be natural materials including smooth quartzite pebbles, shells, granite stones, cinder, brick ballast gravel, crushed rocks, coke, or specially moulded synthetic materials such as polyvinyl-chloride sheets, needle-punched polyester, glass among others (Jawed and Tare, 2000, Tilley, et al., 2005, van Lier, et al., 2008). Based on the mode of feeding, two types of AF are up-flow anaerobic filters (UAF) and down-flow anaerobic filters (DAF) (Jawed and Tare, 2000). In both types, wastewater flows through the filter media where particles are trapped and the organics are broken down by the active biomass attached on the filter media. According to Tilley et al., (2005), the recommended HRT of the system is about 0.5 to 1.5 days and a maximum surface loading rate of 2.8 m3/m2/day. AFs can attain removal efficiencies of up to 85% of suspended solids and 90% of BOD (Tilley, et al., 2005).

Advantages

AF has advantages that they can be raised and used in difficult situations including rocky and flood prone areas where pit latrines and other technologies requiring excavation are not suitable, they have long life of service, can reduce odour and flies nuisance, and require small space. Anaerobic filters can be constructed with locally available materials, does not require electricity to operate.

Limitations
The treatment system requires water to operate, a long start up time of 6 to 9 months (necessary for biomass to stabilize), and expert design and construction (Tilley, et al., 2005). Anaerobic filters are susceptible to clogging and thus restricted to treat wastewater with low solids concentration. The filters have possibilities for odour generation (von Sperling and Chernicharo, 2005). The effluent and sludge requires secondary treatment.

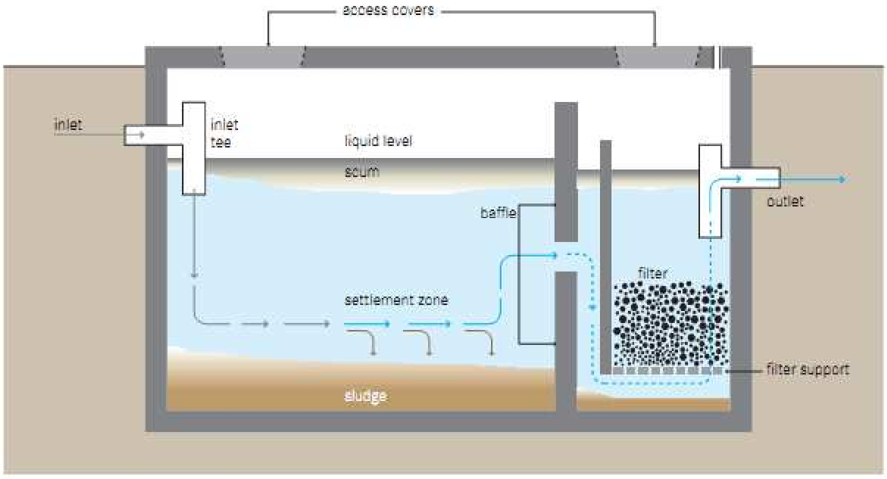


Figure 3.14 Schematic layout of Anaerobic Filters (AF) [Source: (Tilley, et al., 2005)]

Costs
Monvois, et al. (2010) gave the investment cost and operating cost for AF to be 150-400 Euros and 2-4 Euros respectively (equivalent to 196 - 523 and 2 - 5 USD based on the exchange rate of 1Euro equivalent to 1.31 USD on 9th January 2013).

iii. Anaerobic Baffled Reactor (ABR)
An anaerobic baffled reactor is an improved version of the septic tank. It has a series of baffles in narrow up-flow chambers in which wastewater has an increased contact time with active biomass as it flows through, thus improving the effluent quality (Foxon KM, 2004, Parkinson and Tayler, 2003, Tilley, et al., 2005). The flow of wastewater through the chambers is dependent on the design of the baffles. In one design according to Parkinson and Tayler (2003), the wastewater is fed from the bottom of the first chamber where it flows through the biomass accumulated at the bottom before passing up the chamber where it is conveyed through a pipe to the bottom of the next chamber(Parkinson and Tayler, 2003)(Parkinson and Tayler, 2003). In another design, the ABR is compartmentalized by alternating hanging and standing baffles where wastewater flows up and down from one compartment to the next (Foxon KM, 2004). The ABR system yields a low sludge production based on its anaerobic digestion nature. Much of the solids removal is achieved at the sedimentation chamber which takes about 50 percent of the reactor's total volume. The BOD removal efficiency of an anaerobic baffled reactor can be up to 90 percent. Like the AF and septic tank systems, the ABR can be used for onsite treatment of wastewater generated from wet sanitation systems during emergency.

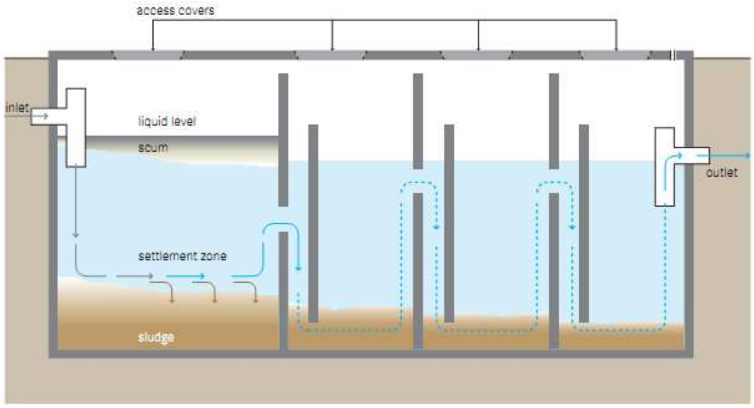


Figure 3.15 Schematic layout of (ABR) [Source: (Tilley, et al., 2005)]S

Advantages
The ABR has advantages that it can be constructed with locally available materials, has long life of service, reduces odour and flies nuisance, and high reduction efficiency of organics. It does not require electricity, has low yield of sludge, and is resistant to organic and hydraulic shock loads (Foxon KM, 2004, Tilley, et al., 2005). Moreover, the system requires minimal maintenance (Foxon KM, 2004). The ABR serve a number of people per unit thus reducing the land requirements.

Limitations
ABR is limited in that it requires a constant supply of water, the effluent and sludge require secondary treatment due to low reduction in pathogens and organics, and pre-treatment is required to prevent clogging. Moreover, ABR requires expert design (Tilley, et al., 2005). The construction and start up of the ABR system may take a long time.

Costs
Monvois, et al. (2010) gave the investment cost and operating cost for ABR to be 150-400 Euros and 2-4 Euros respectively (equivalent to 196 - 523 and 2 - 5 USD based on the exchange rate of 1Euro equivalent to 1.31 USD on 9th January 2013).

iv. Aqua privies
An aqua privy consists of a latrine build directly over a septic tank with a drop pipe (10-15cm dia.) extending about 7.5-10cm below the liquid level in the tank to form a water seal that excludes odours from the superstructure. The tank of the aqua privy is made water tight to ensure a constant liquid level. Since the tank is directly underneath the drop hole interface, an aqua privy uses less flush water than that used for septic tanks (Cairncross, 1987, Harvey, et al., 2002). Aqua privies are most appropriate where pit latrines are limited due to social or technical reasons (Harvey, et al., 2002).

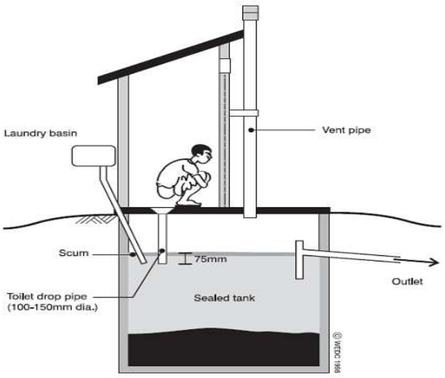


Figure 3.16 Aqua Privy [Source: (Harvey, et al., 2002)]

Advantages

The use of aqua privies has advantages that they can be raised and used in difficult situations including rocky and flood prone areas where pit latrines and other technologies requiring excavation are not suitable, they can be constructed with locally available materials, have long life of service, can reduce odour and flies nuisance, and require small space. Aqua privies do not require electricity (Tilley, et al., 2005). They use less water compared to septic tank toilets.

Limitations

Aqua privies require constant water supply, their effluent and sludge is poor quality and require secondary treatment. Moreover, adoption of aqua privies can only be suggested for very specific applications since they require frequent emptying and constant maintenance (Tilley, et al., 2005). Furthermore, installation of the aqua privies may take long time, and the systems are applicable for blackwater disposal.

Costs

The manual on low cost sanitation technologies in Mongolia present the capital cost of a Aqua privies to be 90 - 375 USD (Lahiri. S, 2006).

v. Fossa Alterna

Fossa alterna is an alternating double pit dry toilet designed to make ecohumus. The pits are lined and have a maximum depth of 1.5m and require constant usage of soil (Stauffer, 2012). The pits are used alternately since one pit is left to degrade the waste once it fills up and the other pit is put into operation. The degradation of the waste usually takes about one year. Soil, ash, and leaves are added after every defecation (not urination) for hygiene and also to enhance degradation of the waste (Tilley, et al., 2005). When the waste is degraded (after 1 year) the humus is removed for land applications and the pit can be reused. Fossa alterna can be emptied manually.

Advantages

Fossa alternas can be built and repaired with locally available materials and present a good opportunity for reuse as the stored faecal material can be used as soil conditioner. The technology requires small land space, does not need constant water source, offers significant reduction in pathogens, and is suitable for all types of users like squatters, sitters, wipers and washers. Moreover, fossa alternas have low operating costs and their service life is unlimited due to the alternate use of the double pits (Tilley, et al., 2005).

Limitations

The fossa alternas require continuous source of cover material like soil, ash and leaves (Tilley, et al., 2005). It is not suitable in areas with a high groundwater table.

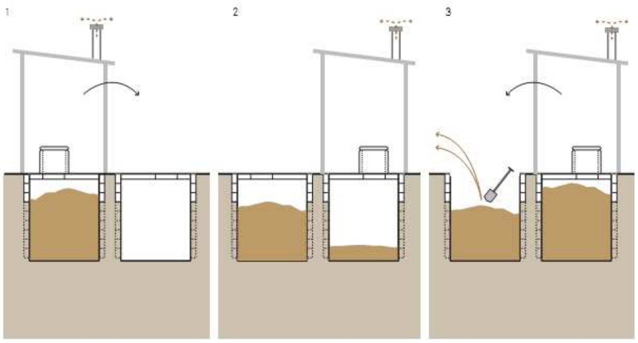


Figure 3.17 Fossa Alterna [Source: (Tilley, et al., 2005)]

Costs

The fossa alterna are cost effective technologies. They use locally available materials. PILS (2011) gave a cost estimate for a fossa alterna made of local material to be 248,400 UgSh equivalent to 92USD based on the exchange rate of 1UgSh equivalent to 0.0004 USD on 9th January 2013.

3.2.2.4 Storage latrine

Storage latrines refer to sanitation technologies that are water tight and do not require excavation. The storage latrines are applicable in areas where it is not possible to dig and in areas that have a high water table or are flooded. Moreover, they can be used together with different user interface devices including UD, drop hole and pour flush. Storage latrines can be raised in areas that are difficult to excavate, or in areas having a high groundwater table (GWT) (e.g. raised latrine), or can float in flooded areas (e.g. floating latrine). Storage latrines are environmentally friendly as all waste is contained in the storage container. Pollution and contamination are minimal in this case.

i. Floating latrines

A floating latrine is a urine diversion latrine technology provided in water logged and flood prone areas. A floating latrine contains a separate container for solid, urine and cleansing water. These containers are replaceable whenever they are full. The floating latrine is efficient on a water body. The empty containers act as buoyant in order to keep the latrine floating.

Advantages

The floating latrine has an in-built system ensuring separate storage of faeces, urine and anal cleaning water. It's possible to use products as fertilizers.

Limitations

Floating latrine function all the time on the water (before, during and after flood). Excreta disposal place need to be identified.

Costs

Compared to a normal latrine they have higher costs. Ali (2011) from Oxfam gave cost of floating latrine in a Ecosan toilet seminar in Bangladesh to be BTD 24,000 which is equivalent to 300 USD based on the exchange rate of 1BDT equivalent to 0.01 USD on 9th January 2013.

Figure 3.18 Floating emergency latrine [Source: Oxfam]

ii. **Raised/Storage latrine**

Storage tank toilets are also known as raised latrines constituting of big tanks positioned above ground with wooden platforms and superstructure fitted above with provision of steps for users to access the latrine. They can be used in emergency situations with flooding conditions or where the ground is difficult excavate due conditions such as high groundwater table, hard or rocky soils, and land regulations that do not allow for excavation. A final disposal site and proper emptying mechanism should be identified well in advance as the tanks would require regular emptying. Storage/raised latrine can be used with user interfaces such as UD and drop hole.

Advantages

Raised latrines provide a good solution to difficult areas where excavation is impossible, and offer a solution to minimize contamination of groundwater. The latrines can be installed relatively fast and used immediately, are easily understood, do not require continues water supply, offer reliable performance and service, and do not always have a high energy demand to operate except in de-sludging operations.

Limitations
Storage tank latrines need regular emptying, suitable materials must be available for superstructure and steps, and containers which could be used for other purposes are required in large numbers for the latrines (Harvey, et al., 2002). These latrines do not provide any treatment thus the raw faecal sludge need treatment before final disposal. Spills and overflows may pollute the environment.

Figure 3.19 Raised toilet units in Haiti [Source: International Federation of Red Cross and Red Crescent Societies]

Costs
UN-HABITAT (2011) in the trial study for peepoo use in Pakistan did a comparison of technologies including raised toilet. The cost of raised toilet for duration of three month is 30 USD

3.2.2.5 Composting Toilets

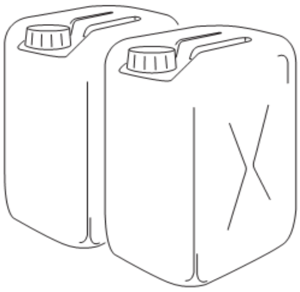
A composting toilet is a dry toilet whereby excreta are treated separately from urine and other liquids like flush water. The composting toilets include UDT and UDDT systems. Composting toilets undergo aerobic decomposition. Composting toilets are designed for minimal use of water. Furthermore with composting toilets there is an advantage of capturing nutrients from urine and faeces for agricultural use. Excreta are normally mixed with sawdust to support aerobic processing, absorb liquids, and to reduce the odour. The decomposition process is generally faster than the anaerobic decomposition used in wet sewage treatment systems such as septic tanks. Composting toilets follow the following sanitation chain. The UDT/UDDT results in two waste streams, yellowwater from urine and brownwater. The yellowwater is collected in jerrycans or urine bladder whereas the dried faecal matters are collected in vault chambers. The vault chambers can be single vault or double vault chamber.

i. UDT/UDDT
Urine-diversion toilets are built in such a way that they divert all liquids (i.e. urine and anal cleansing water, if applicable) from the faeces to keep the processing chamber contents dry. UDDTs make use of desiccation (dehydration) processes for the hygienically safe on-site treatment of human excreta. After defecation normally wood ash, lime, sawdust, dry earth etc. is added in order to lower the moisture content and raise the pH, which enhances pathogen die-off during storage. If wet anal cleansing habits prevail in a community, anal cleansing water must be diverted (e.g. by providing a separate washbowl) for practical reasons. Separately collected urine is rich in nutrients and low in pathogens and can be used as fertiliser. Faeces from UDDTs can be composted or stored and dried before using them as soil amendment for crop production. Both UDT and UDDT are emptied manually and transport.
Advantages
UDT/UDDTs are built entirely above ground to provide for easy access to the processing chambers, which are placed on a solid floor of concrete, bricks or clay and the floor is built up to at least 10 cm above ground so that heavy rains do not flood it (WINBLAD et al. 2004). Therefore, it is suitable for hard rock soil areas, high ground water levels and areas prone to flooding. It's is simple in construction, does not require water, and no groundwater source contamination. There is reuse potential since both urine and dried faecal matter can be used as fertilizers.

Limitations
Double-vault UDDTs require a large surface area for construction. If not operated well, there is a possibility of smell. Regular shifting of containers from single-vaults is needed as well the transport of human excreta to secondary storage and/or processing site. Furthermore, the bulking material is needed.

Single-vault UDDT in Libertad, Misamis Oriental, Philippines [Source: www.sswm.info].

Double-vault UDDT, Vietnamese style, Bhutan [Source: www.sswm.info].



Jerrycan Source: (Tilley, et al., 2005)

Urine storage tank made of a plastic bladder [Photo commissioned by: E. v. Münch, 2007.]

Figure 3.20 Urine Diversion Dehydrated Toilets (UDDT)

Costs
The cost for UDDT toilets can be varying depending on design and material used. The manual on low cost sanitation technologies in Mongolia present the capital cost of a UDDT to be 130 - 250 USD (Lahiri. S, 2006). Monvois, et al. (2010) gave the investment cost and operating cost for UDDT to be 200 - 400 Euros and 5-15 Euros respectively (equivalent to 261- 523 and 6- 19 USD based on the exchange rate of 1Euro equivalent to 1.31 USD on 9th January 2013). Furthermore, Van Buuren (2010) gave a construction cost for UDDT to be 90 - 892 USD with a total annual cost per household of 27 -28 USD/hh/yr.

ii. Terra preta
Terra Preta sanitation (TPS) is a technology that has been re-developed and adopted based on former civilisation in the Amazon which resulted in high fertile soil (Factura, et al., 2010). TPS includes excreta containment, additional of biochar, and includes lacto fermentation process as well as vermicomposting (Andreev, et al., 2012, Factura, et al., 2010). Terra preta uses the urine diversion interface which facilitates the lacto fermentation process. Excreta are collected in a container and a mixture of sawdust, soil, and biochar is added. Upon full, excreta can be conveyed using plastic bags and closed to create anaerobic conditions which initiates lacto fermentation process. The end product is rich in macro nutrients from urine and faeces and hence poses potential for soil amendments. TPS lacto fermentation process showed higher pathogen removal compared to composting (Andreev, et al., 2012).

Advantage
TPS technology is simple. It reduces smell and reduces risk to pathogens (Andreev, et al., 2012). Moreover, it contributes to high value soil improvers. It requires no water or energy.
Limitation
Technology requires addition cover material or biochar.
Costs
Relatively low. No cost calculations were found based on literature.

iii. Porta preta
Porta preta is a portable toilet which uses same principle as in terra preta. Porta preta is ready made toilet unit with urine diversion interface. Urine is collected and ready for reuse whereas faeces collected and let to undergo lacto fermentation process. The final product can be used as soil additive. According to Kinstedt (2012), the porta preta unit designed for disaster relief serves five users. Despite the emergency circumstances, the organic waste residuals can be used as biochar.

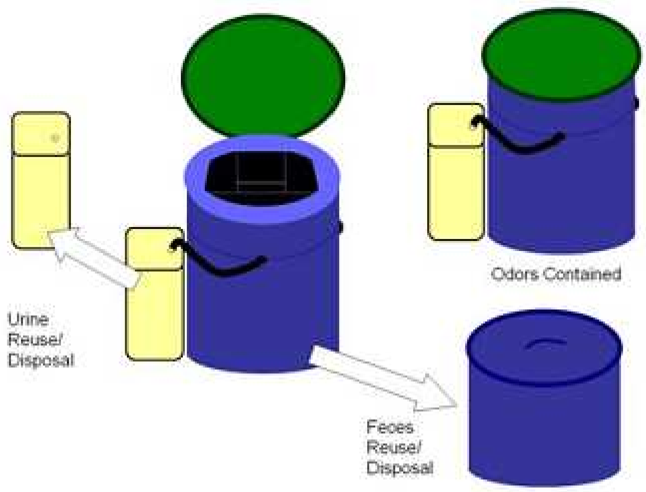


Figure 3.21 Porta preta [source: (Kinstedt, 2012)]

Advantages
Porta preta is portable and can be delivered at site easily. It is odourless.
Limitation
It requires users to stir for proper functioning of the system. Also, to deliver lactofermenting bacteria is a challenge (Kinstedt, 2012).
Costs
The porta preta unit cost USD 25

3.2.2.6 Chemical toilet
Chemical toilets (Portaloos) are prefabricated plastic units with toilet seats, a lockable door and sealed holding tank containing chemicals. The chemical used can be either formaldehyde or bromine, which are diluted with water and placed in holding tanks. The chemicals help in digesting the waste and reducing odour. Moreover, there are two main types of portable chemical toilets i.e. those that flush and those that do not. The toilets that flush look similar to a regular house toilet. Instead of water being used during flushing, the toilet chemicals are re-circulated during the flush cycle. Portable toilets that do not flush have an open design where you can see directly into the tank. The tanks are regularly emptied. To empty the portable toilets, a hose is hooked up to a connection on the toilet and the toilet connection is opened allowing the waste and chemicals to exit. For health safety reasons and to avoid groundwater contamination, toilet waste must be emptied in a proper disposal facility. Chemical toilets are generally considered an expensive and unsustainable solution only used temporarily in developed countries (Harvey, et al., 2002).

Figure 3.22 Chemical Toilet. [Source: http://www.cdc.gov/healthywater/emergency/cleaning/sanitation.html]

Advantages
The chemical toilets are hygienic, require short start up time, simple to use, do not require water to operate, minimize odour problems, and can be used in difficult situations such as flooding and non-excavation sites. Moreover, chemical toilets can be easily deployed to the site, and do not require power supply.

Limitations
The operation and maintenance of chemical toilets is expensive due to regular emptying and cleaning, they are difficult to transport, and the resulting sludge may require treatment before final disposal. Furthermore, chemical toilets do not use local materials, do not provide reuse opportunities, and can only handle one stream, the excreta.

