SEI STOCKHOLM ENVIRONMENT INSTITUTE

Stockholm Environment Institute, EcoSanRes Series, 2011-1

Microbial Exposure and Health Assessments in Sanitation Technologies and Systems

Thor Axel Stenström, Razak Seidu, Nelson Ekane, and Christian Zurbrügg

sustainable sanitation alliance

eawag aquatic research

Sandec
Water and Sanitation in Developing Countries

Norwegian University of Life Sciences MDCCCLIX

EcoSanRes

Microbial Exposure and Health Assessments in Sanitation Technologies and Systems

Thor Axel Stenström, Razak Seidu,
Nelson Ekane, and Christian Zurbrügg

EcoSanRes Programme
Stockholm Environment Institute
Kräftriket 2B
106 91 Stockholm
Sweden

Tel: +46 8 674 7070
Fax: +46 8 674 7020
Web: www.sei-international.org and www.ecosanres.org

This publication is downloadable from www.ecosanres.org

Head of Communications: Robert Watt
Publications Manager: Erik Willis
Research and Communications Manager, EcoSanRes Programme: Arno Rosemarin
Layout: Richard Clay

Cover Photo: Burera District, Rwanda © Nelson Ekane

SEI STOCKHOLM ENVIRONMENT INSTITUTE

ISBN 978-91-86125-36-3

sustainable sanitation alliance

eawag aquatic research

Sandec
Water and Sanitation in Developing Countries

Norwegian University of Life Sciences MDCCCLIX

EcoSanRes

CONTENTS

ACKNOWLEDGEMENT

Several individuals within the SuSanA network have given valuable comments on different parts of this book. There is one person who especially should be acknowledged. This is Elisabeth Tilley who have given valuable review comment on the full book and also substantially contributed with text input to the 3rd part of the book.

We are also thankful to EAWAG/SANDEC for the general kind support in letting us use the different system figures that has constituted a valuable part of the earlier "Compendium of Sanitation System and Technologies", which also formed the inspiration for this expansion focussed on the microbial health parts.

This work has mainly been financed within the framework of the EcoSanRes program financed by Sida. We are grateful for the support of the work by the former program director Gunilla Brattberg as well as the present support by program Director Madeleine Fogde and Communication Director Arno Rosemarin.

PART 1 - INTRODUCTION

Photo: Razak Seidu

The main objective of a sanitation system is to protect and promote human health. This is done by providing and maintaining a clean environment without faecal contamination and by adopting measures that break the cycle of disease transmission. To achieve the direct effects of containment and reduction of pathogenic organism the system should be technically appropriate, economically viable, socially acceptable, and institutionally manageable which are factors that all affect the health outcomes.

Human health and environmental impact are interlinked. When the products from a sanitary system should be considered as potential resources, either for food production or for energy generation, the health issues and aspects of risk reduction need to be accounted for in addition to the benefits of nutrient recovery.

In the technical improvement of existing sanitation systems or in the design and implementation of new ones, health risk considerations are crucial and should always be an integral part of the planning and decision making process. Here, human exposure through different routes and exposure reduction in the system context, against pathogens or where applicable hazardous substances, are central. The local relevant organisms or substances are prioritized in an initial "hazard identification" step (WHO, 2006). Different critical points of exposure in the full sanitation system, from the toilet, through the collection and treatment part of the system to the point of reuse or disposal should be accounted for. This also implies consideration for the downstream populations.

This book focuses on the health factors related to pathogenic organisms. The attempt is to assess and review evidences in relation to health impact and to discuss the findings based on epidemiological evidence, risk assessment and behavioural aspects and practices.

The book is partly based on the "Compendium of Sanitation Systems and Technologies" (Tilley *et al.*, 2008) but focuses on human exposure and health. It further relates to the Sustainable Sanitation Alliance (SuSanA) Working Group 4 on treatment options, hygiene and health.

The aims are to:

- highlight and examine the "Critical Exposure Points (CCPs)" in a sanitation system
- assess the health risks associated with the technologies that make up different sanitation systems

- exemplify the sanitation system gaps that may impact health outcomes

THE PARTS OF THE BOOK

The book has three main parts.

Part 1 gives a general background on the link between sanitation and health, and presents a framework for assessing and mitigating the health risk associated with sanitation systems from technical and social-cultural points of view.

Part 2 describes different technologies that form a sanitation system relating and referring to earlier descriptions in the "Compendium of Sanitation Systems and Technologies" (Tilley *et al*., 2008). The term 'technology' has been expanded beyond 'engineered tools' or 'infrastructure' and also includes processes like spreading urine or transporting faeces as integral parts of a sanitation system from a human exposure perspective. Each functional group is introduced with an overview of the common hygiene and behaviour aspects for the represented technologies. For each functional group, exposure to pathogens resulting from technical malfunctions and the common hygiene and behaviourial practices are presented, and the associated health risks assessed

Part 3 exemplifies complete sanitation systems with a sequence of functional groups based on case studies. These examples illustrate a range of systems - from incomplete ones, with a high risk to the user or workers, to more complete systems. The best practices to reduce risk to users are illustrated.

The book is intended for planners, engineers, health workers and other professionals who are familiar with sanitation technologies and processes, but who require a better understanding to assess the health risks associated with the components of sanitation systems. It can be used as examples for professionals, who need to perform a rapid assessment of the potential health impact of sanitation systems and/or technologies. It can also be used for student training. The users of the book must have a basic understanding of environmental microbiology and health.

THE SANITATION CHALLENGE

Worldwide, about 2.6 billion people lack access to improved sanitation (WHO/UNICEF, 2010). The situation is most severe in sub-Saharan Africa and South Asia with almost 30 per cent and 50 per cent respectively affected. Yearly about 1.8 million children under five years die, corresponding to about 4900 young lives lost daily from diarrhoeal diseases. Soil-transmitted helminths and water related schistosomes are among the most common parasitic infections worldwide. Most cases occur in tropical and sub-tropical low-income countries. The intestinal worms are an indicator of poor sanitation – about 1 billion people are infected with roundworm and 700 million with hookworm. These cause diminished productivity among adults and missed educational opportunities for children – girls in particular (WHO, 2007).

A general sanitation challenge is that only a fraction of sewage and drainage water is treated before being discharged into waterways (Clarke and King, 2004). For instance in India, 80 per cent of the pollution load contaminating the country's rivers is reported to be human waste (Nadkarni, 2002).

An example of the relationship between health status (here child mortality) and sanitation coverage is shown in Figure 1 below.

EXCRETA RELATED PATHOGENS AND DISEASE

A large range of pathogenic organisms of viral, bacterial, parasitic protozoan and helminths origins may be present in faeces. Few are excreted with urine. The main risks both with urine and greywater are the related degree of faecal cross-contamination in these fractions. All infective organisms related to faeces may also be present in anal cleansings and in ablution water. In many developing countries excreta-related diseases or carriership (infection and excretion without clinical symptoms) are common, with correspondingly high concentrations of excreted pathogens. The faecal pathogens with environmental transmission mainly cause gastro-intestinal symptoms such as diarrhoea, vomiting and stomach cramps. Several may also cause symptoms involving other organs and severe sequels or be an interrelated factor for malnutrition. Table 1 provides an exemplification of some major selected pathogens of concern and their symptoms.

In developing countries outbreaks of cholera, typhoid and shigellosis are of major concern. In both industrialized and developing countries bacterial pathogens, like *Salmonella, Campylobacter* and enterohaemorrhagic *E. coli* (EHEC) are of general

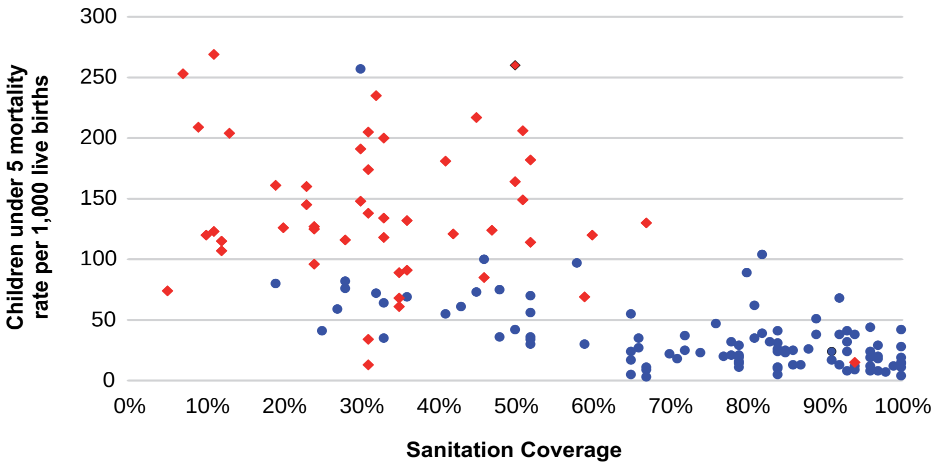


Figure 1: Under 5 mortality compared to sanitation coverage for individual developing countries. Each point represents a separate country. Red diamonds are countries in sub-Saharan Africa

(Adapted from Rosemarin *et al*., 2008; data from WHO/UNICEF, 2008a and WHO, 2008)

importance, when microbial risks from the reuse of faeces, sewage sludge or animal manure are considered.

More than 120 different types of viruses may be excreted in faeces, including members of the enteroviruses, rotavirus, enteric adenoviruses and human caliciviruses (noroviruses) groups. Hepatitis A is also of major concern and the importance of Hepatitis E is emerging, and considered a risk for both water- and food-borne outbreaks, especially where the sanitary standards are low.

The parasitic protozoa, *Cryptosporidium* and *Giardia* occur with high prevalence as enteric pathogens. *Entamoeba histolytica* is also recognised as an infection of concern in developing countries. In developing countries, geo-helminth infections are of major concern. The eggs (ova), of especially *Ascaris* and *Taenia* are very persistent in the environment. Hookworm disease is widespread in most tropical and subtropical areas. These infections exacerbate malnutrition. The eggs from *Ascaris* and hookworms that are excreted in the faeces require a latency period and favourable conditions in soil or deposited faeces to hatch into larvae and become infectious.

Schistosoma haematobium are excreted both in faeces and urine while other types of *Schistosoma*, e.g. *S. japonicum* and *S. mansoni* are just excreted in faeces. More than 200 million people are currently infected with schistosomiasis. The use of treated excreta has no impact. Untreated faecal material, constitutes a risk when applied close to fresh water sources if the intermediate snail hosts is present. Environmental transmission of urinary excreted pathogens is of limited concern in temperate climates. Misplaced faeces in urine-diverting toilets ends up in the urine fraction and is a determinant of health risk. Faecal contamination of collected urine is considered the greatest risk for this excreta fraction. Additionally a few pathogens like *Leptospira interrogans, Salmonella typhi, Salmonella paratyphi* and *Schistosoma haematobium* are excreted in urine. There is a range of other pathogens, including some human viruses that have been detected in urine, but their health impact is normally considered insignificant for further environmental transmission.

The main hazard of greywater is, as for urine, due to faecal cross-contamination. This may emanate from contaminated laundry (i.e. diapers), childcare and showering. If anal cleansing is combined in greywater the risk is increased. These sources will be the main drivers for the subsequent microbial health risks.

Generally, infectious organisms from infected persons excreta may reach other individuals through contact with contaminated areas and thereafter accidentally be transmitted in minute quantities to the mouth. The same occurs when contaminated crops are eaten or when drinking contaminated water. In some instances infections occur through contact with the skin (e.g., hookworm and schistosomiasis) or through inhalation of contaminated aerosols or particulate material. The relative importance of pathogens in causing illnesses depends also on other factors including their persistence in the environment, low infective dose (a few organisms can result in an infection), ability to induce human immunity, and latency

Table 1: Example of pathogens that may be excreted in faeces (can be transmitted through water and improper sanitation) and related diseases, including examples of symptoms they may cause

(adapted from Ottosson, 2003)