Costs
No cost calculations were found based on literature.

3.2.3. Conveyance

3.2.3.1 No emptying and transport

After collection and storage, the faecal sludge and dried aecal matter needs to be conveyed to a treatment point. Some of the collection/ storage technologies do not require conveyance (i.e. No emptying and transport) since they are onsite sanitation. Below is the sanitation chain with technologies that require no emptying and transport.

3.2.3.2 Human power emptying/ collection and Transport

Manual emptying and transport refers to the different ways in which people can manually empty and/or transport sludge and dried faecal matter. The process can be achieved through the use of buckets and shovels, hand-pump specially designed for sludge e.g. the Pooh Pump or the Gulper (WaterAid, 2010); and using a portable, manually operated pump e.g. MAPET: Manual Pit Emptying Technology (Thye, 2009). The type of emptying that can, and should be employed, is very specific to the technology that needs emptying. Some sanitation technologies can only be emptied manually, including, the Fossa Alterna or UDT. These technologies must be emptied with a shovel because the material is solid and cannot be removed with a pump. Hand-pump e.g. MAPET are used when sludge is viscous or watery rather than buckets because of the high risk of collapsing pits, toxic fumes, and exposure to the unsanitized sludge (Tilley, et al., 2005). Manual sludge pumps are relatively new inventions and have shown promises as being low-cost, effective solutions for sludge emptying where, because of access, safety or economics, other sludge emptying techniques are not possible. Figure below indicates different technologies in the chain that can be manually emptied and transported.

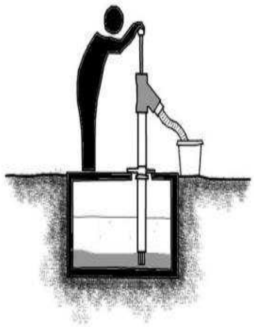


Figure 3.23 Human powered emptying (www.sswm.info)

Advantages
Human powered emptying/ collection and transport use locally available materials. The equipments used are easy to clean and are reusable. It can serve in unsewered areas. Human powered emptying/ collection and transport do not require electricity.
Limitations
It is time consuming as it can take several hours in a day depending on the size of a pit. During emptying and transportation spills may happen. Also it requires some specialized repair like welding for the case of MAPET.
Costs
According Thye (2009), the cost of pit emptying is 39 - 104 USD (Bongi and Morel, 2005), 130 USD (Eales, 2005). Manual de-sludging Hand Pump (MDHP) cost 40 USD (Thye, 2009).

3.2.3.3 Human powered emptying / collection and motorised transport

This is similar like human powered emptying/ collection and transport but with motorised transport. In some cases the treatment or disposal pints are offsite, therefore motorised transportation is required. An example of motorised transport is cartwheels which are used to carry used buckets or biodegradable bags.
Advantages
Human powered emptying/ collection and motorised transport can be used in areas that are not accessible by vehicle. It can serve in unsewered area. It does not require electricity.
Limitations
It is time consuming as it can take several hours in a day depending on the size of a pit. During emptying and transportation spills may happen.
Costs
According Thye (2009), cost of pit emptying is 39 - 104 USD (Bongi and Morel, 2005), 130 USD (Eales, 2005).

3.2.3.4 Motorised emptying and transport

Motorized Emptying and Transport refers to a vacuum truck or another vehicle equipped with a motorized pump and a storage-tank for emptying and transporting faecal sludge, septage and urine. Humans are required to operate the pump and manoeuvre the hose, but not to lift or transport the sludge. The pump is connected to a hose that is lowered down into a constructed tank (e.g. septic tank or aquaprivy) or pit, and the sludge is pumped up into the holding tank on the truck. The cost of hiring a vacuum truck can sometimes be the most expensive part of operation (Tilley, et al., 2005). A fully sustainable system for emptying pit latrines in refugee camps was introduced by UN-HABITAT Vacutug Project in 1995. The Vacutug consists of a 0.5 m^3 steel vacuum tank connected to vacuum pump which is connected to a gasoline engine. Below figure show different technologies in the chain that can be motorised emptied and transported.

Advantages
Motorised emptying and transport are fast and generally efficient. It can also serve in un-sewered areas.
Limitations
It cannot pump thick dried sludge, and sometimes the hose can be blocked by garbage. Pumps can only suck down to a limited depth (Tilley, et al., 2005).). Some of materials are not locally found. It can encounter accessibility difficulties for location without access to 4-wheeled vehicles.
Costs
Thye (2009) present a vacuum tanker to be 50,000 - 80,000 USD. Moreover the cost of motorised vacuum tanker is 20,000 - 100,000 USD (Brikké and Bredero, 2003). Furthermore, Monvois, et al. (2010) presented an investment cost of Euro 10,000-50,000 and operation cost of Euro 1,000 to10,000 per truck (equivalent to 13,085 -65,425 and 1,308.5 - 13,085 USD respectively as per exchange rate of 9th january,2013).

3.2.3.5 Sewerage systems

Whenever a sewerage system exists in the area affected by disaster, it can be used for sewage disposal. Toilet blocks can be installed and connected to the sewers. However, the system should be inspected first to ensure that it is functioning normally and it has the capacity to handle the increased load. Adequate quantity of water, about 20-40 litres per user per day, should be availed for flushing.

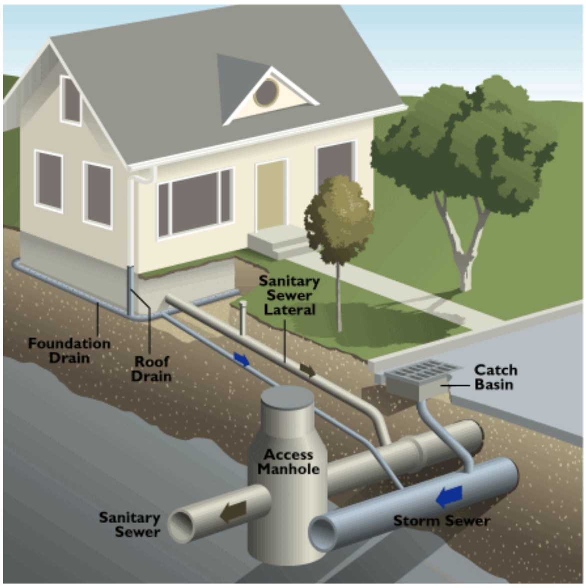


Figure 3.24 Sewerage systems [Source: http://hurricaneplumbing.com/sewer/]

Advantages
Existing sewerage systems speeds up the response delivery, it saves cost, and minimal land requirement. Furthermore, it requires no electricity to operate and it can serve large population.
Limitations
The sewerage system requires adequate water to flush. If the population increases, the system is not resistance to shocking loads (if not designed for extra load).
Costs
According to Van Buuren (2010) the sewerage cost in Vietnam was 68 - 150 USD/hh/yr. The construction cost was 63. - 134. USD/hh/yr and the recurrent cost was between 4 - 15 USD/hh/yr.

3.2.4. Semi Centralized Treatment System 1

3.2.4.1 Co-composting

Co-Composting is the controlled aerobic degradation of organics using more than one feedstock of faecal sludge and organic solid waste. Faecal sludge has a high moisture and nitrogen content while biodegradable solid waste is high in organic carbon and has good bulking properties (i.e. it allows air to flow and circulate). By combining the two, the benefits of each substance can be used to optimize the process and the product (Tilley, et al., 2005). Open composting; the mixed material (sludge and solid waste) is piled into long heaps called windrows and left to decompose. Windrow piles are turned periodically to provide oxygen and ensure that all parts of the pile are subjected to the same heat treatment. Windrow piles should be at least 1m high, and should be insulated with compost or soil to promote an even distribution of heat inside the pile. Depending on the climate and available space, the facility may be covered to prevent excess evaporation and protection from rain.

Advantages

Co-composting can be built and repaired with locally available materials and requires no electrical energy. It's easy to set up and maintain with appropriate training. It has high removal efficiency of helminth eggs hence provides a valuable resource for local agriculture and food production.

Limitations

Co-composting requires expert design and operation. It needs longer storage times and its labour intensive. It can't be applicable in areas where space is lacking, as it requires well located large area.

Costs

No cost calculations were found based on literature.

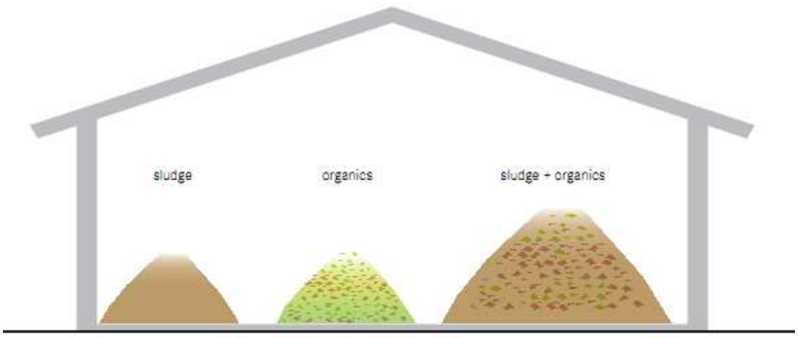


Figure 3.25 Co-composting [Source: (Tilley, et al., 2005)]

3.2.4.2 Unplanted 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. The bottom of the drying bed is lined with perforated pipes that drain away the leachate. On top of the pipes are layers of sand and gravel that support the sludge and allow the liquid to infiltrate and collect in the pipe. The sludge should be loaded to approximately 200kg TS/m2 and it should not be applied in layers that are too thick (maximum 20cm), or the sludge will not dry effectively. The final moisture content after 10 to 15 days of drying should be approximately 60%. A splash plate should be used to prevent erosion of the sand layer and to allow the even distribution of the sludge. When the sludge is dried, it must be separated from the sand layer and disposed of. The effluent that is collected in the drainage pipes must also be treated properly. The top sand layer should be 25 to 30cm thick as some sand will be lost each time the sludge is manually removed.

Advantage

It uses locally available material for building as well for repair. No electrical energy is required.

Limitation
Unplanted drying beds requires expert for design and operation. It is applicable where land is available since it requires a large land area due to wet/dry cycles. Also, it needs longer storage times. The leachate requires secondary treatment. Odours and flies are normally noticeable.
Costs
Monvois, et al. (2010) presented an investment cost and operational cost for unplanted drying beds per house hold (hh) to be 20 - 50 Euro/hh and 2 - 4 Euro/hh/yr respectively (equivalent to 26 - 65 USD/hh and 2 - 5 USD/hh/yr).

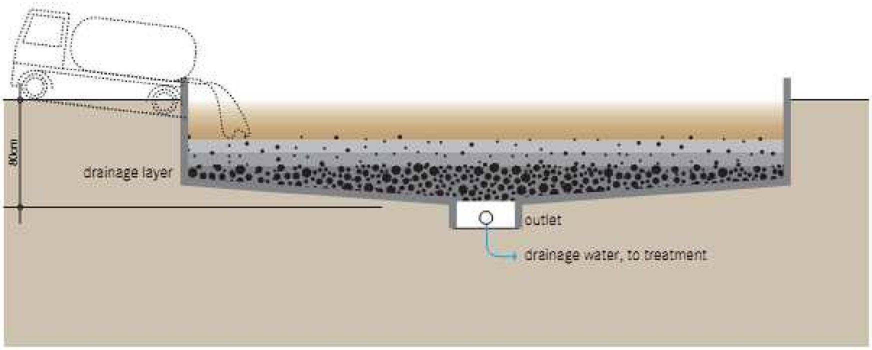


Figure 3.26 Unplanted drying beds [Source: (Tilley, et al., 2005)]

3.2.4.3 Planted drying beds
A Planted Drying Bed is similar to an Unplanted Drying Bed with the benefit of increased transpiration. The key feature is that the filters do not need to be desludged after each feeding/drying cycle. Fresh sludge can be applied directly onto the previous layer; it is the plants and their root systems that maintain the porosity of the filter. This technology has the benefit of dewatering as well as stabilizing the sludge. Also, the roots of the plants create pathways through the thickening sludge to allow water to escape more easily. 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 to collect in drains. When the bed is constructed, the plants should be planted evenly and allowed to establish themselves before the sludge is applied. Echinochloa pyramidalis, Cattails or Phragmites are suitable plants depending on the climate. Sludge should be applied in layers between 7.5cm to 10cm and should be reapplied every 3 to 7 days depending on the sludge characteristics, the environment and operating constraints. Sludge application rates of up to 250kg/m2 /year have been reported. The sludge can be removed after 2 to 3 years (although the degree of hygienization will vary with climate) and used for agriculture.
Advantages
Planted drying beds can be built and repaired with locally available materials. They have an advantage of handling high load. No electricity energy is required.
Limitation
It is applicable where land is available since it requires large land area due to wet/dry cycles. Also, it needs expert for design and operation and requires longer storage times. Leachate requires secondary treatment. Odours and flies are normally noticeable.
Costs
Monvois, et al. (2010) presented an investment cost and operational cost for unplanted drying beds per house hold (hh) to be 20 - 50 Euro/hh and 2 - 4 Euro/hh/yr respectively (equivalent to 26 - 65 USD/hh and 2 - 5 USD/hh/yr).

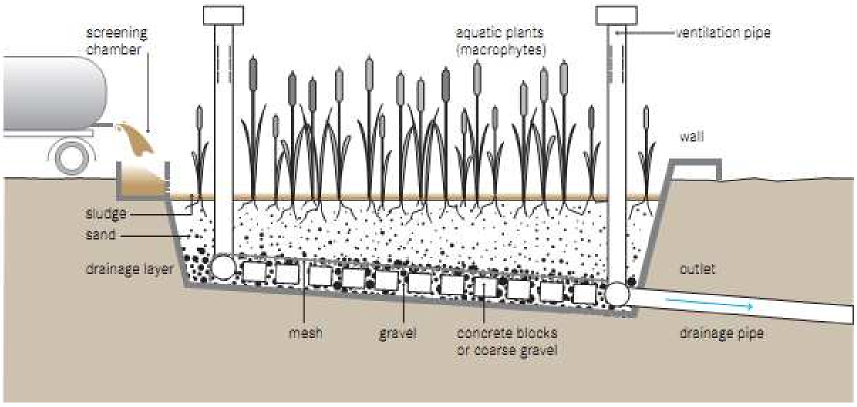


Figure 3.27 Planted drying beds [Source: (Tilley, et al., 2005)]

3.2.4.4 Sedimentation / Thickening

Sedimentation or Thickening Ponds are simple settling ponds that allow the sludge to thicken and dewater. The effluent is removed and treated, while the thickened sludge can be treated in a subsequent technology. Faecal sludge is not a uniform product and therefore, its treatment must be specific to the characteristics of the specific sludge. High strength sludge is still rich in organics and has not undergone significant degradation, which makes it difficult to dewater. Low strength sludge has under-gone significant anaerobic degradation and is more easily dewatered. In order to be properly dried, high strength sludges must first be stabilized. Allowing the high strength sludge to degrade anaerobically in Settling/Thickening Ponds can do this. The same type of pond can be used to thicken low strength sludge, although it undergoes less degradation and requires more time to settle. The degradation process may actually hinder the settling of low strength sludge because the gases produced bubble up and re-suspend the solids. To achieve maximum efficiency, the loading and resting period should not exceed 4 to 5 weeks, although much longer cycles are common. When a 4-week loading, and 4-week resting cycle is used, total solids (TS) can be increased to 14% (depending on the initial concentration). As the sludge settles and digests, the supernatant must be decanted and treated separately. The thickened sludge can then go on to be dried or composted further.

Advantage
Can be built and repaired with locally available materials. No electrical energy required.
Limitation
Sedimentation process requires large land area due to wetting/drying cycles. Odours and flies are normally noticeable. It requires long storage times and the front-end loader for monthly desludging. Furthermore it requires expert design and operation.
Costs
No cost calculations were found based on literature.

3.2.4.5 Waste stabilization ponds (WSP)

Waste stabilization ponds are large shallow basin in which sewage is treated by natural processes involving both algae and bacteria. WSP are effective in removing faecal coliform bacteria. There are three types of ponds including anaerobic, facultative and maturation ponds which can be used individually, or linked in series. To achieve effective treatment, a combination of three or more ponds in series is suitable where the effluent is transferred from anaerobic to facultative and then to the maturation pond. The anaerobic pond is responsible for removal of suspended solids and some of the soluble element of organic matter (BOD) whereas most of the remaining BOD is removed through the coordinated activity of algae and heterotrophic bacteria in the facultative pond. Pathogen and nutrients removal is highly achieved in the maturation pond. WSP performs better in tropical and subtropical countries because the intensity of the sunlight and temperature are key factors for the efficiency of the removal processes. Waste stabilization pond technology is the most cost-effective wastewater treatment technology for the removal of pathogenic micro-organisms provided land availability (Mara, et al., 1992).

Advantages

Waste stabilization ponds can be constructed and repaired with locally available materials, requires no electrical energy to operate, and have no significant problems with flies or odours if designed and operated well. Moreover, waste stabilization ponds manifest simple construction, operation and maintenance, and low cost operation (Tilley, et al., 2005, von Sperling and Chernicharo, 2005). Furthermore, the technology offers satisfactory BOD removal, pathogens removal, has adequate resistance to load variations, and low sludge production with removal periods of over 20 years (von Sperling and Chernicharo, 2005). The system units can be designed to handle wastewater from a big population, and can treat both blackwater and greywater streams.

Limitations

Notwithstanding the advantages of the technology, the waste stabilization ponds (WSPs) are limited in that they require large land area, special geological formations which may not be possible to investigate in emergency situations thus limiting the deployment time, and also require expert design and supervision. Furthermore, WSPs have variable capital costs depending on the cost of land, their effluent requires secondary treatment (Tilley, et al., 2005), especially if reuse is anticipated. WSP systems require water to operate, may not be applicable in difficult conditions especially in flooding areas, they have a slow start up, and their performance is dependent on climatic conditions including temperature and sunlight.

Costs

Monvois, et al. (2010) presented an investment cost and operational cost for WSP to be 15 - 100 Euro/hh and 5 - 50 Euro/hh/yr respectively (equivalent to 19 - 130 USD/hh and 6 - 65 USD/hh/yr).

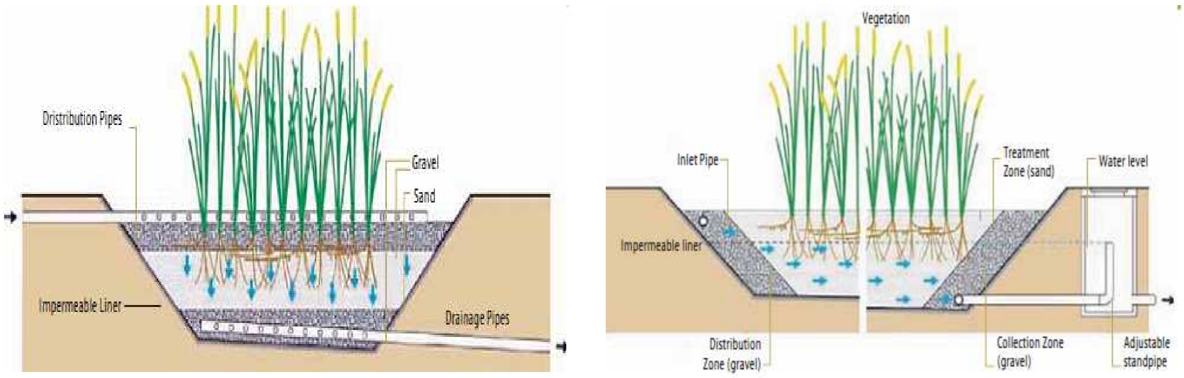
Figure 3.28 Waste stabilisation ponds

3.2.4.6 Constructed wetlands

Constructed wetlands (CW) are constructed natural vegetation/wetlands for wastewater treatment. CW remove various types of pollutants present in wastewater through the plants. There are two types of CW; free flow constructed wetlands and subsurface flow constructed wetlands. CWs plants are either floating plants or emergent one, and their responsible for biochemical transformation of pollutants. CW systems are not complicated and sophisticated technology but need a proper design and a careful construction. CW systems in emergency can treat pre treated wastewater from primary treatment system like septic tanks, AF, ABR, e.t.c. The figure below entails sanitation chain with respect to constructed wetlands.

Subsurface flow constructed wetlands

Subsurface flow constructed wetlands are divided into two types depending on the direction of flow of wastewater. These include vertical subsurface flow constructed wetlands (VSFCW) and horizontal subsurface flow constructed wetlands (HSFCW). A vertical flow constructed wetland is composed of a filter bed planted with aquatic plants. Wastewater is dosed over the surface of the wetland by use of a mechanical dosing system. The filter media removes solids, acts as a fixed surface upon which bacteria can attach and also provide a base for the vegetation growth. The vegetation, usually planted on top layer, is allowed to develop deep, wide roots which permeate the filter media. The wetland is dosed intermittently to allow saturated and unsaturated phases that create anaerobic and aerobic conditions (Tilley, et al., 2005, von Sperling and Chernicharo, 2005). The horizontal subsurface flow constructed wetlands consist of a subsurface bed filled with small stones, gravel, and sand or soil media that support aquatic plants. They do not have free water on the surface as the influent is fed in the subsurface bed (von Sperling and Chernicharo, 2005). Wastewater is fed through a wide inlet zone to ensure even distribution of the flow. The subsurface flow is ensured by maintaining the water depth at 5-15 cm below the surface (Tilley, et al., 2005). Wastewater flows through the roots and rhizomes of the plants where bacterial bio-film grows. Anaerobic conditions dominate a large portion of the subsurface zone with aerobic sites immediately adjacent to the roots and rhizomes of the plants (von Sperling and Chernicharo, 2005). Prior to application in the wetland the wastewater is pretreated to prevent clogging and ensure efficient treatment.