Pathogen	Symptoms
Bacteria	
Aeromonas spp	Enteritis
Campylobacter jejuni/coli	Diarrhoea, cramping, abdominal pain, fever, nausea, joint pain, Guillain-Barré syndrome
Escherichia coli (EIEC, EPEC, ETEC, EHEC)	Enteritis
Plesiomonas shigelloides	Enteritis
Salmonella typhi/paratyphi	Fever - headache, malaise, anorexia, slow pulse, enlarged spleen, cough
Salmonella spp.	Diarrhoea, fever, abdominal cramps
Shigella spp.	Dysentery (bloody diarrhoea), vomiting, cramps, fever
Vibrio cholera	Cholera - watery diarrhoea, lethal if severe and untreated
Yersinia spp.	Fever, abdominal pain, diarrhoea, joint pains, rash
Virus	
Enteric adenovirus 40 and 41	Enteritis
Astrovirus	Enteritis
Calicivirus (incl. Noroviruses)	Enteritis
Coxsackievirus	Various, respiratory illness, enteritis, viral meningitis
Echovirus	Aseptic meningitis, encephalitis, often asymptomatic
Enterovirus types 68-71	Meningitis, encephalitis, paralysis
Hepatitis A	Fever, malaise, anorexia, nausea, abdominal discomfort, jaundice
Hepatitis E	Hepatitis
Poliovirus	Often asymptomatic, fever, nausea, vomiting, headache, paralysis
Rotavirus	Enteritis
Parasitic protozoa	
Cryptosporidium parvum/hominis	Watery diarrhoea, abdominal cramps and pain
Cyclospora cayetanensis	Often asymptomatic, diarrhoea, abdominal pain
Entamoeba histolytica	Often asymptomatic, dysentery, abdominal discomfort, fever, chills
Giardia intestinalis	Diarrhoea, abdominal cramps, malaise, weight loss
Helminths	
Ascaris lumbricoides	Generally no or few symptoms, wheezing, coughing, fever, enteritis, pulmonary eosinophilia
Taenia solium/saginata	
Trichuris trichiura	Unapparent through vague digestive tract distress to emaciation with dry skin and diarrhoea
Hookworm	Itch, rash, cough, anaemia, protein deficiency
Shistosomiasis spp	

periods (infective first after a maturation period in the environment) (Shuval *et al.*, 1986). The pathogens with the highest probability of causing infections are consequently those that:

- Have long persistence in the environment;
- Have low minimal infective doses;
- Elicit little or no human immunity;
- Have long latency periods.

The amount of pathogens in collected excreta will mainly depend on the number of infected individuals among the population served and the scale of the sanitation system. In low income countries, where there is a high prevalence of excreta related diseases, a larger number of pathogens are more likely to be introduced into a sanitation systems compared to developed countries where the prevalence is generally low. In terms of variability, pathogens in sanitation systems serving small populations and where the prevalence is normally low will result in a higher variability between the different individual units with time and with low frequency higher peak concentration compared to large systems. The latter represents an integration of many different connected users. In many developing countries the prevalence may be generally high and in these situations differences are not that evident due to the size of the system.

The incidence rate of a disease is the yearly number of reported cases divided by the total population, often expressed per 100,000 people. The incidence will vary due to the prevailing epidemiological situation within an area. The reported number of cases is often substantially underestimated and pathogens causing less severe symptoms are less likely to be reported. The disease incidence and excretion factors will, in general terms, give their concentration at the time of excretion and the subsequent risks will relate to environmental persistence and die-off, dilution factors, exposure and the dose that humans are exposed to. The latter further relate to the efficiency of technical and behavioural barriers within a sanitation system context.

Box 1: Health risk depends on the health status of the toilet users (Source: Peasey, 2000)

In an investigation of individual dry pit toilets *Ascaris* and *Giardia* were found in every 5th one. This reflect the incidence on a household basis (one or several members in 20% of the households are infected with *Ascaris* and/or *Giardia*). The findings indicate the household incidence but not the functionality of the technical installation. The storage time without addition of new faeces is thus the toilet safety barrier in this example. *Ascaris* eggs generally have the longest survival time, so where *Ascaris* infection is endemic, the concentration of viable *Ascaris* eggs per gram is a good marker of pathogen die-off in the pile.

Barriers against disease and transmission pathways

Sanitation systems should serve as a barrier or a series of barriers against different types of pathogens. A barrier mean a part of the treatment or handling chain that substantially reduce the number of pathogens. The barrier function is normally expressed in log-terms, where one log equals 90 per cent reduction, two logs 99 per cent reduction and so on. With technical barriers the reduction can be simplified to occur through different adsorption or inactivation processes. Filtrations that will occur in horizontal and vertical processes as well as coagulation mainly represent different adsorption processes. Composting is a biological inactivation process. Drying, the effects of temperature, pH, or disinfectants represent different physical and chemical inactivation processes. The subsequent risk of disease transmission is related to the remaining fraction after the barrier reduction, the usage of sanitation systems as well as the handling or use of the end products. Exposure may occur at different points in the system; thus representing a risk reduction over none, one or several barriers. Exposed groups may also vary along the treatment/handling chain. A well functioning train of treatment barriers should still be assessed in relation to the interrelated risk of disease transmission for those using the system, handling the end products or consuming crops fertilized with them.

Safe disposal and reuse of human excreta and wastewater should not be based on a single barrier such as treatment - a multiple barrier approach is required to effectively eliminate and/or inactivate the various types of hazardous microorganisms spread through various routes (Figure 2 (Carr, 2001)) and to counteract variations in performance over time. Achieving the objective of the multi-barrier approach requires a paradigm shift from the assessment of sanitation technologies as mere technological units, to one that encapsulates the health risk and mitigation, institutional, socio-cultural, environmental and financial dimensions of sanitation technologies.

Transmission pathways and exposure

The transmission pathways of excreta related pathogens may be either primary (through direct contact exposure) and/or secondary, (exposure through an external route). Primary transmission includes person to person contact but in this context also direct contact with faeces or faecal soiled surfaces. Secondary transmission includes, vehicle-borne (food, water etc), and vector-borne. The first is through contamination of e.g. crops or water sources, the second mainly through created breeding sites of the vectors. Airborne transmission may also occur, for example during wastewater irrigation.

The transmission routes related disease is directly interlinked with the exposure points (which also function as critical control points CCPs from a management perspective). This simple relationship is essential to consider in designing and implementing, or modifying excreta use schemes so that they will lead to a decreased risk of disease.

Closely related to the various transmission pathways are critical questions that need to be addressed in identifying the severity of the health risk associated with a particular pathway.

The central questions for exposure assessment are:

- **WHO? -** defines exposed groups that potentially are at risk.
- **HOW MANY? –** defines number of people (individuals) likely to be exposed directly or indirectly. This may be sub-grouped, for example the individual users, maintenance workers, the number of people that are consuming crops fertilized (with treated excreta, faecal sludge or wastewater, biosolids, greywater or urine), or the people indirectly exposed ("the community" in a broad sense) due to contaminated soil, surface/groundwater or from contaminated drinking water sources.
- **WHERE? -** defines where the exposure occurs within the sanitation system. The system is followed from the user to the potential step of reuse or disposal. It also accounts for secondary exposure due to environmental pollution from the system.

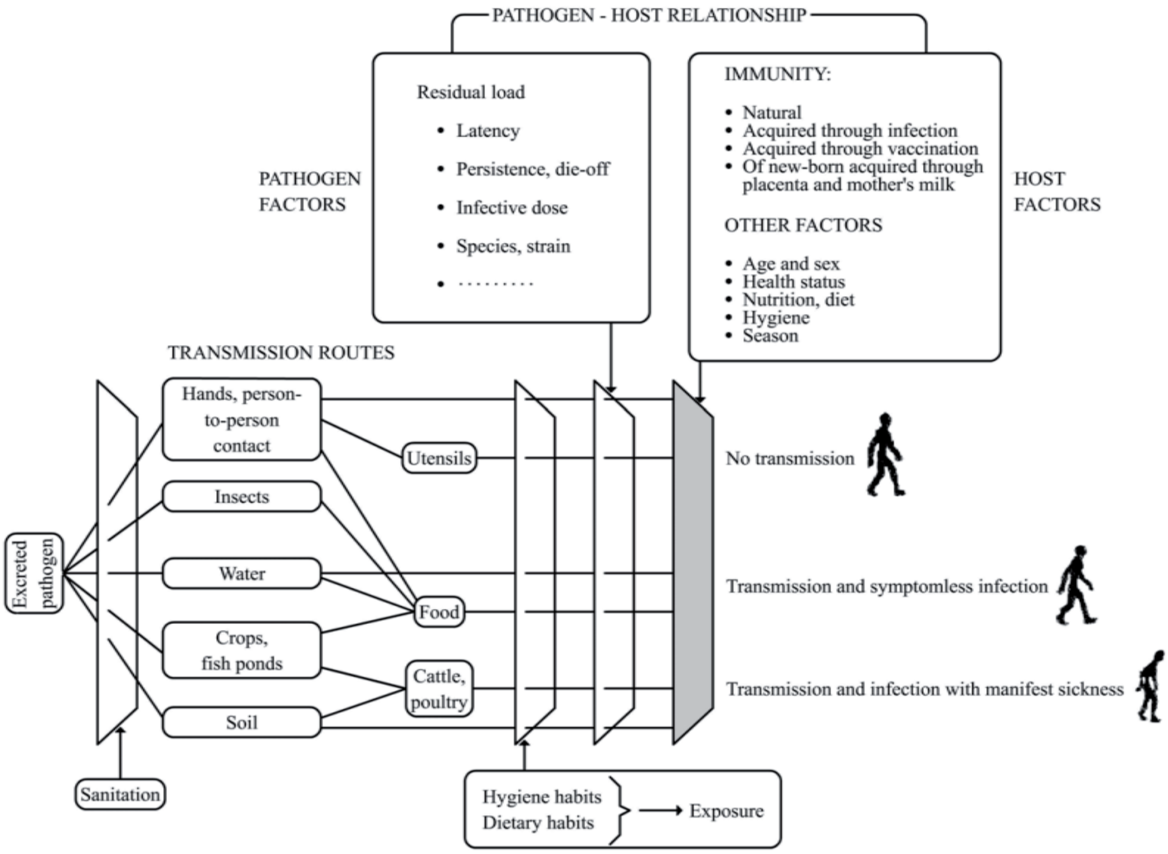


Figure 2: The spread of pathogens from excreta of an infected individual to a healthy individual

(Source: Carr, 2001)

- **WHICH? –** defines the routes to be considered? Is it due to direct contact? Is it due to contamination of crops, soil or water sources? Is it due to mosquito breeding? A combination of these routes will normally occur.
- **HOW? –** defines the exposure frequency. Is it every time, daily, weekly or perhaps just once a year? Even if exact figures cannot be obtained, it may be of value to at least have a "guesstimate" about the frequency of exposure.
- **WHAT? –** defines the likely dose of exposure. This depends on the local situation and is sometimes difficult to estimate. The dose will also differ between groups of individuals but an "estimate" is still of value for an overall calculation of the risk of infection. The dose of organisms (and thereby the risk) depends on the prior treatment (barrier efficiency). It is the amount and type of organism that is of importance for the dose evaluation (within the WHO Guidelines index organisms are proposed for bacterial, viral and parasitic groups). The dose is strongly linked with the occurring human practices.

In this book, the different user and non-user groups exposed in a sanitation system have been subdivided into; (1) Users, [**U**] (2) Workers, [**W**] (3) Farmers [**F**] and (4) the Community [**C**]. In a system assessment the local vulnerable groups may be further accounted for, like exposure of children, the elderly or people with other underlying disease.

In the following sections a '**User**' is the person who uses the technology on a regular basis.

A '**Worker**' is a person who is responsible for maintaining, cleaning, operating or emptying the technology. However to avoid ambiguity, the emptying of a given technology is not addressed in the technology description, but is considered under the Functional group 'Conveyance'.

A '**Farmer**'- is the person who is using the products generated (though that could be the same person as the user or the worker, if the same person uses, cleans, empties and applies the products from the different parts of the sanitation system). This group is only applicable to the Functional group of Use and/or Disposal.

A '**Community**' includes anyone who is living near to, or downstream from the technology, and may be passively affected. 'Community' also includes anyone who consumes products (for example crops or fish) that are produced using sanitation products.

Barriers and transmission in a system perspective

The framework presented for the health risk barriers considers sanitation as a system comprising technical (functional groups) and non-technical "components" that work in synergy/concert to safeguard human health.