Vertical flow constructed wetlands **Horizontal flow constructed wetlands**

Figure 3.29 Subsurface flow constructed wetlands [Source: (UN-HABITAT, 2008)]

Advantages
Subsurface flow constructed wetlands provide high reduction of BOD, suspended solids and pathogen, offer simple construction, operation and maintenance practice. In addition, the technology does not require electricity, can be constructed with locally available materials, and produces no sludge (Tilley, et al., 2005, von Sperling and Chernicharo, 2005). Furthermore, the system can be designed to serve many people, and the effluent has a potential for some reuse applications.

Limitations
Subsurface flow constructed wetlands require expert design and supervision, relatively large land area, and continuous supply of water (Massoud, et al., 2009, Tilley, et al., 2005).

Costs
The technology requires moderate capital cost based on land and liner costs, Tilley, et al., 2005. UN-HABITAT (2008) presented construction cost of the wetland amounted to (in number) 2,200,000 to be USD 31,500 that is 5,850 for USD 85 per m^2 of the wetland. The operation and maintenance cost of the wetland is about 36,000 for USD 520 per annum.

3.2.5. Semi Centralized Treatment System 2
Semi centralised treatment system 2 implies to systems that will serve for further treatment of excreta/ wastewater. These treatment technologies receive wastewaster direct from sewer system of wet treatment systems. In additional, semi centalised systems 2 technologies in emergency are utilised when they exist in rellief camp areas, or when they are in the form of potable ready made form.

3.2.5.1 Trickling filters

A trickling filter consists of a coarse materials bed such as stones, gravel, and plastic on which the wastewater is applied in the form of drop or jets. Trickling filters are aerobic and circular in shape. Wastewater applied percolates in downward flow and allows bacterial growth on the surface of the surface the support media which led to a formation of biofilm. As wastewater flow through a media, there is a contact between biofilm and organic matter (Tilley, et al., 2005, von Sperling and Chernicharo, 2005). The system requires pre-treatment to avoid clogging of the filter and to improve treatment efficiency. Filter beds have depths ranging between 1 and 3 meters, however, deep filters up to 12 meters can be constructed when lighter filter materials are used. The filter has a perforated bottom slab that holds the filter media and allows exit of the effluent and excess sludge.

Advantages

Trickling filters can perform in a range of organic and hydraulic loading rates, and have a high BOD removal efficiency (Tilley, et al., 2005, von Sperling and Chernicharo, 2005). Although trickling filters demonstrate simplicity in design and operation (Fenner et al., 2007), some parts especially the dosing system involve complex engineering (Tilley et al., 2005). Furthermore, the trickling filters produce little and stabilized sludge, and it can serve a large number of people.

Limitations

It requires experts for design and construction, require a constant source of wastewater flow and electricity, and often has flies and odour problems. Moreover, trickling filters require pre-treatment to avoid clogging and not all parts and materials may be locally available (Tilley, et al., 2005).Trickling filters may take time to deploy in emergency cases, have high land area requirements but relatively smaller than the land WSPs.

Costs

Trickling filters have high capital costs and moderate operating costs. Zahid (2007) gave the cost estimation for treating wastewater of flow of 200,000 m^3/day with BOD 400 mg/L and SS of 300 mg/L with a trickling filter in Saudi Arabia Riyal (SAR) to be 1 SAR/m^3 (equivalent to USD0.28/m^3).

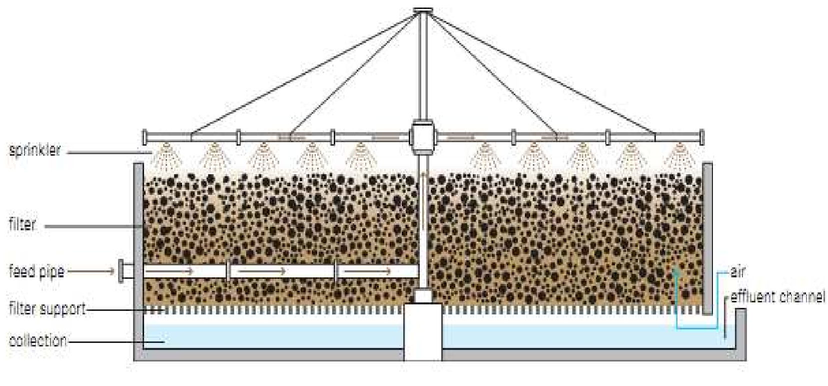


Figure 3.30 Trickling filters [Source: (Tilley, et al., 2005)]

3.2.5.2 Upflow Anaerobic Sludge Blanket (UASB)

Upflow Anaerobic Sludge Blanket (UASB) is a high-rate anaerobic treatment process typically applicable for treatment of various type of wastewater. The technology is well established in the large scale industrial wastewater treatment (Tilley, et al., 2005), however, good results have been achieved with the UASB in the treatment of domestic wastewater in warm climates (von Sperling and Chernicharo, 2005). An UASB reactor consists of a circular or rectangular tank in which wastewater flow in upward direction through a suspended sludge blanket. The suspended sludge blanket simultaneously treats and filters the wastewater as it passes through. The technology uses the anaerobic digestion process of fermentation in which organic matter is degraded and biogas (mainly methane and carbon dioxide) is produced. The process has several benefits including, the production of useful energy and very small amounts of well stabilized excess sludge (van Lier, et al., 2008).

Advantages

The UASB is most suited for treatment of high strength wastewater. The process can also achieve high organic, produces stable and few sludge, and produces biogas which can be scrubbed and used as a source of renewable energy (Fenner, et al., 2007, Tilley, et al., 2005). Moreover, the technology has a low land requirement due to its compactness. Energy consumption can be offset by the internal biogas production. The technology can be availed in packaged forms making for easy deployment and application in difficult conditions, and can be designed so that a unit can serve a substantial number of people.

Limitations

UASB employs complex expert design, and requires constant source of water. In addition, capital cost may be high since materials for construction may not be locally available, the process may be unstable with variable hydraulic and organic loads, it may be difficult to meet stringent discharge standards due to poor ammonia removal efficiency thus the effluent may require post treatment, and proper hydraulic conditions may be difficult to maintain (balancing of up-flow and settling velocities) (Tilley, et al., 2005). Furthermore, there is a chance of the generation of bad odour (but can be controlled), the process is sensitive to load variations and toxic compounds (von Sperling and Chernicharo, 2005).

Costs

Monvois, et al. (2010) presented an investment cost and operational cost for UASB to be 200 - 1000 Euro/hh and 5 - 50 Euro/hh/yr respectively (equivalent to 261- 1307 USD/hh and 6 - 65 USD/hh/yr).

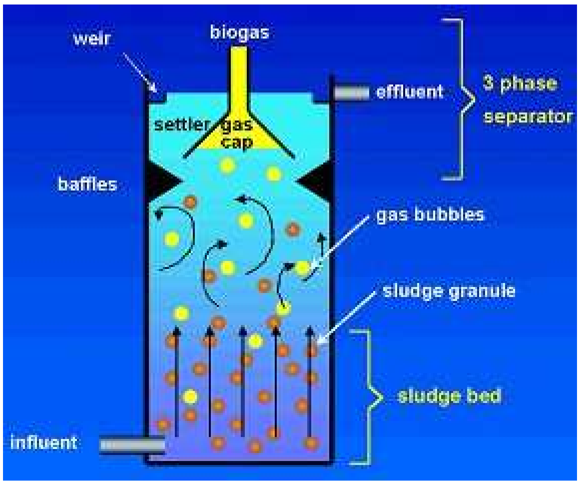


Figure 3.31 UASB reactor [Source: http://www.uasb.org/discover/agsb.htm]

3.2.5.3 Membrane bioreactor (MBR)

A membrane bioreactor (MBR) is a combination of the activated sludge process with a membrane filtration step that replaces the secondary clarifier in the conventional activated sludge process. The activated sludge process is responsible for biodegradation of the organic matter while the membrane is responsible for physical separation of the treated water from the mixed liquor. The MBR technology has been successfully used in the treatment of municipal and industrial wastewaters (Hoinkis, et al., 2012). Its success in high strength industrial wastewater applications portrays the potential for use in the treatment of high strength blackwater generated in emergency situations. MBR systems are easy to install, but require high level operation since they are most often dependent on sophisticated instrumentation and control applications (Fenner, et al., 2007). Figure below indicates what can be treated by MBR system in the chain.

Paul (2005) presented a proposal for a rapidly deployable emergency sanitation treatment system based on membrane bioreactor (MBR) technology, to be used in emergency situations such as a refugee camp. The study carried out on behalf of Oxfam GB assessed the feasibility of using a MBR to treat the wastewater generated from emergency context. In this study, three different concept designs were developed to meet sanitary needs of the emergency situation and they were put in field for test. Amongst the options presented, one shows the most flexible and economical solution to be used in large camps with fluctuating populations. The feasible option unit include the use of existing pre-packaged Oxfam water tank kit combined with an aerated lagoon design (**Figure 3.32** entails). Furthermore; Paul (2005) concluded that the use of a MBR in these difficult circumstances could prove appropriate on technical and operational grounds if not purely financial ones. This study shows the potential of MBR in emergency.

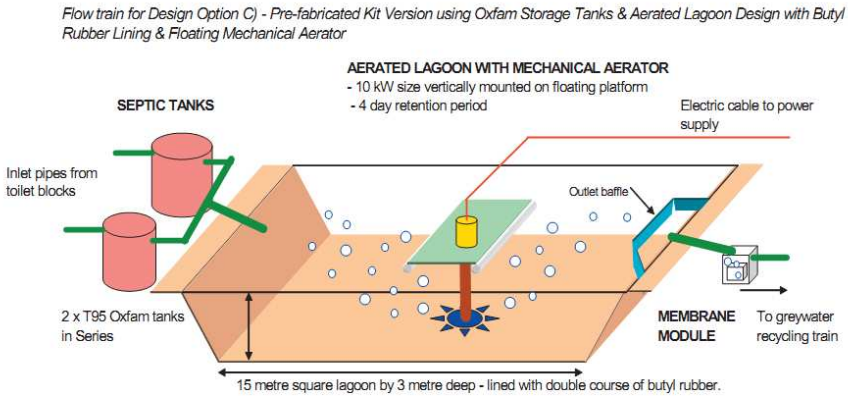


Figure 3.32 Recommended Oxfam rapidly deployable emergency sanitation design system [Source: (Paul, 2005)]

Advantages

MBRs are compact with small footprint thus have low land requirement, and present high resistance to variation in organic and hydraulic loading. MBRs consistently produce high quality product water presenting potential for reuse, have high organic matter removal efficiencies, and are available in packages that can be easily deployed to emergency areas (Fenner 2007). The possibility of packaging makes the technology applicable in difficult site conditions. Moreover, MBR technology produces few and quite stabilized sludge due to long solids retention times, is reliable providing it is supervised, and can be designed to serve a substantial number people per unit. The initial start-up time can be shortened by seeding with activated sludge from an existing plant.

Limitations

The MBR technology is limited by its high capital and operational costs, requires expert design (complex) and construction supervision, cannot be constructed with locally available materials, and requires high skilled operation due to the dependence on sophisticated instrumentation and control. Furthermore, the MBR system requires constant source of water and energy to operate, and may present environmental problems with noise.

Costs

Anu Shah (2008) presented a MBR cost 1,000,000 - 1,800,000 USD. Operation cost of 10,000 USD/yr

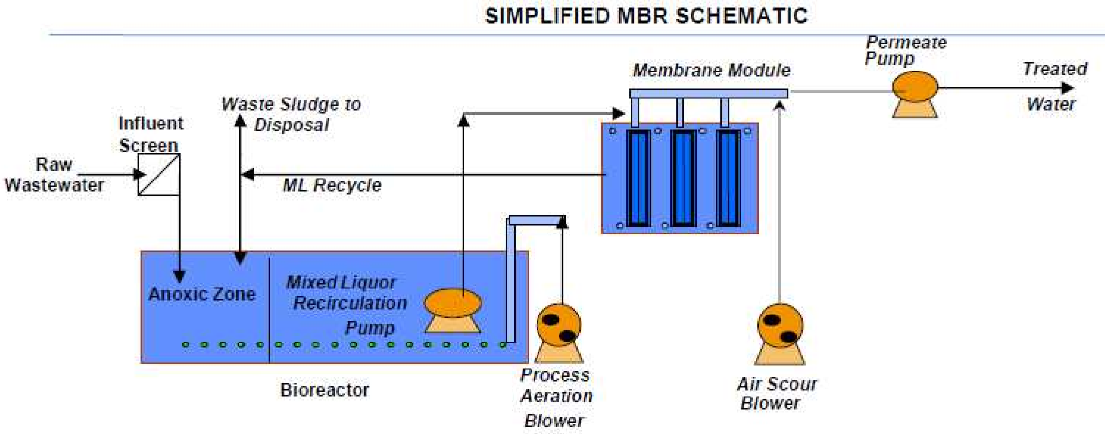


Figure 3.33 MBR schematic [Source: www.tsgwater.com]

3.2.5.4 Conventional activated sludge (CAS)

The conventional activated sludge technology applies the aerobic process for biological wastewater treatment. The main components of the CAS are a biological reactor tank and the settling tank (clarifier). The process is based on the aeration of wastewater in which a concentrated suspension of microbes is cultivated in the reactor to degrade pollutants and the solid and liquid phase separation is achieved by gravity settling in the secondary clarifier. In the clarifier, part of the growth (excess sludge) is wasted and the remainder is returned to the system to ensure continuity of the process. Typically, the biomass concentration in the aeration tank is varied between 2000 to 4000 mg/l. Aeration is achieved by supply of compressed air in the reactor through air diffusers while recirculation pumps are used in the return sludge line. CAS has potential to be used in emergency if it's existing within the IDPs and refugees camps.

Despite sewerage, faecal sludge from septic tanks, AF, ABR, and Aqua prives can be dumped on CAS. The ongoing research at UNESCO-IHE on "Faecal sludge characteristics and co treatment with Municipal wastewater process and modelling considerations" by B. Dangol aim at indicating to what percentage by volume the faecal sludge can be added to a CAS without failure of the system. Based on preliminary results on this research, it was found low digested faecal sludge of 30% of volume can be added while for medium and high digested faecal sludge, 1%-1.5% of volume can be added.

Advantages

The CAS has good performance with high removal efficiencies of up to 99% in BOD and pathogens achieving a relatively high effluent quality, and can be modified to meet specific discharge limits (Tilley, et al., 2005). In addition, the technology can be sized to serve many people, it can be packaged thus making it easy to deploy in difficult conditions (e.g. non-excavation areas). The start-up time can be shortened with seeding.

Limitations

CAS requires expert design, constant source of electricity and water. Moreover, materials for construction may not be locally available, the excess waste sludge from the system may require additional digestion, and the technology is prone to complex chemical and microbiological problems (Fenner, et al., 2007, Tilley, et al., 2005). CAS may present environmental problems with noise and aerosols. The final effluent and sludge requires treatment before disposal.

Costs

Zahid (2007) gave the cost estimation for treating wastewater of flow of 200,000 m^3/day with BOD 400 mg/L and SS of 300 mg/L with a conventional activated sludge to be 1.25 SAR/m^3 (equivalent to USD0.33/m^3).

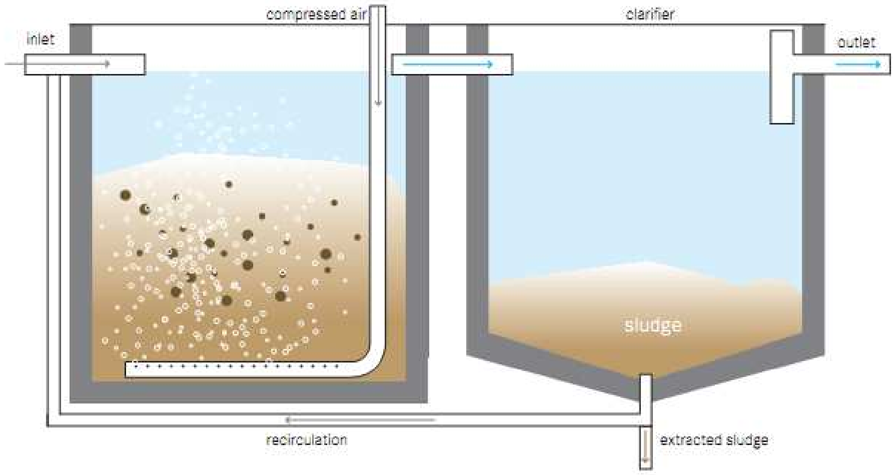


Figure 3.34 Conventional Activated Sludge [Source: (Tilley, et al., 2005)]

3.2.6. Use and/or Disposal

3.2.6.1 Urine fertilizer

Separately collected, stored urine is a concentrated source of nutrients that can be applied as a liquid fertilizer in agriculture to replace all or some commercial chemical fertilizer. The guidelines for urine use are based on storage time and temperature. However, it is generally accepted that if urine is stored for at least 1 month, it will be safe for agricultural application at the household level. If urine is used for crops that are eaten by those other than the urine producer, it should be stored for 6 months (Tilley, et al., 2005). Urine should not be applied to crops within one month before they are harvested. From normal, healthy people, urine is virtually free of pathogens. Urine also contains the majority of nutrients that are excreted by the body. Urine varies depending on diet, gender, climate and water intake among other facts, but roughly 80% of nitrogen, 60% of potassium and 55% of phosphorus that is excreted from the body is excreted through urine (Tilley, et al., 2005). Because of its high pH and concentration, stored urine should not be applied directly to plants. Rather it can be used: mixed undiluted into soil before planting, poured into furrows sufficiently away from plant roots and covered immediately (once or twice during the growing season), and diluted several times and used frequently (twice weekly) poured around plants (Tilley, et al., 2005).

Advantages

Simple technique for all users and it has low cost. There is low risk of pathogen transmission. Reduces dependence on costly chemical fertilizers, and may encourage income generation (tree planting and fruit production)

Limitations

Urine is heavy and difficult to transport. Smell may be offensive and its Labour intensive.

Costs

No cost calculations were found based on literature.

Figure 3.35 Urine fertilizers in jerrycans [Source: http://www.grida.no/publications/et/ep5/page/2823.aspx]

3.2.6.2 Fertilizer (Dried faecal matter or sludge)

Dried faecal matter/ sludge fertilizer

The dried faecal matter from UDT systems can be further used as fertilizer. The dried faecal matter is in the form of crumbs and is rich in carbon and nutrients. The nutrients present are essential for crop growing (P, K). The dried faecal matter can be mixed with soil. The applicability to the soil depends on storage time and temperature.

Advantages

Simple technique for all users and it has low cost. It can improve the structure and water-holding capacity of soil. Moreover it has low risk of pathogen transmission, and may encourage income generation (tree planting and fruit production).

Limitations

It's a labour intensive. Pathogens may exist in a dormant stage (oocysts) which may become infectious if moisture is added, and it does not replace fertilizer (N, P, K) (Tilley, et al., 2005).

Costs

No cost calculations were found based on literature.

Figure 3.36 Sludge fertilizer [Source: http://goodsoilgirls.wordpress.com/]

3.2.6.3 Burying/ Fill and cover

Burying is a disposal method of filling the excreta with earth material either onsite or offsite. This method can be used when trench latrines, buckets, biodegradable bags, controlled open defecation, or Arborloo sanitation technologies are used. Once the pits are full, it will be filled and covered with soil. The covered excreta furthermore biodegrade and become soil humus. A tree can be planted on top. Despite that buckets can be reusable, the excreta waste from it are buried. Sanitation chain below entails which technologies comply with burrying disposed.

Advantage

Burying has low cost. The compost excreta become soil humus. The method results in soil conditioner that can enhance environment protection through tree planting.

Limitations

This method is limited to technologies that are pit non water tight including trench latrines, controlled open defecation, fossa alterna or Arborloo. Moreover it's applicable to sanitation technologies like buckets, biodegradable bags that need to be buried for disposal. The disposal mechanism through burying is applicable where it is possible to dig.

Costs

No cost calculations were found based on literature.

3.2.6.4 Surface disposal/ Open dumping

Surface disposal refers to the stockpiling of sludge, faeces, biosolids, or other materials that cannot be used elsewhere (Tilley, et al., 2005). Once the material has been taken to a surface disposal site, it is not used later. This technology is primarily used for biosolids, although it is applicable for any type of dry, unusable material. When there is no demand or acceptance for the beneficial use of biosolids, they can be placed in monofills (biosolids-only landfills) or heaped into permanent piles. There is no limit to the quantity of biosolids that can be applied to the surface since there are no concerns about nutrient loads or agronomic rates. More advanced surface disposal systems may incorporate a liner and leachate collection system in order to prevent nutrients and contaminants from infiltrating the groundwater. Surface disposal sites can be situated close to where the faecal sludge is treated, limiting the need for long transport distances.

Advantage

Surface disposal has low cost. It can make use of vacant or abandoned land. May prevent unmitigated disposal

Limitations

It's a non-beneficial use of a resource. Odours are normally noticeable (depending on prior treatment). Special spreading equipments may be required. There is a possibility of accumulation of micro-pollutants in the soil, leaching and groundwater contamination.

Costs

No cost calculations were found based on literature.