Each sanitation technology is related to this grouping of components. Technologies are defined as the specific infrastructure, methods, or services that are designed to contain, transform, or transport "products" to another Functional Group or practice. The technologies under each of the functional groups are briefly described in Part 2. Five functional groups make up a full sanitation system. These are a) user interface b) collection and storage/treatment c) conveyance, d) semi-centralised treatment and e) use and/or disposal (Box 2). If a secondary semi-centralised treatment is not needed, this will reduce the number of functional groups to four. Each of the functional groups may be represented by alternative sanitation technologies that may be chosen depending on the local context.

From a health perspective, the selected technology within each of the functional groups will govern the overall reduction efficiency and the likelihood of disease transmission. Each may be linked to "critical points" where pathogens may be transmitted or controlled. Furthermore, the extent of human health protection by the sanitation system in addition relates to practices (non-technical socio-cultural aspects

Box 2: Functional groups of a sanitation system

- **User interface** describes the different types of toilets,
- **Collection and storage/treatment** describes the different pits and tanks that collect and store products,
- **Conveyance** describes how products are transferred,
- **(Semi-)centralized treatment** describes the passive and active additional treatment technologies used for reducing nutrients, solids and pathogens,
- **Use and/or disposal** describes the methods that can be used for recycling the treated products.

Source: Tilley *et al.*, 2008

linked to specific features of the system). These may further reduce (or sometimes elevate) exposure to pathogens either at these critical points or as end-use related risks.

Non-technical barriers – socio-cultural practices.

The non-technical barriers of health protection within a sanitation system are partly governed by practices related to behaviour. Similar to technical barriers, practices define the degree of exposure related to the critical points within the system and corresponding transmission routes. Practices relates to individual habits and socio-cultural perceptions (Fig 3). The former creates risk variability due to personal hygiene and the hygienic conditions of a setting, reflecting individual factors as well as individual and group responsibilities. The latter is further governed by local beliefs, traditions and taboos (religious or cultural) and thus vary locally and regionally. In sanitation, the interlinkage with cultural beliefs and religious practices for example relates to water-centred cleanliness including ablution, bathing after sexual intercourse and proper washing after defecation (Nawab *et al.*, 2006). Acceptance and practice of use of human excreta in agriculture is an example of regional and local variation based on both historical practices, as well as demand and created interest. The perception and attitudes thus become central both related to system acceptance and in the relationship to health protection. When a new sanitation system is to be introduced into a new area, the religious, cultural and spiritual values in the local context must be considered (Falkenmark, 1998).

In some cultures, traditions and religions, the perceived hygienic practices reduce the exposure to pathogens, like the Koranic edict where excreta are regarded as impure (*najassa*) and its use only permitted when the *najassa* is removed (Faruqui, Biswas and Beno, 2001). Similarly, the Luo of western Kenya dispose of children's faeces by digging and burying. This further relates to training. Infants are trained to defecate at designated places, and to inform their care-takers so that the faeces are disposed of (Almedom, 1996).

Cultures or traditions may also involve perception that expose people to pathogens. Child faeces are for example perceived as harmless in many cultures, also when diarrhoeal diseases prevail. Mothers in areas with high prevalence of childhood diarrhoea often relate the cause of the disease to other factors than the poor handling of child faeces or poor hand washing practices. This lack of knowledge between hygiene practices and disease is similar in cultural and traditional practices of direct application of fresh faeces on farms. Positive health impacts may be counteracted by the non-adherence to proper sanitation practices by a fraction of the community. Non-adherence by groups of individuals partly explains a continuous prevalence of parasitic diseases in societies that otherwise use sanitation facilities.

Human behaviour as a barrier determinant

Within the different sanitation systems with its functional group, further dealt with in Part 2 and 3, the likelihood of exposure at critical points is elaborated on. Where appropriate, the degree of exposure as a result of human practices is also exemplified.

When all the steps are well managed, risk reduction will be achieved in the technical steps and with health related precautions taken further risk reduction obtained due to the practices. Use will then contribute to the provision of potent fertilizer and soil enrichment and to greater food security, food self-sufficiency, cash crop production or the sale of compost material. Contrary, if the steps before use are poorly managed with rudimentary hygienic measures, exposure to and direct contact with disease causing pathogens in

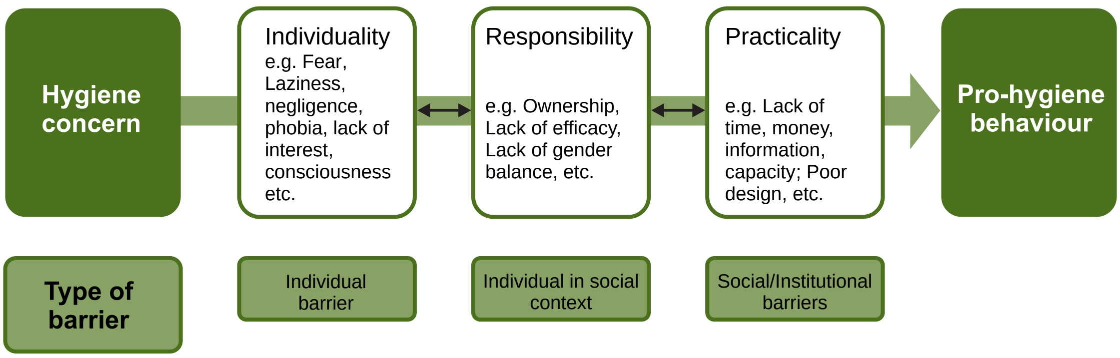


Figure 3: Barriers between health concern and action

(Adapted from Kollmus and Agyeman, 2002; Blake, 1999)

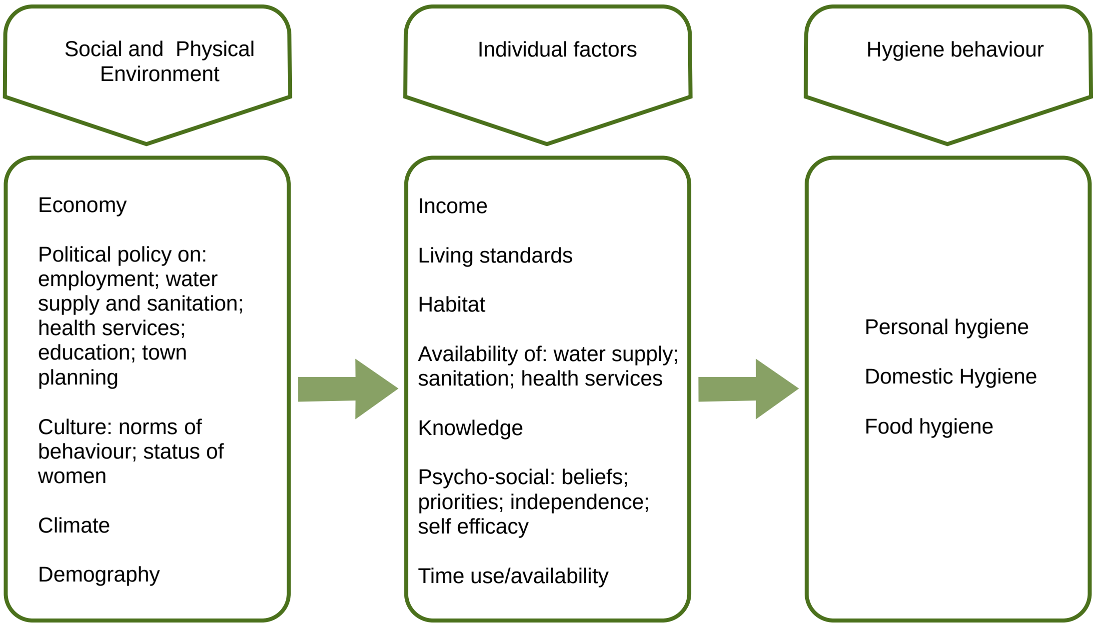


Figure 4: Determinants of hygiene behaviours (Adapted from Curtis *et al*., 1995)

excreta will definitely increase and thus pose a threat to human health.

Curtis *et al.*, (1995) present a conceptual framework for categorizing factors which are potential determinants of hygiene behaviour (Figure 4) including individual and external determinants of hygiene behaviour and influenced by the social and physical environment. The environment and events affect behaviour as well as cognitive factors, reasoning and promotion of behaviour change as determinants of health protective behaviours.

Despite people's perceptions of excreta, the aspect of hand washing after contact with excreta or using the toilet remains a pertinent issue. This basic hygiene practice is rarely performed in water scarce areas and the use of soap is less considered in poor areas. Hands can carry pathogens from faeces to surfaces, to foods, and to other people, and hand washing with soap is effective in removing pathogens (Hutchinson, 1956; Ansari *et al*., 1988). According to Curtis and Cairncross (2003), hand washing after stool contact is relatively rare. They referred to reported studies in developing countries that gave rates of hand washing with soap, after stool contact or after cleaning up child, of below 20 per cent.

Positive human behaviour change will lead to improved personal and community hygiene and function in an integrated manner in the human risk reduction strategies in a sanitation system perspective.

PART 2 - SANITATION TECHNOLOGIES AND HEALTH RISK ASSESSMENT

In this part, the potential health risks associated with the use and/or misuse of each sanitation technology is assessed. The health risk assessment framework is based on the following inter-linked components: 1) Pathogen inputs 2) Barrier, Efficiency, Robustness and Variability 3) Exposure pathways; 4) Disease Risk; and 5) Risk Management. These different components are described below.

Pathogen inputs

The pathogen input relates to organisms of viral, bacterial, protozoan and parasitic helminth origin that may be introduced into the sanitation technology with excreta. The concentration and type of pathogen is defined by the specific disease prevalence in a population, which results in an excreted concentration of the pathogen in question. Due to dilution in water, this will also result in a concentration range in wastewater or greywater.

The resistance towards external factors like temperature, desiccation, pH, solar irradiation and biological competition differs for different pathogen groups with time. These factors will normally result in a varying degree of risk reduction, due to the barrier functionality within each functional group. The concentration is always higher in raw faeces. The risks upon contact are thus high at the "User interface", and subsequently reduced after a functional treatment and storage, followed by conveyance and use. The risk reduction of the "different technologies" relate to their efficiency in reducing the concentration.

Barrier efficiency, robustness and variability

Barrier Efficiency relates to mechanisms for the removal of pathogens in the technology. The barrier efficiency (treatment) is expressed in logarithms as Log C(in) – Log C(out), where C*in* is pathogen input and C*out* is the concentration of pathogens (i.e., viruses, bacteria, protozoa and parasites) exiting the technology.

Robustness relates directly to the technology's design configuration and how this withstands variations in reduction efficiency of pathogens. This also relates to technical malfunctions.

Variability relates to changes in the performance and barrier reduction efficiency of the technology with respect to pathogen reduction. Depending on the design configuration, the reduction of pathogens within the technology may be affected by, for example, changes in flow or weather (precipitation, temperature, humidity etc). Variability in users' compliance or non-compliance with certain practices will also affect the performance in terms of pathogen reduction.

Exposure pathways

Exposure pathways are the routes via which pathogens can be directly or indirectly transmitted to user and non-user groups. The risk relates to the quantities of pathogen at the specific point of exposure, the likelihood and amounts that different groups are exposed to, and the frequency of exposure. Exposure assessment of the risk groups (symbols for users, farmers, worker and community are used as an illustration for each technology) thus is based on the functionality of the technology (pathogen reduction) and the behavioural and hygiene practices of users.

Likelihood represents the probability of occurrence of a particular exposure incident in the transmission of disease causing organisms. In this context occurrence is categorized into: i) most likely, ii) likely and iii) less likely. The categories are differentiated with colour codes: red for most likely; yellow for likely and green for less likely in the summary diagram for each functional group.

Table 2 includes a summary of the key 'exposure pathways'. A standardized, numbered list has been

Box 3: The Risk Groups and corresponding Symbols that have been used for illustration in this book

Risk group	Symbols
User	U
Worker	W
Farmer	F
Community	C

generated and further elaborated on in the Risk Summary under each section.

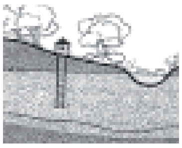
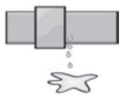
Disease risk

In this book the risk of diarrhoea and infection with parasites related to the exposure pathways are categorized into low, acceptable and high for the risk groups (i.e. users, farmer, worker and community).

Depending on the pathogen and the quantity of material to which individuals or groups are exposed the infection risk may be, low, acceptable (medium) or elevated (high).

The risk categories are differentiated with colour codes in the health risk framework (See Figure 5): green for low, yellow for acceptable and red for high.