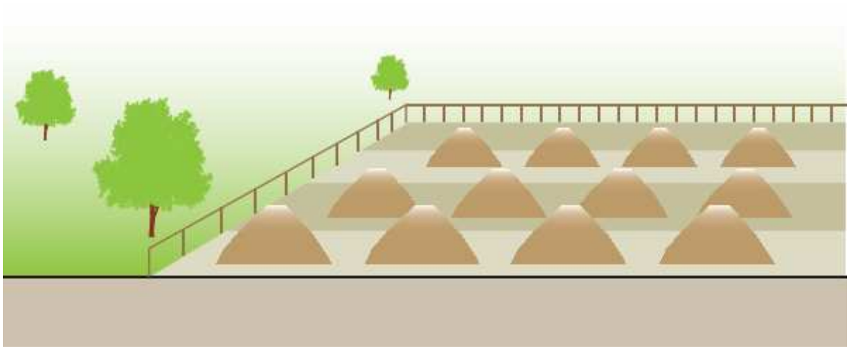


Figure 3.37 Open Surface disposal Source: (Tilley, et al., 2005)

3.3. Development of Criteria

The conceptual framework mainly has two steps, screening and evaluation processes. In each of these stages criteria are needed i.e. screening criteria and evaluation criteria. These criteria help in narrowing down to a feasible sanitation chain option. The criteria development is based on literature, technical knowledge of sanitation technology systems, and field experience.

3.3.1. Screening criteria

Different sanitation technologies for emergency are available and each technology varies from the other. To understand whether the sanitation technologies are applicable for particular disaster scenario, a number of factors are contributing to it. Therefore, screening is important in order to differentiate feasible technologies and unfeasible ones. The screening process is achieved by having screening criteria which acts as inputs. Screening criteria are provided by the user prompted by the DSS tool that helps in identify which sanitation technology chain suit best the users' scenario. **Table 3.3** below present the description to the criteria used for screening.

The criteria are not linked in a continuous flow thus from one criteria to next criteria. Therefore, it is possible for user to just screen based on few criteria s/he thinks are more relevant to the disaster scenario. Criteria developed focused on reducing the challenges on safe sanitation provision in emergency. In most cases the challenges includes, population factor, land availability, water availability, energy availability, possibility for excavation, GWT level, and a disposal site. Moreover, for sustainability of the sanitation systems, the social aspects are also considered for instance sanitation practice of the community to be served.

A number of about twelve criteria for screening were developed. These criteria affect the sanitation chain differently. Criteria 1- 8 affect the entire chain, whereas criteria 9- 11 affect the sanitation chain from conveyance chain to the treatment technology chain. The disposal and/ re-use chain is affected by criteria 12 and criteria 6 modified to be specific for disposal chain.

Table 3.3 Screening Criteria description

S/N	Screening criteria	Possible Answers	Description
1	Existing sanitation infrastructure	No Yes: Sewerage Yes: MBR, UASB, TF, CAS, WSP	The criteria aim to incorporate the existing sanitation systems within the disaster relief camps. When there are already existing technologies, it is better to take advantage of that and suggest sanitation technologies that will comply with the existing systems. For instance, there is existing sewerage system with additional capacity, therefore toilet blocks and septic tanks systems will be constructed and connected to the sewer line. Existing systems has to be checked if a it can receive additional load.
2	Estimated present and future population	High: >2000 persons Low: <2000 persons (Loetscher and Keller, 2002)	The size of population has quite an impact on choice of sanitation technologies as well as during the design. Population size help in predicting the expected wastewater flow production. Some technologies are feasible for larger population whilst others not as a result of technology carrying capacity.

3	Land availability (surface area) for sanitation infrastructure	Small: < 2 m² Average: >2m² and <20m² Large: > 20 m ² (Monvois, et al., 2010)	Availability of land is an important factor to consider in sanitation technology selection as there is variation in space requirements among technologies in the chain. For example simple pit latrines and VIP requires 2m², septic tanks 5m², and infiltration trenches 20m². In such environments where space is limited, technologies with high land requirements such as constructed wetlands and WSPs may not be feasible. Moreover, land may also be limited by ownership regulations. For example in urban IDPs or refugees camps where land is likely to be scare.
4	Water availability to flush	Yes No	The choice between dry and wet sanitation systems is highly influenced by the availability of water to flush. Wet sanitation systems are likely to be adopted where substantial amount of water is available for transporting excreta. Whereas dry systems are chosen when there is water scarcity.
5	Energy availability	Yes No	This screens energy-dependent sanitation technologies (electricity based) from energy free or renewable energy sanitation technologies. In many cases power breakdown is common in emergency. Therefore in the case there is power breakage electricity dependent technologies like MBR can not feasible. This criterion affects the treatment chain part.
6	Ground water table	HIGH (Pit bottom < 1.5m from GWT) LOW (Pit bottom > 1.5m from GWT)	GWT influence the selection of sanitation technologies. In the project area GWT can be high or low. When GWT is high, some sanitation technologies won't be feasible like simple pit latrines. On the other hand, water tight technologies like storage latrines can be feasible.
7	Possibility to excavate	YES YES (Up to 2m depth) NO	Some technologies require excavation and others don't. Therefore, when it's not possible to excavate, all technologies that do not require excavation will be feasible such as raised latrines. If it is possible to excavate, to what level it is possible? Some technologies goes up to 2m depth where as other requires more than 2m depth.
8	Type of waste stream	Excreta Blackwater Yellowwater and brownwater	The type of emergency sanitation system chosen will depend on the kind of waste stream anticipated on site. The anticipated waste stream will influence the collection technologies and de-sludging techniques in the sanitation technology chain. Sludge produced can be either dry or wet sludge. If wet sludge is produced, motorised des-sludging or sewerage conveyance technologies are feasible.

9	Possibility of flooding in the toilet site	YES NO	If the project site area is subject to regular flood, alternatives based on soil absorption are not susceptible. On the contrary, the susceptible one will include technologies like floating latrine.
10	Pre-disaster practices: Anal cleansing	Water Bulk or Hard Material Toilet Paper	Pre-disaster practices of anal cleansing include water anal cleansing, soft paper, bulk or hard materials cleansing. This influence of technology selection especially on collection point and conveyance stage of the sanitation chain. When bulk or hard materials are used for anal cleansing, it limits the number of collection technologies as some like pour flush toilets will not be feasible. Furthermore, anal cleansing practice will influence on the type of sludge produced.
11	Accessibility by vehicle	YES NO	When a disaster occurs in many cases it damages the infrastructure, thus limiting access to the affected areas. Accessibility by vehicle to the site is important for the sanitation technologies which require either frequent de-sludging or removal of large sludge quantities. This is the case in emergency as frequent de-sludging by trucks is needed due to heavy usage. When the site is not accessible by trucks, the feasible sanitation technologies are those based on soil absorption. Moreover, to access the affected people alternative means of transport are needed. Taking an example, when air transportation is the only means of transport, selection of technologies will be limited by its size and weight. The feasible options will be technologies with small size and light weight.
12	Possibility for open dumping	YES NO	Public health is given more weight in emergencies thus placing more emphasis on reduction of pathogen loads to avoid epidemics. Furthermore, waste disposal should adhere to local environmental regulations. It is advisable to consult local authorities upon waste disposal. In some areas open dumping is possible and in some areas open waste disposal is not allowed.

To obtain a feasible sanitation chain, a second screening is done through chain compatibility by collection and/ storage technologies as well as by conveyance technologies. For the remaining screened technologies, the two chains are fixed by allowing users to select the collection and/ storage, and conveyance technology they prefer. The remaining chain are set to comply with the collection and/ storage, and conveyance technology chosen which led to the feasible sanitation chain options. The feasible sanitation chain options will further be evaluated in the evaluation stage.

3.3.2. Evaluation criteria

Evaluation criteria refer to criteria that assess which sanitation technology chain is more feasible compared to the other chains. Different factors are influencing this comparison during the evaluation process. These factors have the impact on implementation. For DSS model for emergency developed, five evaluation criteria were developed. This includes capital and O&M cost, easy of deployment, use of local materials and the skills requirements for sanitation technologies. Each chain of the whole compatible chain will be analysed its effect based on all the five criteria at once.

The evaluation analysis uses the multi criteria approach. All the technological options are evaluated based on the criteria discussed. The evaluation criteria are given weight in relation to its importance. Despite the weights given to criteria, a score should be allocated for the technology option in relation to the criteria. Both weight and scores, higher weight defines the best of the criteria. A total score is then calculated and the highest scorer chain is the best feasible sanitation chain to be implemented in emergency. This process is pre-defined and the scores and weighted factor provided are based on literature and experience. Annex **A2** indicate how the scores were allocated and the weighted factor given. **Table 3.4** gives the description of the evaluation criteria used.

Table 3.4 Evaluation Criteria description

S/N	Evaluation criteria	Description
1	Capital cost	Capital cost comprises of costs to buy, deliver and install the sanitation facility. It also considers the cost of labour, construction materials, and transportation costs.
2	O & M cost	Operation and maintenance is necessary to ensure that the constructed facility serves its designed life. Operation and maintenance assessment implies day to day running cost of the system including spare parts and costs of chemicals or reagents.
3	Ease of deployment	The criterion refers to the ease and speed of putting the sanitation facility into operation. This would include the time of procurement and mobilization of equipment and materials to the site, and setting up the facility in readiness for use. Some technologies may be bulky and heavy so they require assembly on site while others may be small and light and may be deployed to the site readily assembled.
4	Use of local materials	When the sanitation facility is constructed with the locally available materials, it reduces implementation time and costs. On the other hand, facilities relying on high quality imported materials may not be appropriate considering the complexity of procurement logistics and transportation.
5	Skill requirement	Some technologies require expertise in implementation and supervision and some not. The availability of skilled labour will influence on technology evaluation.

CHAPTER 4

Conceptual Framework

Despite the available sanitation technologies, selecting the appropriate one is still a challenge for relief provider as entailed in CHAPTER 3. In order to select optimal sanitation technology chains, selection criteria are required. A conceptual framework integrates both screening and evaluation criteria as inputs towards the feasible sanitation technology chain. This chapter has an objective of constructing a logical sequence in selecting an appropriate sanitation technology chain.

4.1. Conceptual Framework for DSS for emergency sanitation

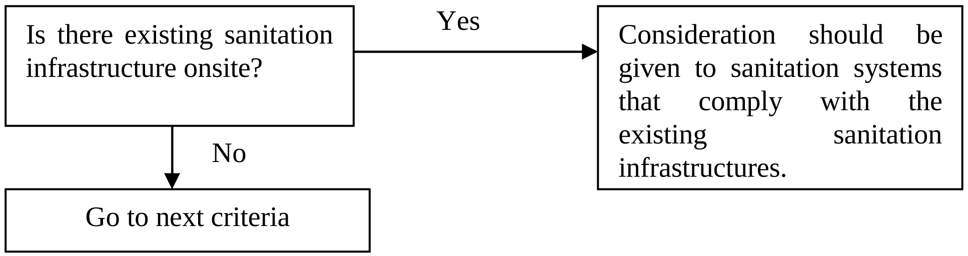
The conceptual framework for DSS for emergency sanitation refers to a logical sequence of information required in narrowing down the available sanitation options based on selection criteria (i.e. screening and evaluation) to obtain the most feasible sanitation option. To build the conceptual framework, two stages are required namely screening stage and evaluation stage.

In screening stage, the screening criteria act as inputs to the framework. This inputs information varies depending on the answers provided by the user in response to the screening criteria questions. Furthermore, compatibility by collection of the screened sanitation technological chain is assessed. The compatibility is achieved by collection and/ storage, and conveyance chain. In the evaluation stage, the screened sanitation chains are evaluated based on multi criteria analysis approach.

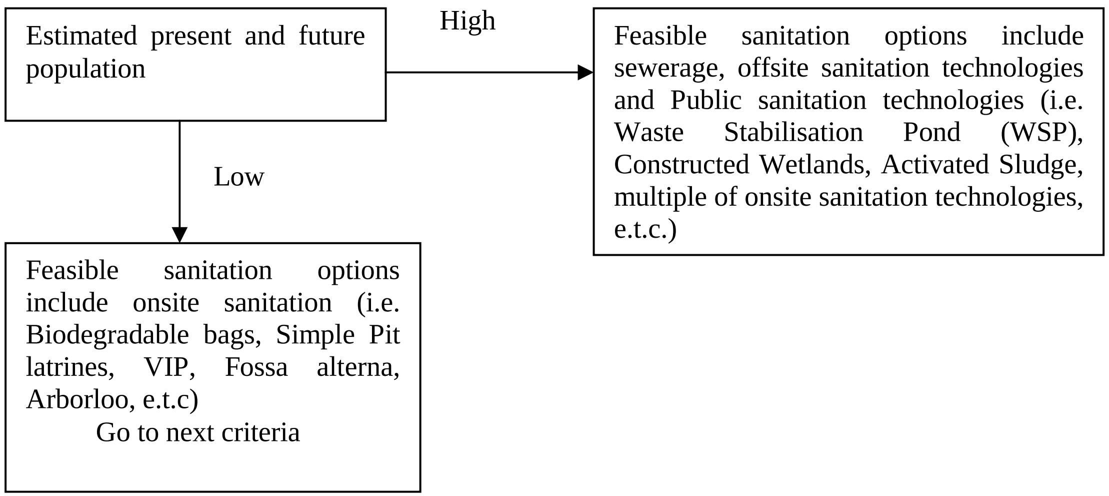
4.1.1. SCREENING 1

In screening process, the screening steps are not in sequential order. Every step is independent. The preference whether to follow the sequence or not, relies upon user. Moreover, following or skipping the screening steps will not affects the screening process. If a technological option in first step is screened out, and if in the next step it is also screened out, it will only be marked as a screened option. Below is the conceptual framework for achieving screening in DSS for emergency sanitation.

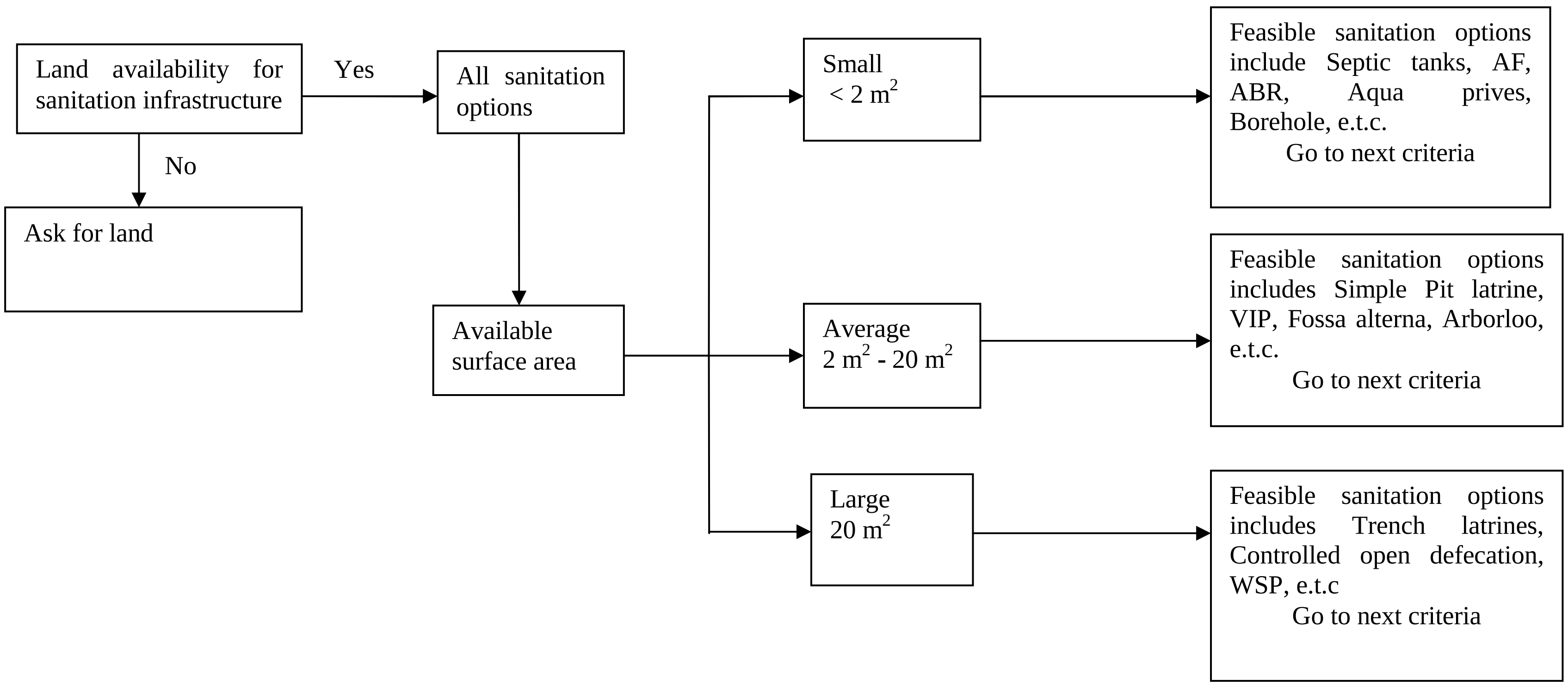
Criteria 1: At IDPs or refugees camps



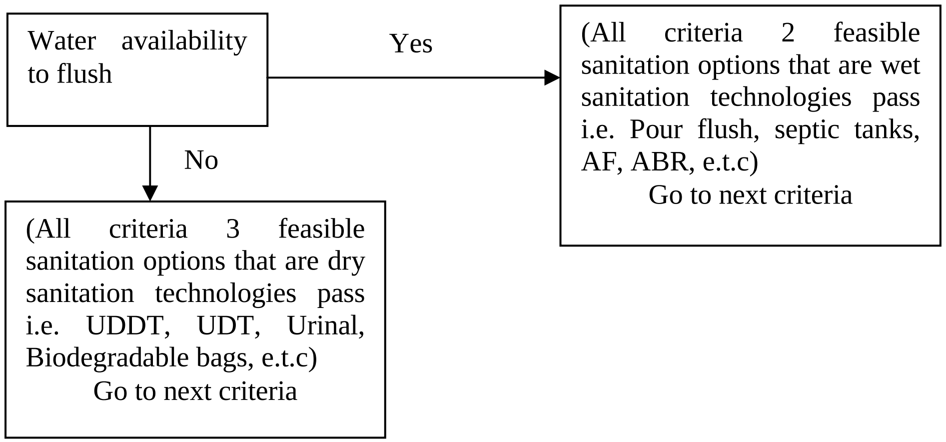
Criteria 2: For all sanitation chain options



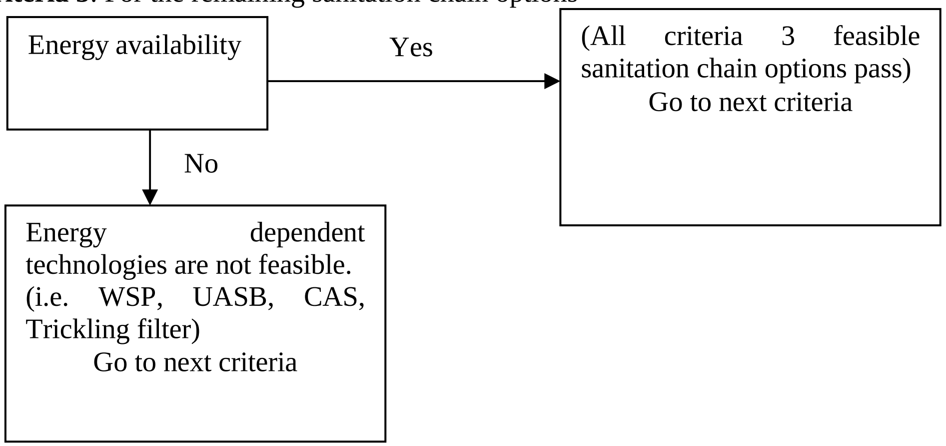
Criteria 3: For the remaining sanitation chain options



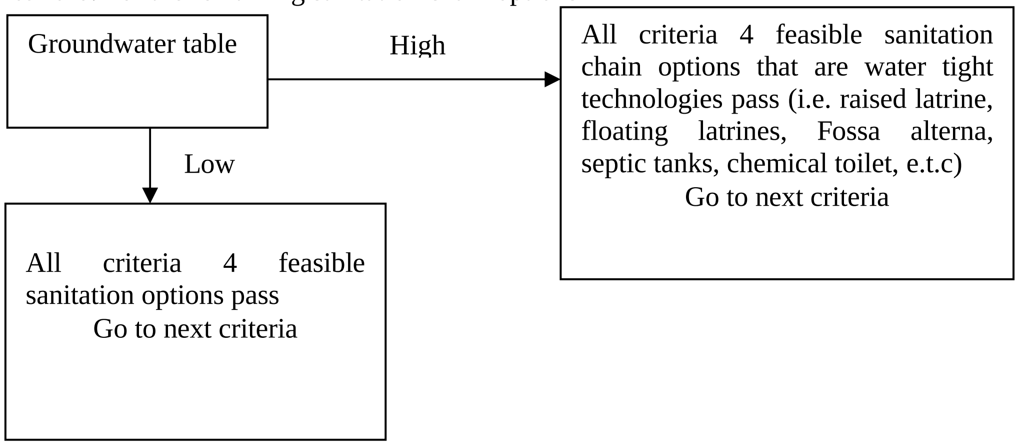
Criteria 4: For the remaining sanitation chain options