Table 2: Key exposure/transmission pathways associated with sanitation technologies

Exposures	Illustration	Description
Ingestion of excreta (e1)		The transfer of excreta (urine and/or faeces) through direct contact to the mouth from the hands or items in contact with the mouth.
Dermal contact (e2)		The infection where a pathogen is entering through the skin (through the feet or other exposed body part) (Example hook-worms)
Contact with flies/mos-quitoes (e3)	 	Includes the mechanic transfer of excreta from a fly to a per-son or food items. Also include bites from a mosquito or other biting insects which could be carrying a disease
Inhalation of aerosols and particles (e4)		Refers to the inhalation of micro-droplets of water and par-ticles which may not be noticeable, but which may carry a pathogen dose and emanate from or is a result of a sanitation technology.
Contaminated ground-water/surface water (e5)		Refers to the ingestion of water, drawn from a ground or sur-face source, that is contaminated from a sanitation technology
Contact with overflow-ing/leaking contents (e6)		Refers to subsequent contact as a result of malfunction of a sanitation technology. (Example - pit or tank overflowing as a result of flooding, groundwater intrusion or general malfunc-tion)
Falling into pit/con-tainer/escavation (e7)		
Ingestion of urine (e8)		Refers to the specific case of ingestion of urine (reference to E) from handling practices of specific technologies.
Consumption of con-taminated produce (vegetables) (e9)		Refers to consumption of plants (Example lettuce) that have been grown on land irrigated or fertilized with a sanitation product or where accidental contamination is likely to occur.

Technology	Barrier efficiency and robustness			Exposure pathways	Likelihood of occurrence	Diarrhoea Risk				Helminths Risk				Risk Management
	Input pathogens	Treat-ment	Typical malfunc-tion			User	Worker	Farmer	Community	User	Worker	Farmer	Community	*assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Dry toilet	Viruses	NA		- ingestion of excreta from hands (E1)										--reinforced concrete or pre-fabricated plastic construction with smooth surface
	Bacteria	NA		- stepping on faeces with bare foot (E2)										
	Protozoa	NA		-contact with flies (E3)										
	Helminths	NA												

Figure 5: Health risk assessment framework

For each of the technologies, these categories were based on a meta-analysis of existing epidemiological and quantitative microbial risk assessment studies. In cases where there was no evidence for health risk for a particular exposure pathway, expert opinion was sought. Definitions of the categorization are:

Low: An exposure pathway results in diarrhoea infection or a helminthiasis risk ratio (odd ratio) of < 1 or infection risk of < 1 in 10,000 per person per year.

Acceptable: An exposure pathway associated with a technology results in diarrhoea infection or helminthiasis risk ratio (or odd ratio) of 1 or results in an infection risk of approx 1 in 10,000 per person per year.

High: An exposure pathway associated with a technology results in a diarrhoea infection or helminthiasis risk ratio (or odd ratio) of > 1 or infection risk of > 1 in 10,000 per person per year.

Risk management.

This part of the health risk assessment framework relates to different practices that will reduce exposure or further reduce the inputs of organisms to a technology and thereby reduce the risks further.

USER INTERFACE TECHNOLOGIES

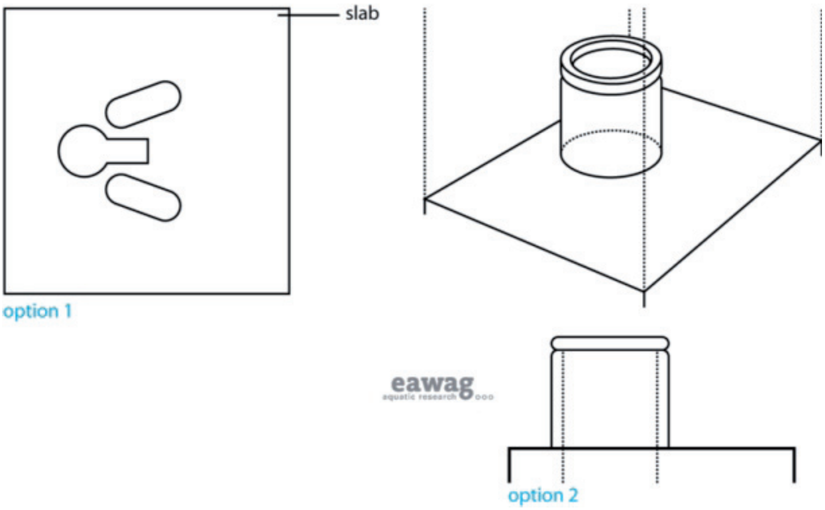
Introduction

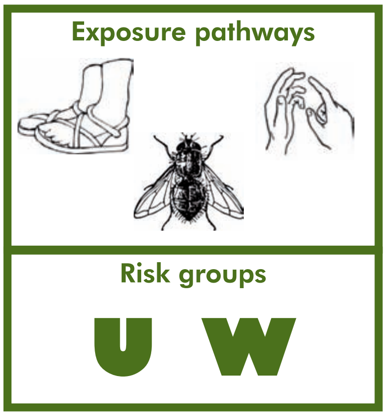
User Interface technologies provide users access to a sanitation system and is the interface where the first exposure may occur. This interface may vary in design depending on the need, financial capacities and management considerations. Irrespective of the alternatives, their proper use, operation and maintenance is critical both for the acceptance and for the optimal functionality of the entire sanitation system and thus a prime determinant for further health considerations.

The most commonly used term for the user interface technologies is the 'toilet'. The word 'toilet' gives little information about the use, appropriateness or health implications. In this book, four main types are included: (1) Dry Toilet, (2) Urine Diverting Dry Toilet, (3) Pour Flush Toilet and (4) Flush toilets

Exposure to disease causing pathogens is greatly reduced when toilets are properly used. This depending on the design; sitting or squatting and to avoid mixing urine, faeces, and/or anal cleansing water for urine diversion toilets (UDDTs) are linked with different degree of contamination. This is further discussed from an operational and risk management perspective under each technology (Risk Mitigation Measures).

Dry Toilet





Technology description

A dry toilet operates without water. It may be a raised pedestal that the user can sit on, or a squat pan that the user squats over. In both cases, urine, faeces and anal cleansing materials and/or water are deposited in the toilet. Sanitizing additives and bulking materials may be applied to the faeces deposited in the toilet.