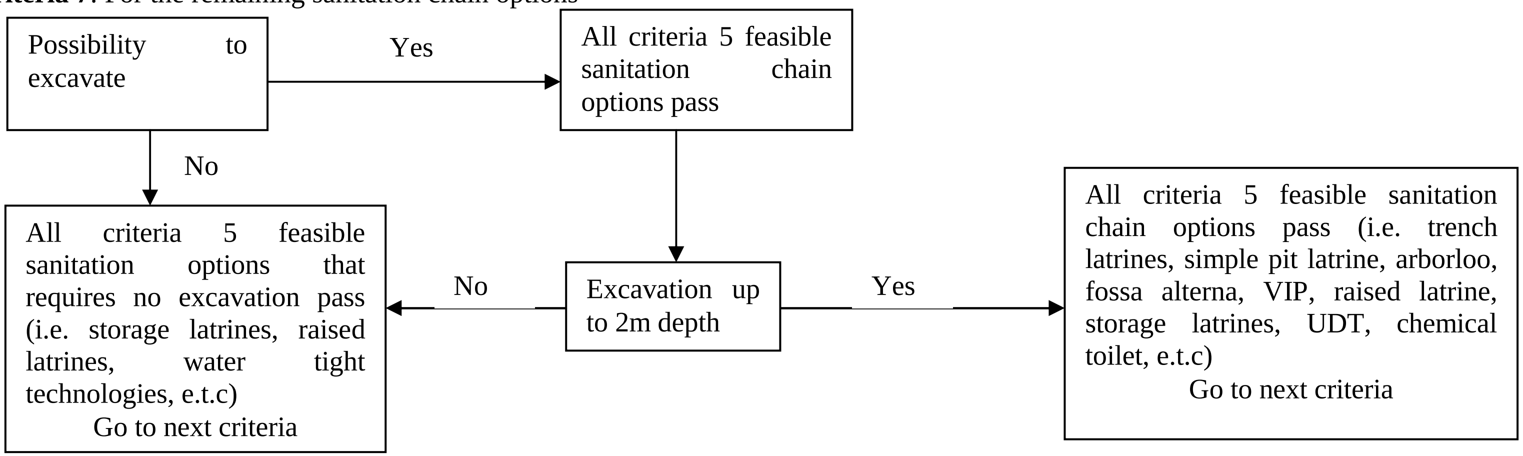
Criteria 5: For the remaining sanitation chain options



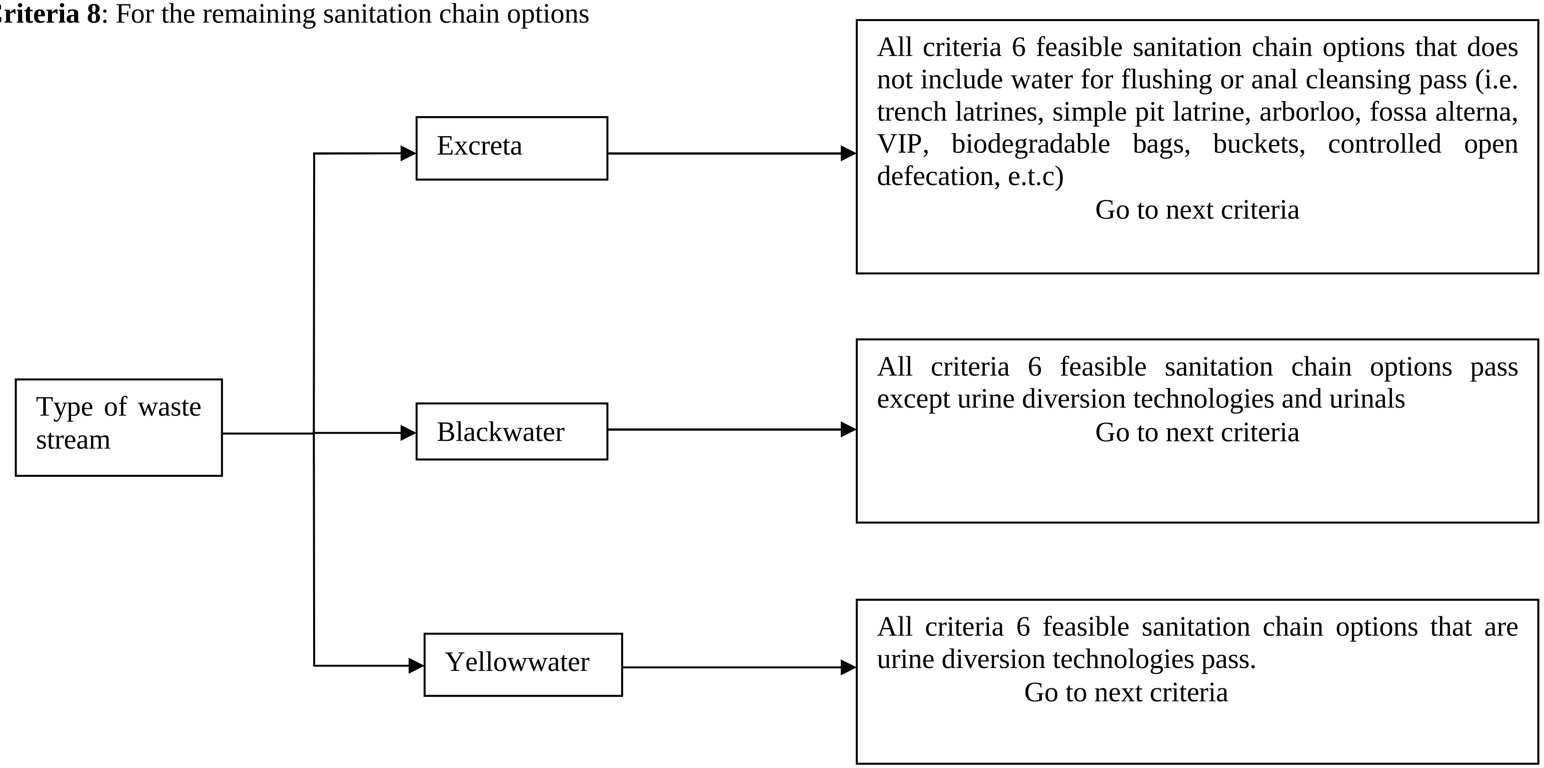
Criteria 6: For the remaining sanitation chain options



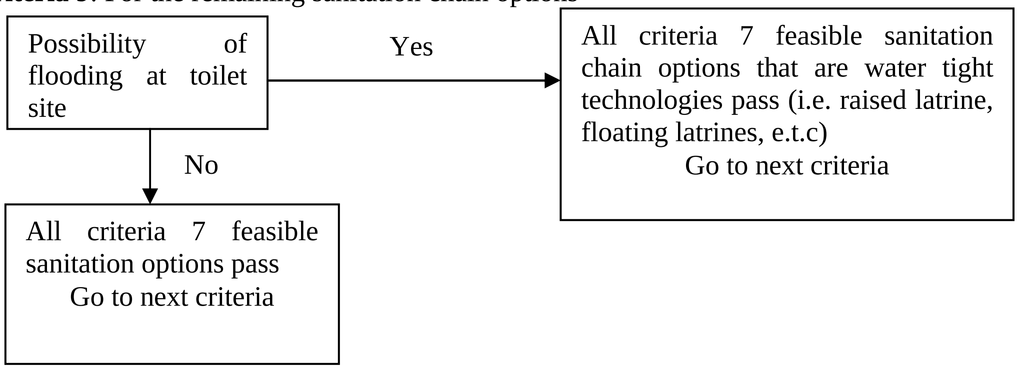
Criteria 7: For the remaining sanitation chain options



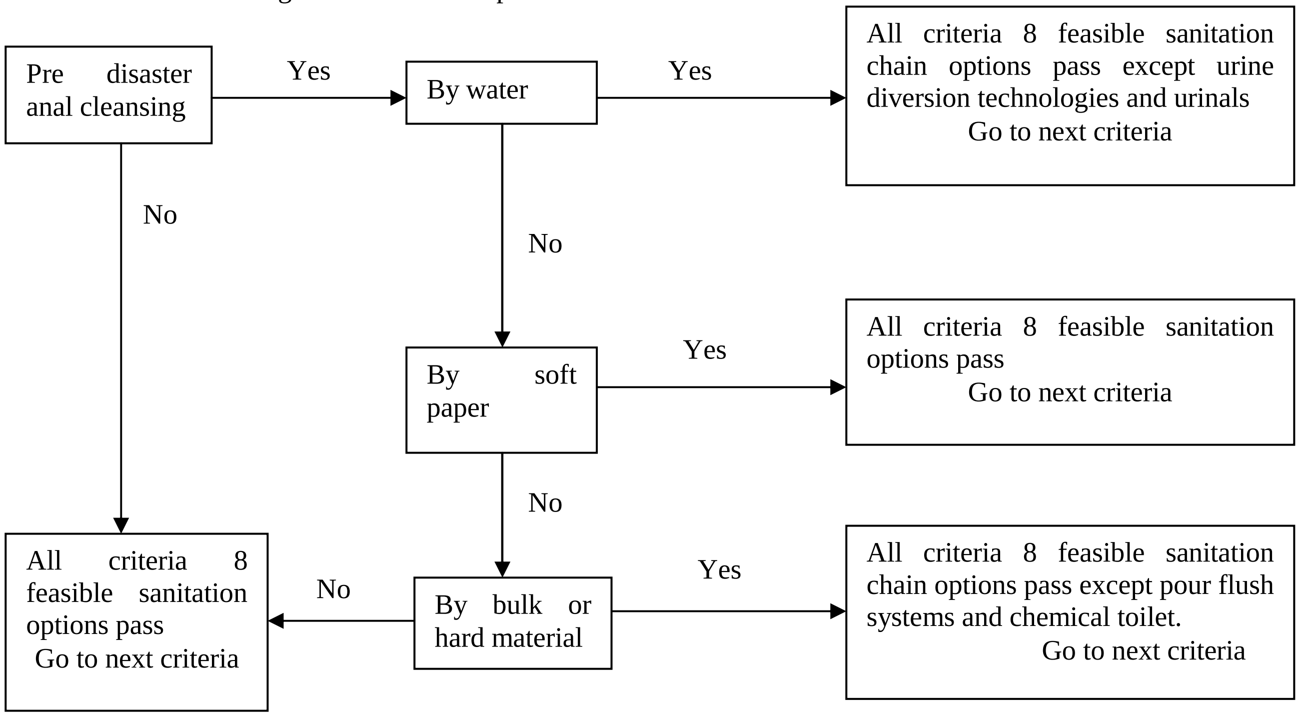
Criteria 8: For the remaining sanitation chain options



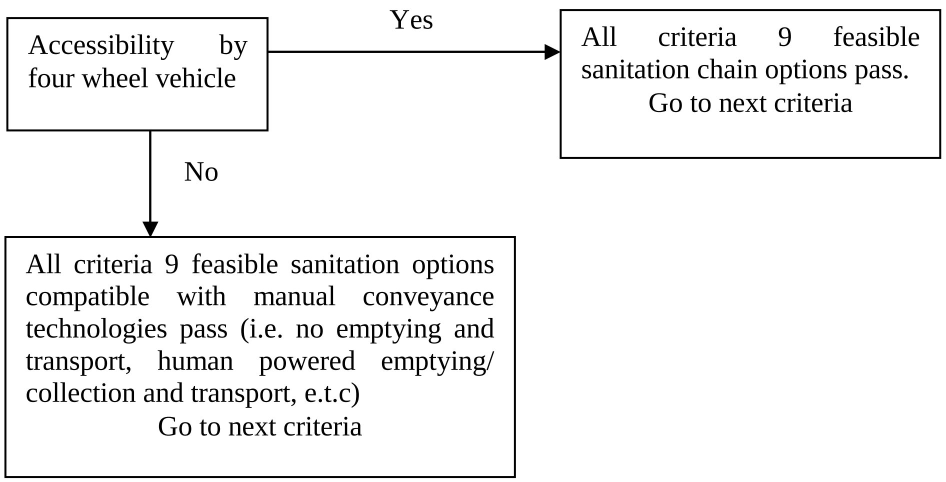
Criteria 9: For the remaining sanitation chain options



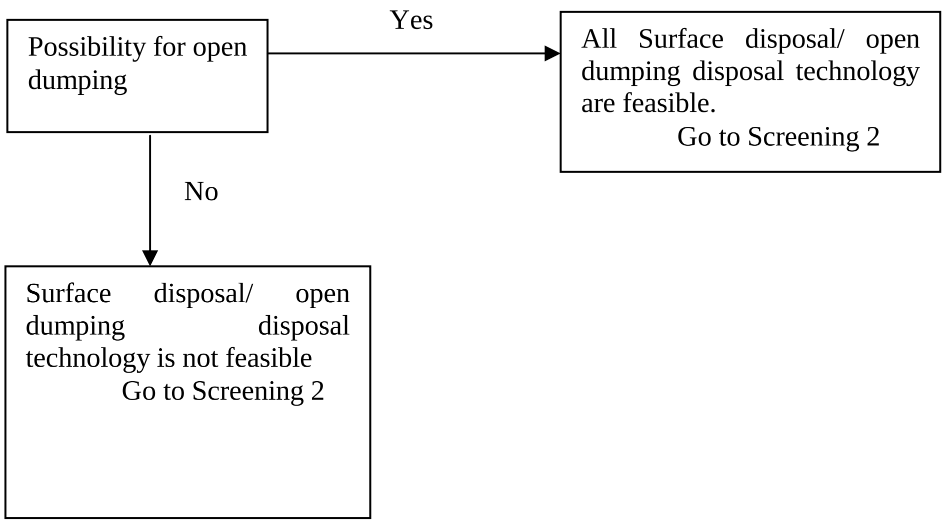
Criteria 10: For the remaining sanitation chain options



Criteria 11: For the remaining sanitation chain options



Criteria 12: For the remaining sanitation chain options



4.1.2. SCREENING 2:

At screening 2, compatibility by collection and conveyance is achieved.

Compatibility by collection system

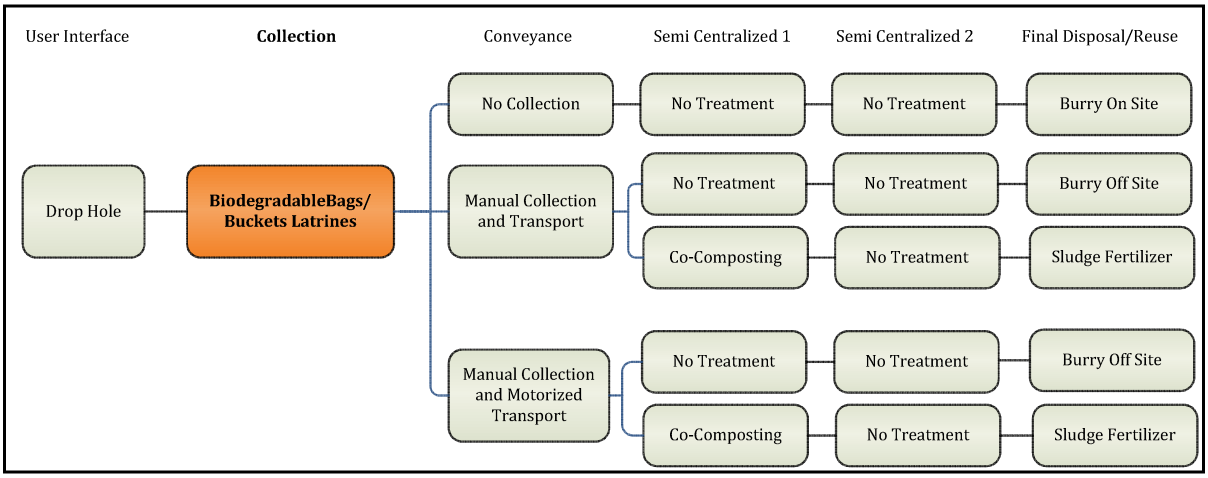


Figure 4.1 Biodegradable bags and buckets

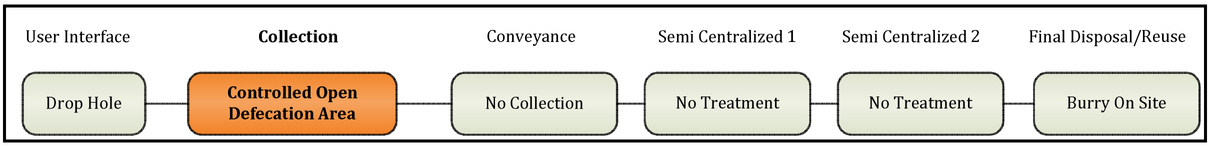


Figure 4.2 Controlled open defecation

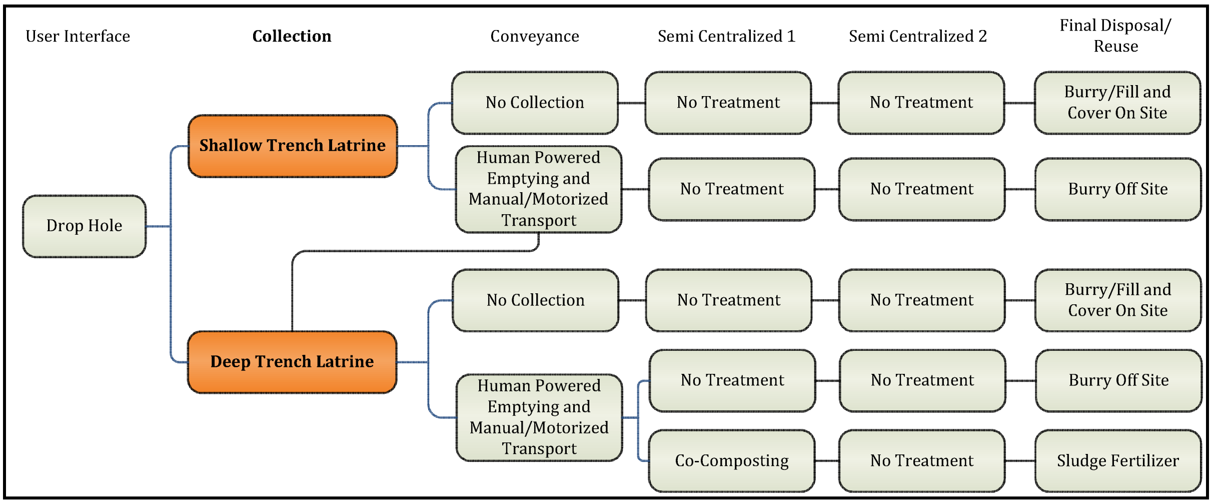


Figure 4.3 Shallow and deep trench latrine

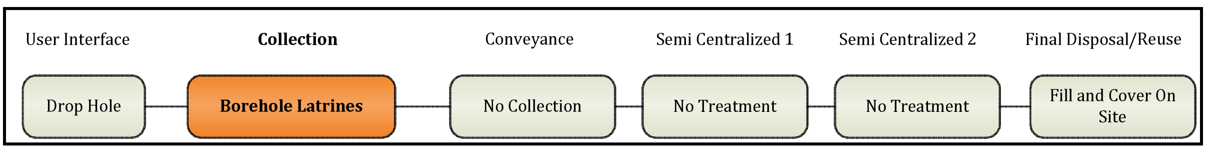


Figure 4.4 Borehole latrine

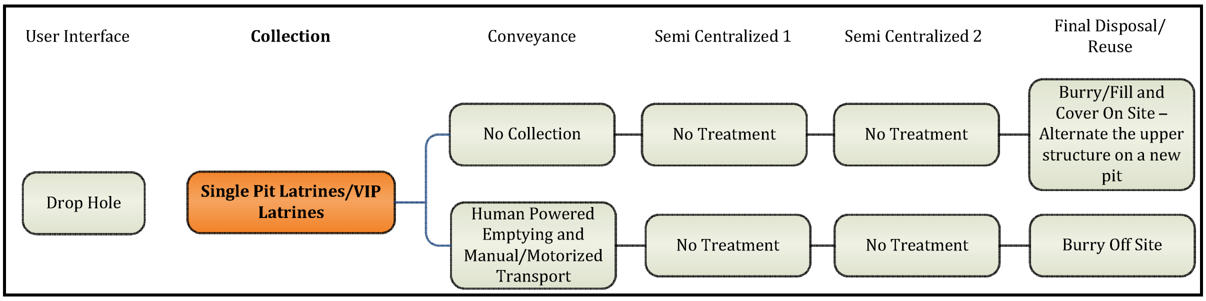


Figure 4.5 Simple Pit and VIP Latrine

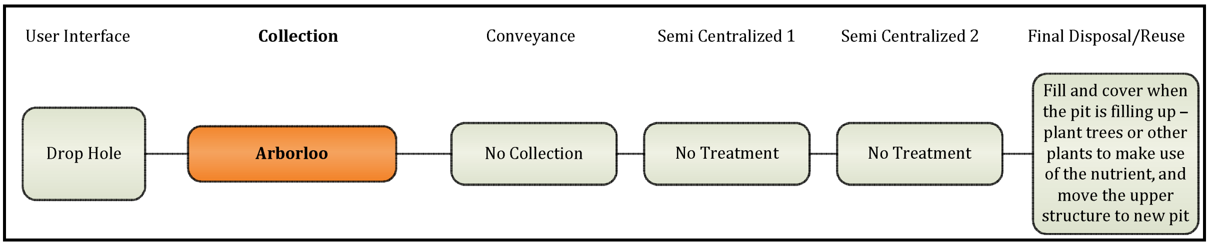


Figure 4.6 Arborloo

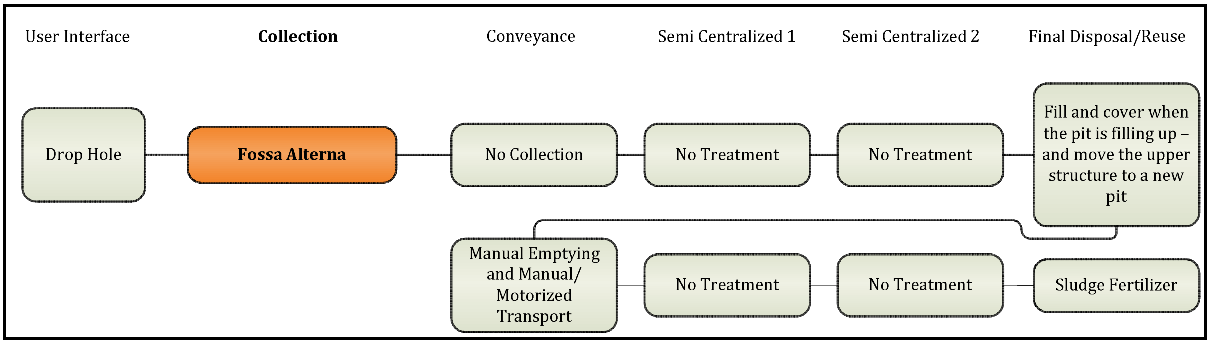


Figure 4.7 Fossa alterna

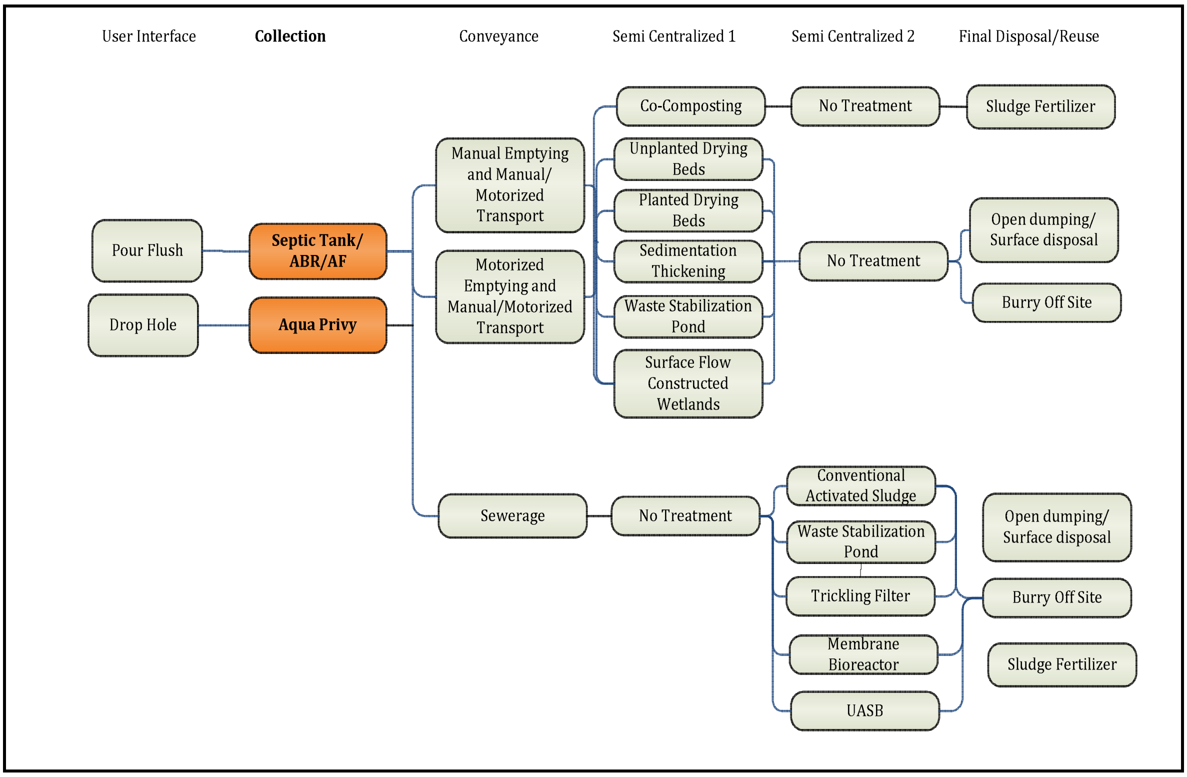


Figure 4.8 Septic tank/ ABR/ AF and aqua privy

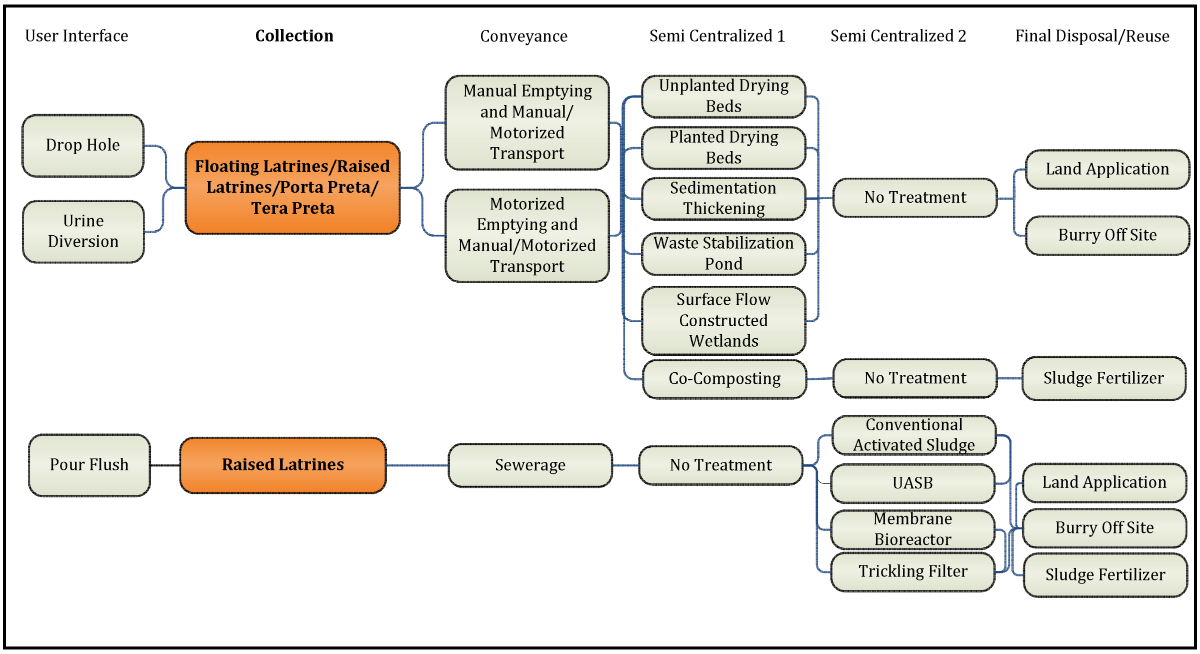


Figure 4.9 Storage latrines

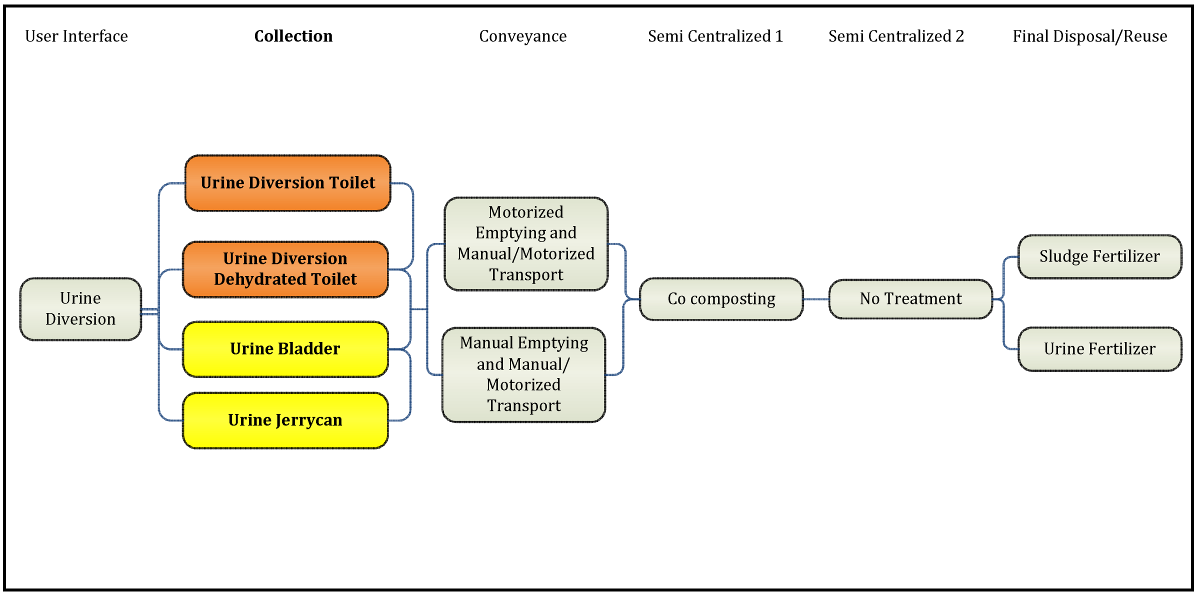


Figure 4.10 Urine diversion toilets

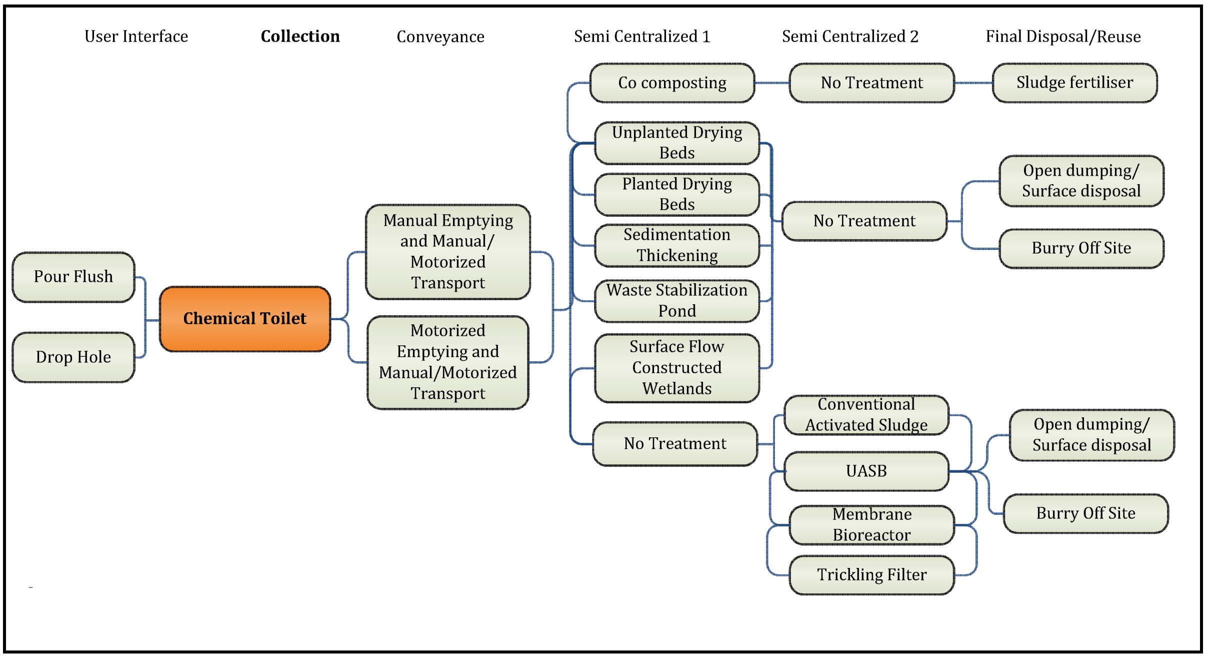


Figure 4.11 Chemical Toilet

Compatibility by conveyance system

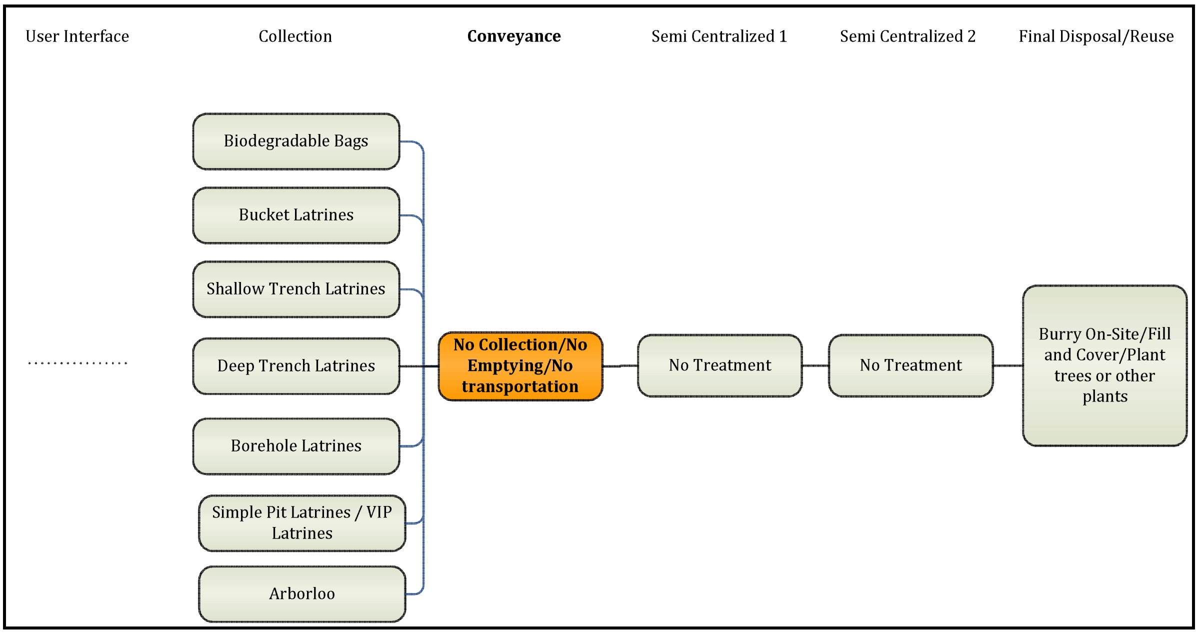


Figure 4.12 No collection emptying and transport system

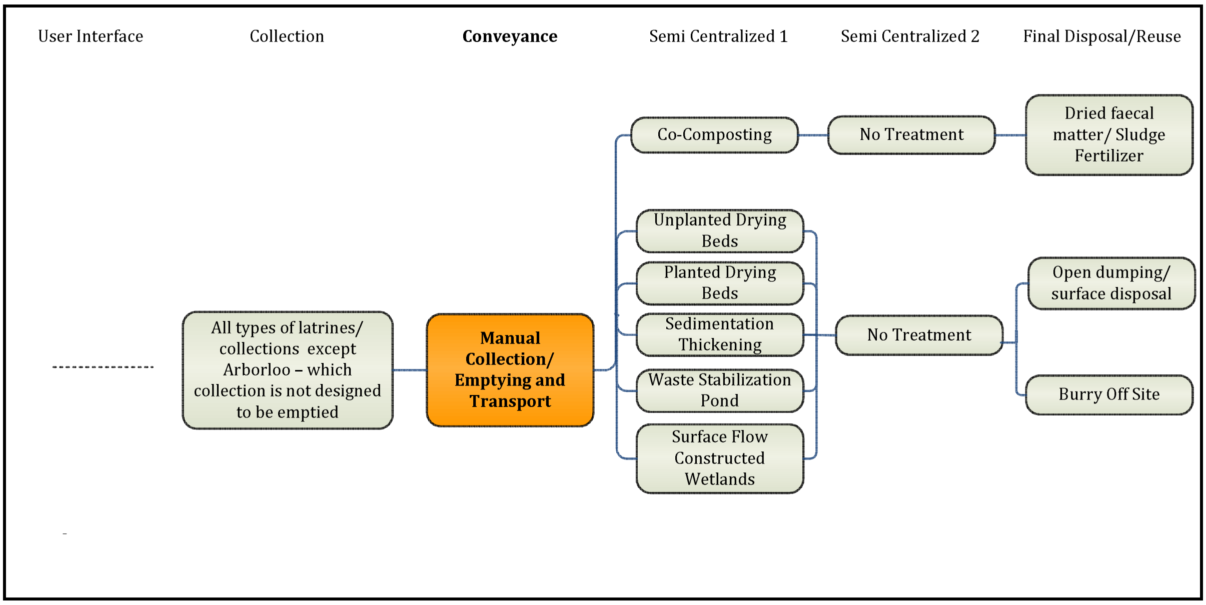


Figure 4.13 Manual collection/ emptying and transport conveyance system

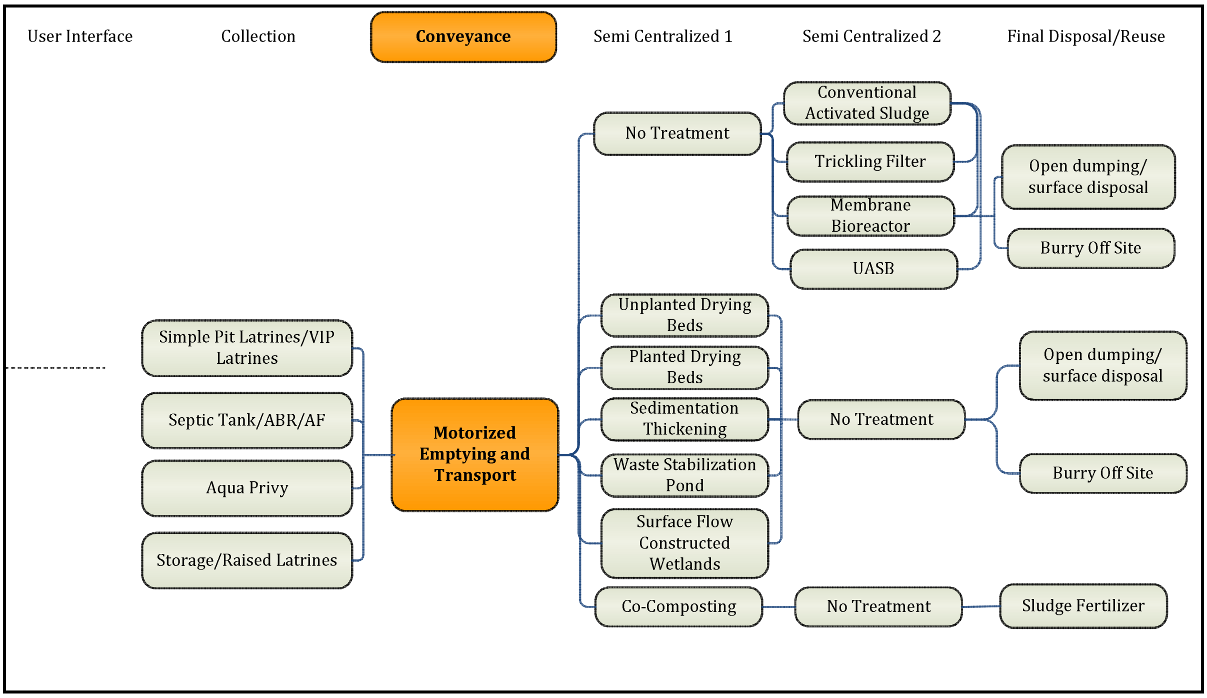


Figure 4.14 Motorised emptying and transport conveyance system

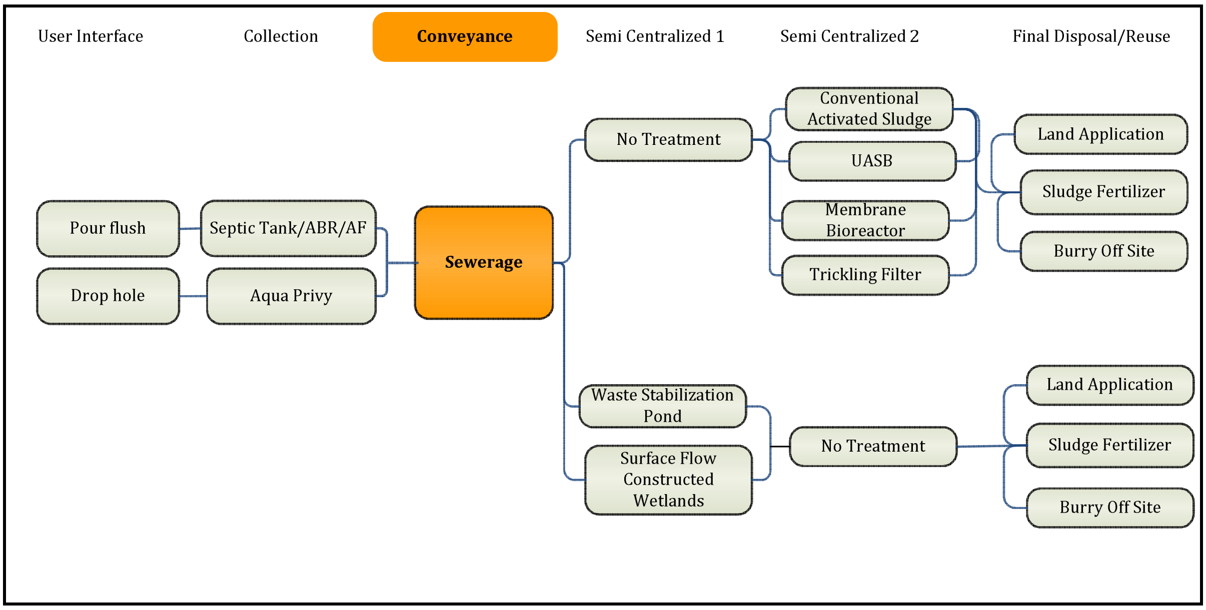


Figure 4.15 Sewerage conveyance system

4.1.3. EVALUATION

Evaluation of the screened sanitation chain is achieved by a pre-defined multi criteria analysis approach. Each criterion was given weight which implies on its importance. The weight allocated varies from 1-4 whereby 1 represent not important and 4 represent extremely important criterion. The sanitation chain to be evaluated is rated by scores which are varying from 1-5. 5 describe the best quality of each criterion such as low capital cost and 1 describe poor aspect of the criterion such as high capital cost. The total score are calculated based on this formula below.

$$Total\ score = \sum_{i=1}^{n} (Criteria\ score\ x\ criteria\ \ weight\ factor) \qquad equation\ 4.1$$

The scores and weight used in building the DSS model are entailed in the Annex **A2**. The sanitation chain with highest total scores the best option which can be implemented.

CHAPTER 5

Results: Decision Support System (DSS)

Previously chapters describe the need of having a workflow that will assist relief providers in selecting an appropriate and sustainable sanitation technology. To provide for the above indicated needs, a conceptual framework was developed. The designed conceptual framework in CHAPTER 4 is further translated in a Decision Support System (DSS) model. The (DSS) model for emergency sanitation was built up on an excell visual basic application (VBA) environment using visual basic programming language. The DSS model was developed based on conceptual framework design in section 4.1 above. The model is simple and user friendly; it can be used by relief providers regardless of their technical background.

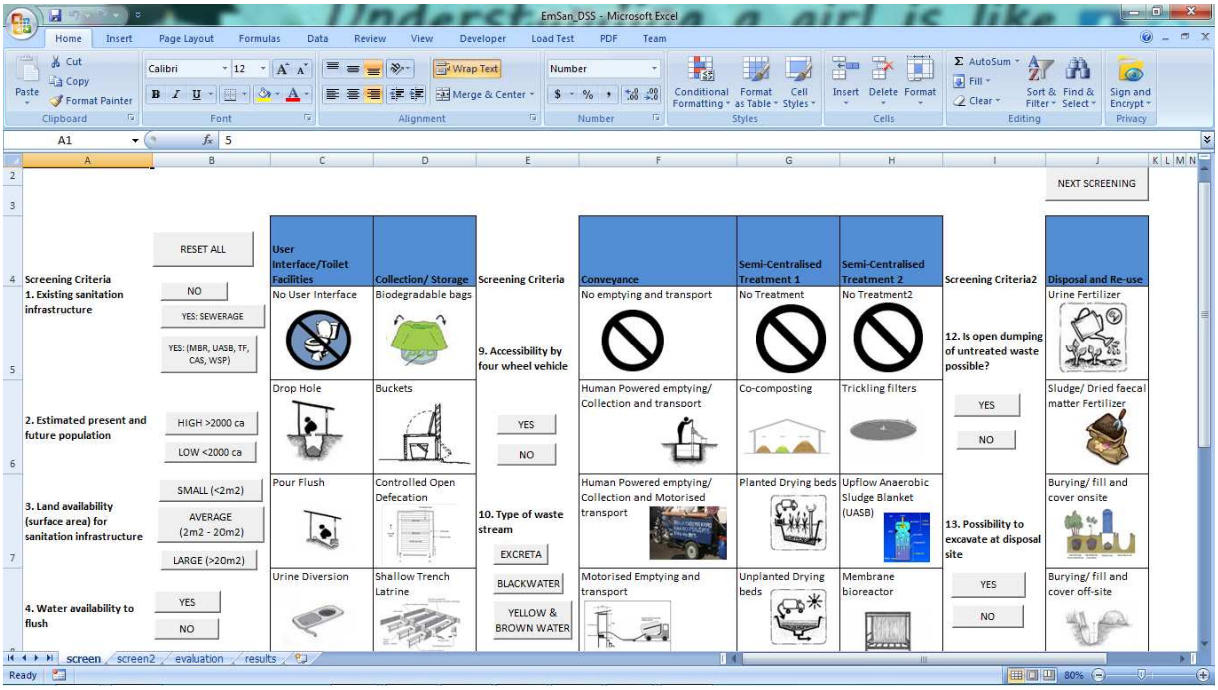
5.1. How to use the DSS model

5.1.1. Opening Excel and Enabling Macro

- From your computer main menu, start Microsoft Excel (2007) programme.
- A developer tab should appear in the ribbon, if not enable it.
- Enabling developer tab: Click office button, go to excel options. A dialog box will appear. Tick the show developer tab and OK. Close dialog box.
- From the ribbon click developer tab, then click macro security. A macro security dialog box will appear. Click Enable all macros (not recommended, potentially dangerous code can run) option. Click OK and close the dialog box.

5.1.2. Open DSS for emergency sanitation

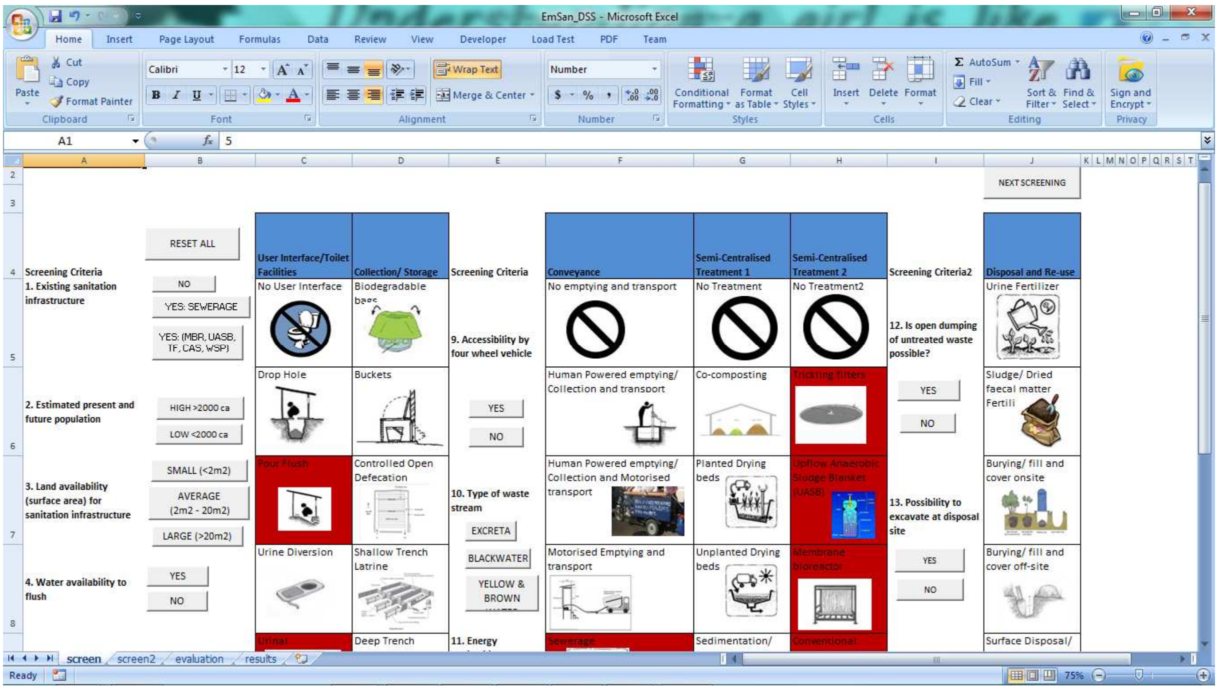
- Open excel file that contain DSS model for emergency sanitation
  The first worksheet namely "screen" will appear whereby screening 1 is performed.



5.1.3. Define the inputs: Screening 1

The screening criteria in the form of questions are presented in first worksheet namely "screen".

- Provide the appropriate information depending on the disaster scenario by clicking on the correct answer button.

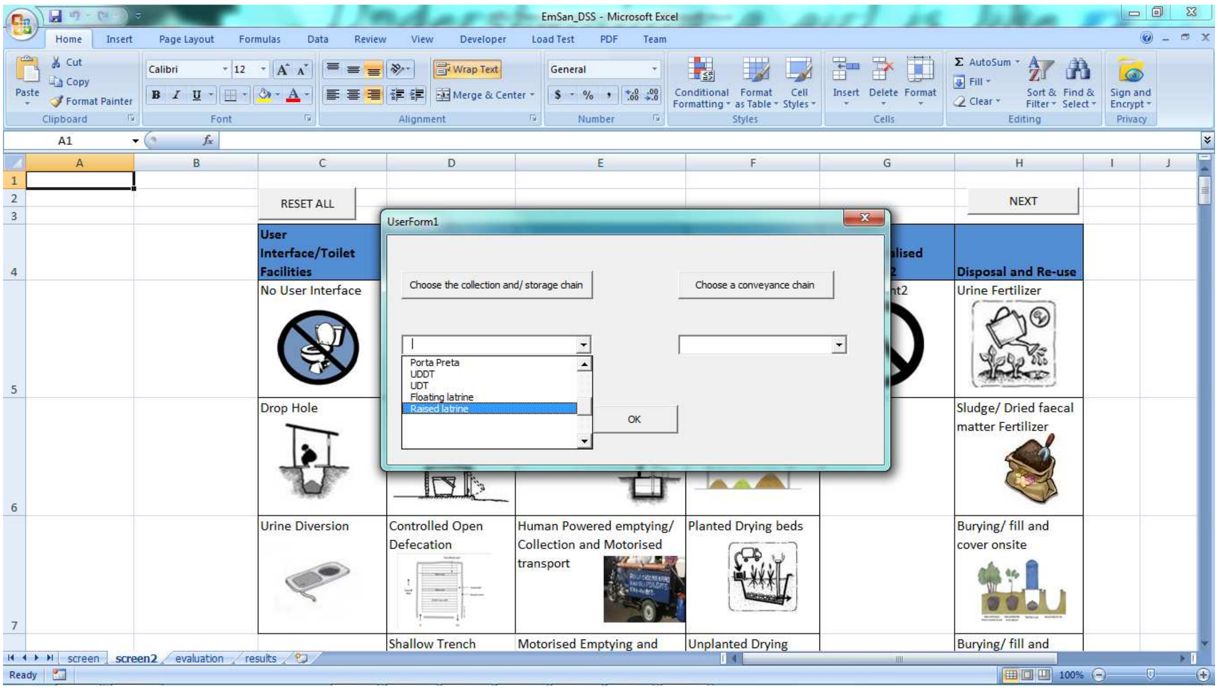


- Do this for all the necessary criteria presented. Then press "NEXT SCREENING" button. Upon doing so the model will automatically move to next worksheet namely "screen2". In worksheet "screen2" a dialogue box will appear.

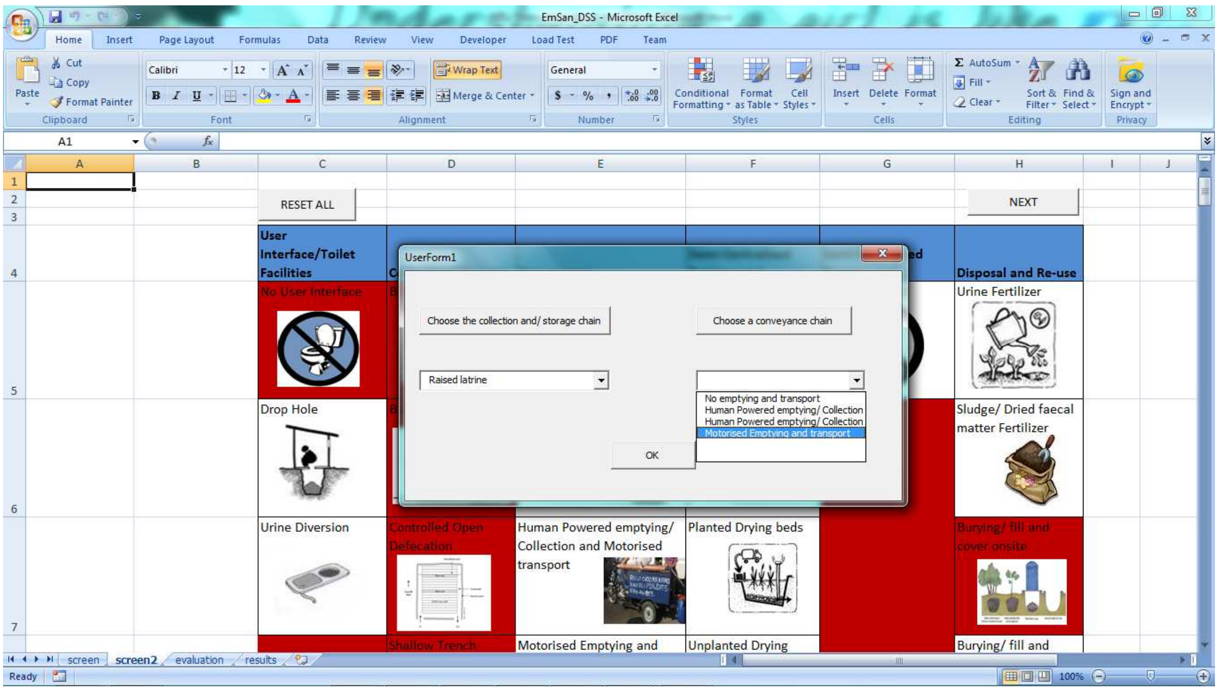
5.1.4. Define the inputs: Screening 2

In this stage compatibility by collection and / storage systems along with compatibility by conveyance systems of the screened options is achieved.

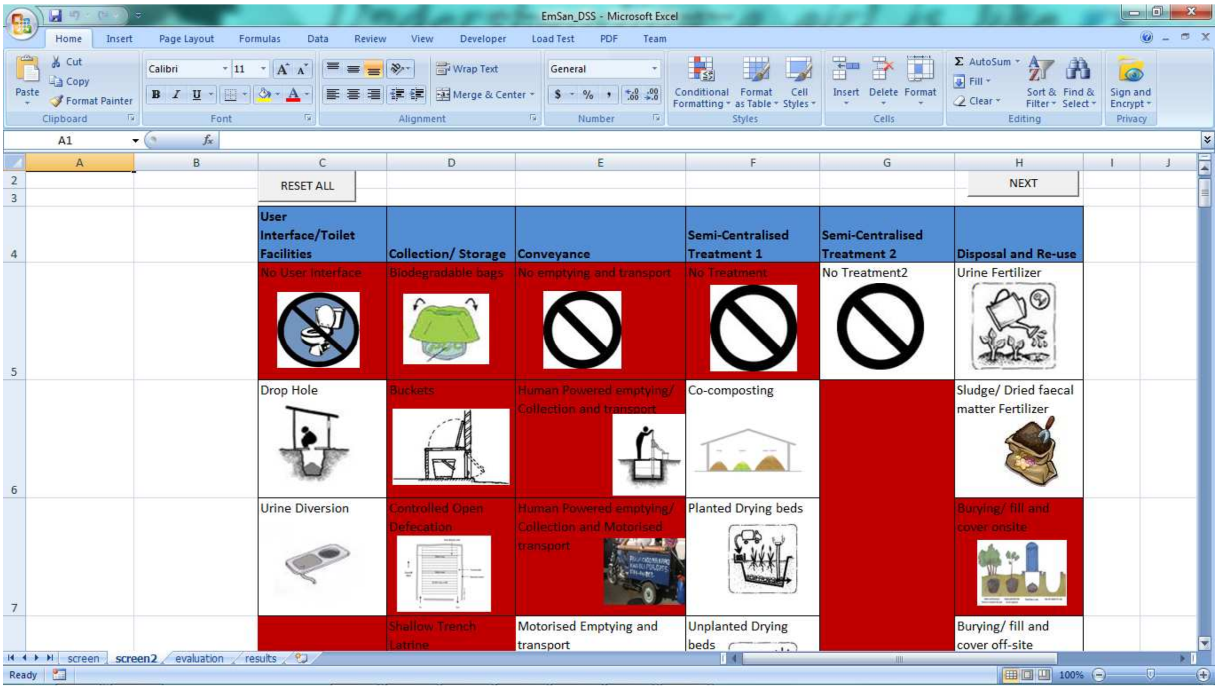
- Choose the collection and/ storage chain from a dialogue box dropdown menu.



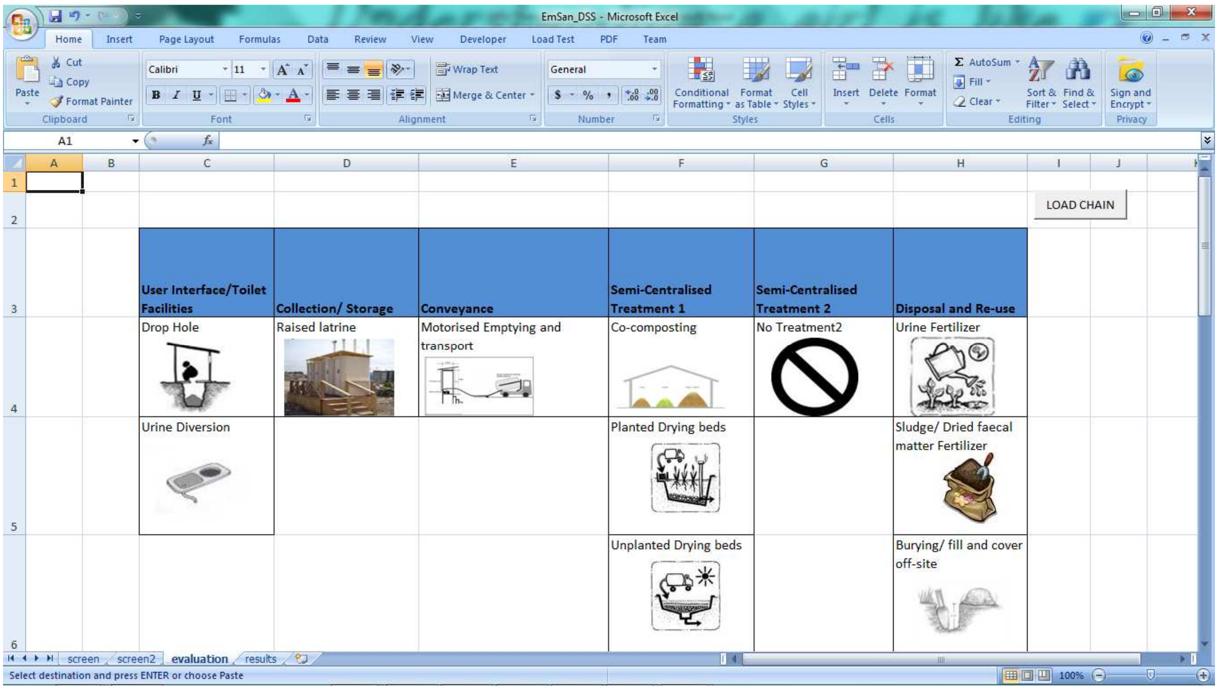
- Choose a conveyance chain from a dialogue box dropdown menu.



- Upon selection click "OK" to unload the dialogue box.



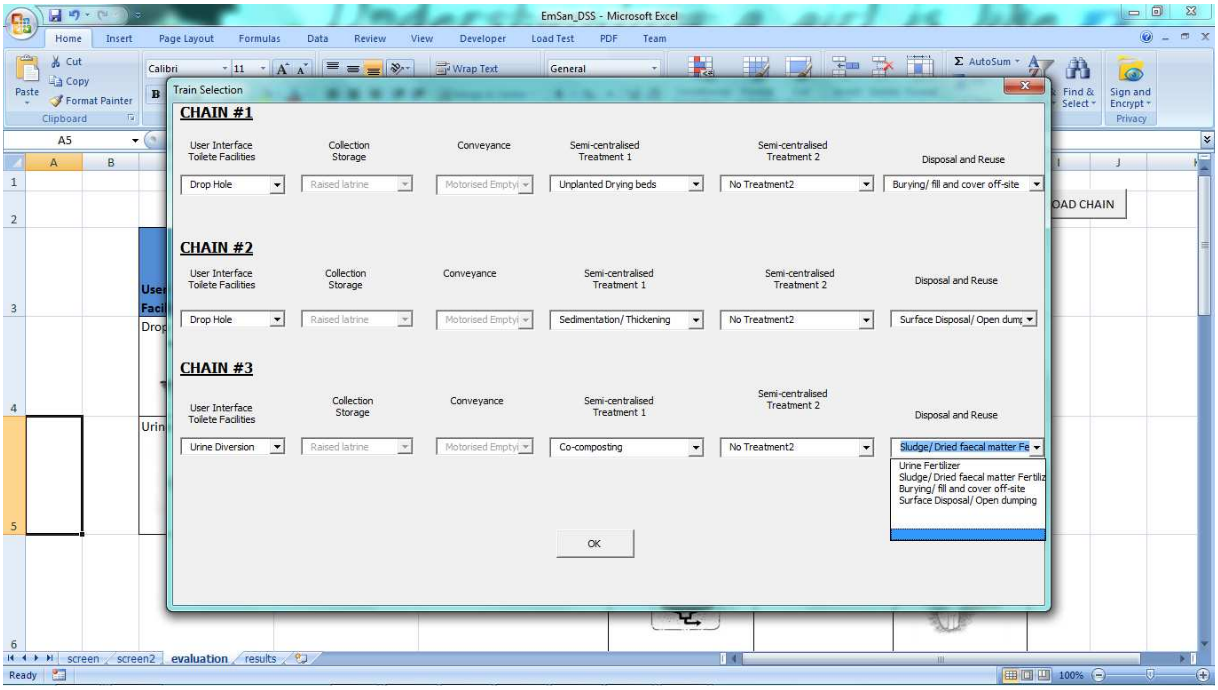
- Then click "NEXT" button to move to next worksheet namely "evaluation". The compatible chain for evaluation will appear.



5.1.5. Evaluation

In this stage the compatible chain are further evaluated. User is required to give up to three chains that will be evaluated.

- Click "LOAD CHAIN" button. A dialogue box will appear with three possible chains.
  Based on first and second screened options, the dropdown menu list will automatically be filled.

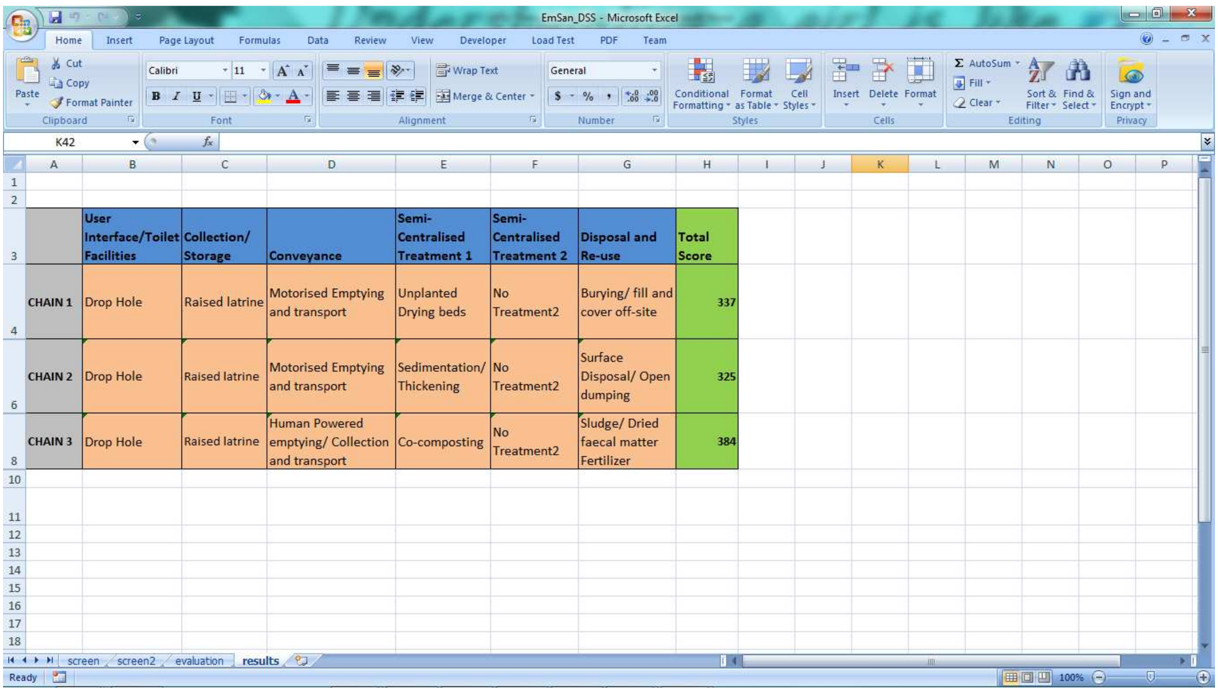


- From the dropdown menu of each chain, select the technology option for your preference.
  Note: For collection and/ storage systems and conveyance systems they are automatically selected, therefore user can not select. If not preferred user should start new screening.
- After selection the three sanitation chains, click "OK".

5.1.6. Results display

The results of the feasible sanitation technology chain options are displayed in worksheet namely "results". In this worksheet, three sanitation chain selected will appear with the total scores.

- From the total scores, the chain with highest scores is selected as the feasible chain.



	User Interface/Toilet Facilities	Collection/ Storage	Conveyance	Semi-Centralised Treatment 1	Semi-Centralised Treatment 2	Disposal and Re-use	Total Score
CHAIN 1	Drop Hole	Raised latrine	Motorised Emptying and transport	Unplanted Drying beds	No Treatment2	Burying/ fill and cover off-site	337
CHAIN 2	Drop Hole	Raised latrine	Motorised Emptying and transport	Sedimentation/ Thickening	No Treatment2	Surface Disposal/ Open dumping	325
CHAIN 3	Drop Hole	Raised latrine	Human Powered emptying/ Collection and transport	Co-composting	No Treatment2	Sludge/ Dried faecal matter Fertilizer	384

5.2. Scope of the tool

The DSS model for emergency covers the following areas,

- The model assist relief provider in deciding which sanitation technology chain to apply in the case of emergency.
- It filters the few sanitation technologies chains options from a pool of options.
- It analyse sanitation system compatibility based on collection and/ or storage technologies as well as conveyance technologies chain.
- It evaluates the screened options in order to come up with best feasible sanitation technology chain options.
- The model contains the inputs criteria which are linked to pre-defined sanitation technology chains, and hence make it easy for users regardless of background in emergency sanitation technologies.
- The model considers the sustainability of the whole chain by integrating both technical and social aspects.
- The model evaluates the sanitation chain based on all evaluation criteria developed at once. It also uses a multi criteria analysis (MCA) aproach for evaluation.
- The capital cost criteria for evaluation does not cover the super structure cost.

5.3. Limitation of the tool

Palaniappan, et al. (2008) presented existing gaps for sanitation tools. The DSS model for emergency addressed some of the gaps. On the contrary, the developed model is also limited to the following aspects.

- The model did not cover selection of sanitation chain based on gender despite that the use of sanitation facility in some cases is gender bias.
- The model suggests the best feasible sanitation technology chain but it does not involve the Design specification of it as this depends on actual grounds conditions.
- The model is limited to selection of sanitation chain but it does not cover the implementation and monitoring processes.
- The DSS model for emergency sanitation does not take into account the effect of mass balance of the sanitation chain.

  Annex **A.1** present a mass balance comparison of two sanitation chains and their impacts towards the environment based on chemical oxygen demand (COD) and volume. In sanitation chain 2 it was observed that there is a possibility of groundwater pollution due to leaching whilst for the sanitation chain 1 treated excreta both solid and liquid part are returned back to nature in a safe way.

CHAPTER 6

Conclusion

Understanding the problem in making the selection of sanitation technology options in emergency relief, a conceptual framework to aid in this selection was developed. Furthermore the framework was developed in a DSS computer based model. This model will assist relief provider in selection appropriate technology for providing safe sanitation for the case of emergency. This chapter intends to draw a research study conclusion

6.1. General Conclusion

The overall objective of this thesis was to develop a Conceptual Framework decision support tool for emergency sanitation that could be translated into a computer program. A decision support system (DSS) has been developed based on the designed conceptual framework. The model was built in Microsoft excel 2007 using visual basic application. The DSS model has two stages; screening, and evaluation. At screening stage, the possible sanitation technology chains in emergency are screened based on screening criteria presented. The model requires inputs defined by users through responding to developed screening criteria both technical and social aspect criteria. Based on this inputs, screening process will be achieved. A compatibility analysis is done to the screened in sanitation options. The compatibility is done base on collection/ storage chain and conveyance chain. Furthermore the compatible chains will be evaluated for final feasible sanitation chain. Evaluation is achieved by predefined multi criteria analysis. The model evaluates the entire chain based on all five evaluation criteria at once. The predefined multi criteria analysis (MCA) was done based on technical background and experience on sanitation projects. For the same reasons the weight factor of each evaluation criteria and scores of each criteria towards the sanitation technology chain was allocated. Lastly, user will be able see the total score of three possible sanitation chains with the highest scorer as the best feasible sanitation chain for implementation.

The DSS model developed for emergency sanitation provides an interactive interface whereby users are prompt to give feed inputs to the model. Furthermore, the model presents the visual of all sanitation technologies for emergency in iconic way (picture) which helps user to quickly have an idea of the technologies involved. In addition, a review of all sanitation technology presented is discussed that can be used as a compendium together with the DSS model for emergency sanitation.

The DSS model for emergency sanitation developed will enable relief provider to select a sanitation chain to implement in disaster relief which is sustainable and appropriate. The model also provides solutions which are for long time measure solutions. Furthermore, the DSS model for emergency can be used by relief provider both with and without technical background on emergency sanitation.

6.2. Challenges

The major challenge with wastewater/ excreta treatment technologies is the amount of sludge produced. The volume of sludge produced has great impact on ways of de-sludging, treatment mechanism for sludge, as well as how to dispose it. Nevertheless faecal sludge management (FSM) aims in reducing the amount of sludge produced from sanitary facilities. On the other hand to implement this aspect in the conceptual framework and the model was challenging since the volume of sludge produced is varying greatly depend of several factors including the sanitation collection technology used, microbiological activities within the collection chamber, and the treatment technology applied. In spite of this, volume of sludge produced in this model was somehow reflected in waste stream criteria at screening stage. The urine diversion sanitation technology systems results in less sludge production. Another challenge was specific units to quantify this criterion. At collection point it refers the volume accumulated which is also depending on the time until it is ready for de-sludging. At conveyance stage it implies the number of trucks involved in moving sludge from collection point to treatment point. At treatment point it reflects the area required for a sludge treatment technology. Similarly for disposal point, the areas required for disposal is a subject of concern. To sum up, volume of sludge produced is an important criterion to be incorporated provided the units are clearly stated.

6.3. Recommendations

To improve on the model, the following can be included;

- The evaluation of the model is done by predefined multi criteria analysis basis. It is also good to involve user at this stage by allowing them to give the weight factor to each criteria based on their preferences.
- Currently, the model uses all the evaluation criteria at once to evaluate the possible chain. Sanitation chains can be evaluated using one or multiple criteria. Therefore, in future a dialogue box can be incorporated that will allow user to select one or more criteria to be used for evaluation. This will also present the sensitivity analysis of the model towards varying of evaluation criteria.
- For implementation purpose, it is wise to understand the impacts of evaluation criteria towards the feasible chain. Therefore a display result box can be incorporated, that will indicate the effect of selected chain towards the evaluation criteria for instance high, medium, or low.
- Volume of sludge produced should be included in the screening criteria.

In conclusion, despite of this decision support system (DSS) model achievement, there is a room for further research on this topic based on the above recommendations.

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ANNEXES

A.1 Mass balance

Introduction
Mass balance refers to accounting for all matter that enter, leave, accumulate or are transformed in the system. The basis for this accounting process is the law of cnservation of mass i.e. matter cannot be created or destroyed. Mass balance accounts for changes due to fluid and chemical transformations. In mass balance a system indicate confined boundaries of system technology volume.

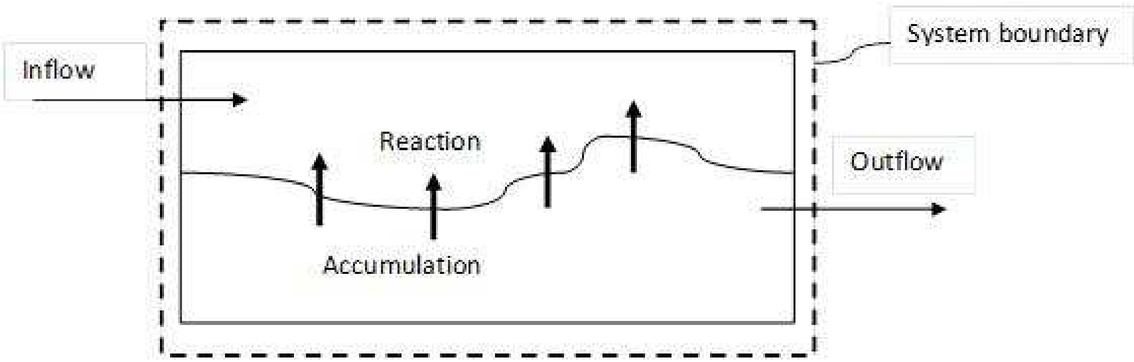

Figure 6.1 Mass balance concept

Mass balance for sanitation systems

Inflow - Reaction - Outflow = Accumulation (6.1)

Whereby
- Inflow refer to what are collection system receive (i.e. urine, faeces, and anal cleansing materials)
- Reaction refers the transformation activities such as anaerobic or aerobic reactions.
- Outflow refers what comes out of the system boundaries. It can be desludging or disposal techniques.
- Accumulation refers to building up of biodegradable sludge.

Chain 1: UDDT + Human powered and motorised transport + No treatment + No treatment + Urine fertilizer & sludge fertilizer
Assumptions
- 20 people will be using the latrine per day (TheSphereProject, 2011)
- One person produces 1.5 litres per day
- One person produces 51 kg/cap/year equivalent to 140g/cap/day
- BOD is half COD

Table 6.1 Urine, Faeces, and blackwater waste stream characterisation

Parameter	Units	Urine	Faeces	Total	Urine	Faeces	Total
					With 20 people		
Wet mass	g/cap/day	1507	140	1647	30140	2800	32940
Volume (before drying)	l/cap/day	1.5	0.1	1.6	30	2	32
Dry mass	g/cap/day	57.5	30	87.5	1150	600	1750
Total nitrogen	g/cap/day	11.0	1.5	12.5	220	30	250
Total phosphorus	g/cap/day	1.0	0.5	1.5	20	10	30
Potassium	g/cap/day	2.7	1.1	3.8	54	22	76
COD	g/cap/day	9.9	39	48.9	198	780	978
BOD	g/cap/day	4.9	19.5	24.4	99	390	489

[source: (Jönsson, et al., 2004, Otterpohl, 2003)]

Mass balance: COD

Chain 1: UDDT + human powered emptying, collection and transport + No Treatment + No Treatment + Fertilizer(urine&sludge)

COD received due to faecal sludge is 780 g/d, urine is 198 g/d, blackwater is 978 g/d (refer **Table 6.1**)
Consider the whole chain to be a system boundary
In emergency, sludge stay for at least 6 weeks (42 days) before de-sludge. During the sludge will accumulate and at the same time will biodegrade. According to (Foxon, et al., 2011) 80% of sludge is considered biodegradable. Therefore after 6 weeks 20% of the sludge at collection point will be emptied. Since the collection technology is containers therefore there will be no leaching.

At collection and/or storage chain

Faeces

Inflow COD = 780 gCOD/d
Accumulation = 20% of inflow COD
= 156 gCOD/d
Reaction = 80% of inflow COD which has been consumed by bacteria
= 624 gCOD/d
Outflow = zero (no outflow at collection since the collection system is sealed)
780 - 624 - 0 = 156
156 = 156 balanced
The amount of COD to be taken out by de-sluding the sanitation technology is the same amount that has been accumulated within the collection technology i.e 156 gCOD/d or 6552 gCOD after 42 days.

At conveyance chain

The dry faeces are conveyed to the disposal point by human powered emptying, collection and transport and in some cases a motorised transport is used if the final disposal point if far. The amount of COD that is conveyed is the same as the amount taken out the sanitation facility i.e. 6552 gCOD.

At semi-centralised treatment 1

For UDDT systems, no treatment is required. The time that the faeces allowed to biodegrade is enough as treatment.

At semi-centralised treatment 2

For UDDT systems, no treatment is required. The time that the faeces allowed to biodegrade is enough as treatment.

At disposal and/ or reuse chain

The dry faeces from a UDDT can be used as organic fertilizer in crop growing. The amount of COD conveyed will be further disposed to a final disposal point as fertilizer i.e. 6552 gCOD.

Urine

At collection and/or storage chain

Inflow COD = 198 gCOD/d

Accumulation = 20% of inflow COD

= 39.6 gCOD/d

Reaction = 80% of inflow COD which has been consumed by bacteria

= 158.4 gCOD/d

Outflow = zero (no outflow at collection since the collection system is sealed)

198 - 158.4 - 0 = 39.6

39.6 gCOD = 39.6 gCOD balanced

The amount of COD to be taken out by de-sluding the sanitation technology is the same amount that has been accumulated within the collection technology i.e 39.6 gCOD/d.

At conveyance chain

The dry faeces are conveyed to the disposal point by human powered emptying, collection and transport and in some cases a motorised transport is used if the final disposal point if far. The amount of COD that is conveyed is the same as the amount taken out the sanitation facility i.e. 39.6 gCOD/d.

At semi-centralised treatment 1

For UDDT systems, no treatment is required. The time that the faeces allowed to biodegrade is enough as treatment.

At semi-centralised treatment 2

For UDDT systems, no treatment is required. The time that the faeces allowed to biodegrade is enough as treatment.

At disposal and/ or reuse chain

Urine from a UDDT can be used as organic fertilizer in crop growing. The amount of COD conveyed will be further disposed to a final disposal point as fertilizer.

Chain : VIP + human powered emptying, collection and transport + Unplanted drying beds + No Treatment + Fertilizer sludge

Blackwater

At collection and/or storage chain

Based on COD fractionation concept, 80% of total COD is biodegradable and 20% of total COD is unbiodegradable. From the unbiodegradable COD 17% is particulates which ends in the system as sludge while 3% will escape the system as soluble effluent. In this chain the 3% is due to leaching COD which infiltrates to the soil as the VIP is not sealed.

Inflow COD = 978 gCOD/d

Accumulation = 17% of inflow COD

= 166.26 gCOD/d

Reaction = 80% of inflow COD which has been consumed by bacteria

= 782.4 gCOD/d

Outflow = 3% of inflow COD

= 29.34 gCOD/d

978 - 782.4 - 29.34 = 195.6

166.26 = 166.26 balanced

The amount of COD to be taken out by de-sluding the sanitation technology is the same amount that has been accumulated within the collection technology i.e 166.26 gCOD/d.

At conveyance chain

The dry faeces are conveyed to the disposal point by human powered emptying, collection and transport and in some cases a motorised transport is used if the final disposal point if far. The amount of COD that is conveyed is the same as the amount taken out the sanitation facility i.e. 166.26 gCOD/d.

At semi-centralised treatment 1

The conveyed sludge will be taken for the first treatment chain i.e. unplanted drying beds. When exposed to sun for drying, the sludge will be settled and dry while the liquid part will leave as effluent. (Tilley, et al., 2005) indicate 60% to 80% of faecal sludge will drain as liquid. Assuming 70% will drain as liquid and 30 % will be dried solids. In unplanted drying beds, faecal sludge can be removed after 2 to 3 years. Due to this continuous additional of sludge, the sludge results in anaerobic conditions.

Dried solid COD = 30% of 166.26 g COD/d

= 49.88 gCOD/d

COD leave with liquid is 70% of 166.26 g COD/d

= 116.38 gCOD/d

At semi-centralised treatment 2

No treatment is required, hence same COD from the previous treatment chain.

At disposal and/ or reuse chain

The dried sludge from unplanted drying beds can be removed and used as soil conditioner in crops growing. Moreover the effluent can be used in irrigation or let to infiltrates.

Mass balance: Volume

Fresh faecal sludge is produced

Faecal sludge produced = 0.1 litres per capita per day
Urine produced = 1.5 litres per capiata per day
Total blackwater produced = 1.6 litres per capita per day
Total faecal sludge produced = 20 *1.6 = 32 litres/day

In emergency, the VIP will be deployed within 3- 6 weeks
For 6 weeks: sludge volume accumulated will be

= 32 litres/day * 42 days = 1,344 litres = 1.344 m^3

Transport capacity
Sludge is conveyed to a treatment point by means of manual transport with a transport unit which has a minimum volume of 1.5 m^3
Number of trips that will be made

= 1.344/1.5 = 0.89

Hence, one trip is enough

Semi centralised treatment 1
Unplanted drying bed with a depth of 80cm
Therefore; area required is 0.0.220m^2
Assume 70% of sludge volume will drain as liquid and 30% of sludge volume will become dried solids.
Therefore sludge volume will be

= 1.344 * 0.30 = 0.4 m^3

The dried sludge is further taken to final disposal point.

A.2 Multi criteria analysis (MCA)

User Interface	**Capital costs**	**Ease of deployment**	**O&M costs**	**skill requirement**	**Use of local materials**
No User Interface					
Drop Hole					
Pour Flush					
Urine Diversion					
Urinal					

WEIGHT FACTOR	**Capital costs**	**Ease of deployment**	**O&M costs**	**skill requirement**	**Use of local materials**

Weight factor	
1	Not important
2	Important
3	Very important
4	Extremely important
score	
1	very high
2	high
3	moderate
4	low
5	very low

Collection/ Storage	**Capital costs**	**Ease of deployment**	**O&M costs**	**skill requirement**	**Use of local materials**
Biodegradable bags					
Buckets					
Controlled Open Defecation					
Shallow Trench Latrine					
Deep Trench Latrine					
Borehole latrine					
Simple Pit latrine					
VIP					
Arborloo					
Fossa alterna					
Tera Preta					
Porta Preta					
Septic tank					
AF					
ABR					
Aqua privies					
UDDT					
UDT					
Floating latrine					
Raised latrine					
Urine Jerrycan storage					

Conveyance	**Capital costs**	**Ease of deployment**	**O&M costs**	**skill requirement**	**Use of local materials**
No emptying and transport					
Human Powered emptying/ Collection and transport					
Human Powered emptying/ Collection and Motorised transport					
Motorised Emptying and transport					
Sewerage					

Semi-Centralised Treatment 1	**Capital costs**	**Ease of deployment**	**O&M costs**	**skill requirement**	**Use of local materials**
No Treatment					
Co-composting					
Planted Drying beds					
Unplanted Drying beds					
Sedimentation/ Thickening					
Waste stabilisation ponds (WSP)					
Constructed wetlands					

Semi-Centralised Treatment 2	**Capital costs**	**Ease of deployment**	**O&M costs**	**skill requirement**	**Use of local materials**
No Treatment2					
Trickling filters					
Upflow Anaerobic Sludge Blanket (UASB)					
Membrane bioreactor					
Conventional activated sludge					

Disposal and Reuse	**Capital costs**	**Ease of deployment**	**O&M costs**	**skill requirement**	**Use of local materials**
Urine Fertilizer					
Sludge/ Dried faecal matter Fertilizer					
Burying/ fill and cover onsite					
Burying/ fill and cover off-site					
Surface Disposal/ Open dumping					

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