Exposure pathways

The user may sit on or squat over the dry toilet. Their individual habits relate to different exposure pathways, due to contact by the user and soiling of surfaces by earlier users.

- Sitting on a pedestal may lead to direct contact but does not by itself create a greater exposure to excreta than squatting over a slab.
- Poorly kept pedestals and squatting slabs become foci for disease transmission upon touching by hands with later contact with the mouth by soiled hands or stepping on soiled areas.
- Soiled areas may transmit hookworm to subsequent individuals if they use the facility bare footed (Schad, 1978). Rough toilet floors are difficult to clean and faecal remaining may enhance the likelihood of contact.
- Since there is no water seal for the dry toilet, flies and mosquitoes are able to access and breed in it. Besides being a nuisance, the flies and mosquitoes can act as mechanical vectors for the transmission of diseases. *Aedes* mosquitoes transmitting dengue may also breed in open compartments/containers for ablution water.
- If the slab or toilet floor is not stable or well built, it may collapse or crack, exposing the user to greater levels of health hazards.

Vulnerable groups such as the disabled, visually impaired, children and the aged are frequently in direct contact with different surfaces and are thereby more exposed. The aged may also fall more frequently during toilet visits (Ashley *et al.*, 1977) and children often have more frequent hand-mouth contact. Soiled feet and shoes can carry faecal material to the home environment where further contamination and transmission may occur.

Epidemiological and health risk evidence
The health risks relate to both (a) individual behaviour and (b) cleanliness of the toilet. Systematic studies between these factors, disease outcome and further transmission to the home environment are lacking. The health risks will relate to the likelihood and type of contact as well as cleaning and/or maintenance. The likelihood of soiling surfaces may be high for users squatting during high-risk events, like diarrhoea. The individual handling of anal cleansing material may also result in a risk for subsequent users. Workers cleaning and maintaining the toilet are always at risk of infection and the risk relates to their degree of contact and their proper handling and washing afterwards. Two epidemiological studies where users of dry latrines and flush toilets were compared are cited under 'flush toilets' (page 21).

Risk mitigation measures
Cleanliness of toilets and individuals are naturally central. The presence of flies and other insects can vary significantly depending on the subsequent type of Collection and Storage/Treatment (page 23).

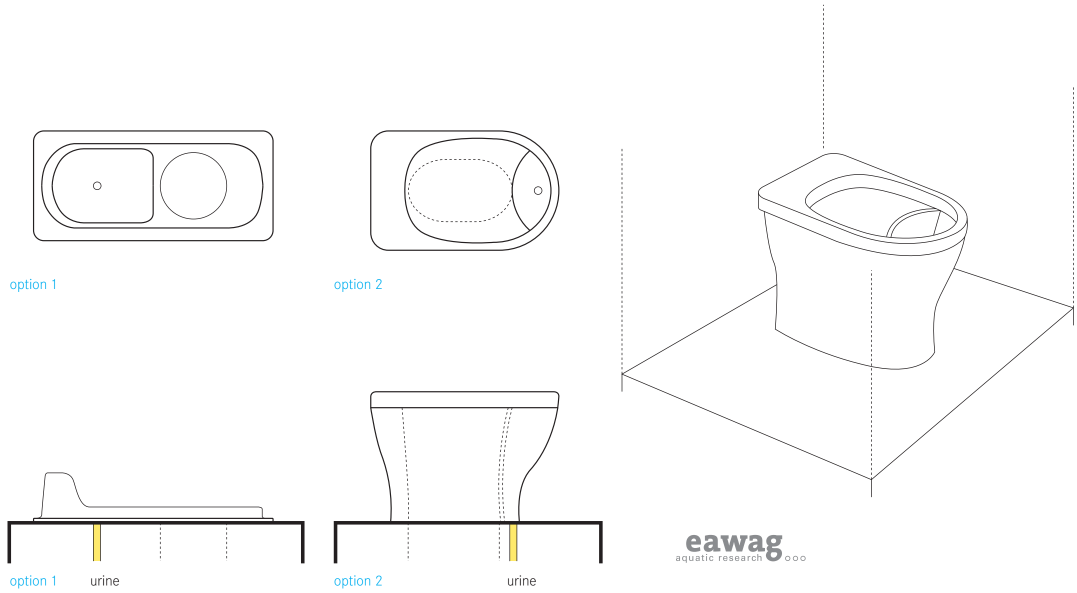
A dry toilet with a squatting slab should be reinforced to withstand the load from users. The floor surface and area around the drop hole should be smooth to facilitate cleaning and where the user stands should be raised and kept as dry as possible. The slab hole should be big enough to avoid defecation on the slab.

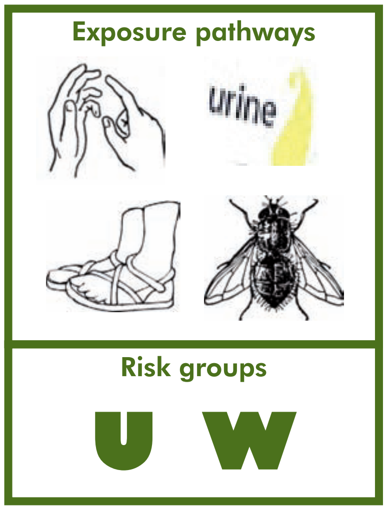
Risk Summary
Number of exposed: 1-several depending on the number of users sharing the same toilet

Frequency of exposure: DAILY for user (multiple contacts daily), MEDIUM-LOW for workers who clean (weekly - monthly)

Level of risk: HIGH for users of dirty toilets (LOW for clean ones and if handwashing is practiced); MEDIUM for workers who clean the toilet/ toilet room; (HIGH after incidence of diarrhoea).

Urine Diverting Dry Toilet





Technology description
A Urine-Diverting Dry Toilet (UDDT) operates without water and has an internal divider and two outlets; one for urine and one for faeces. Neither urine nor faeces are diluted with flushing water which facilitates treatment and/or nutrient recovery at a later stage. If anal cleansing with water is practiced, the anal cleansing water must be disposed of in a separate (third) outlet and not on the ground (subsurface disposal acceptable). A urinal sometimes exists as a separate device for collecting urine mainly for men (though variations for women exist).

Exposure pathways
A UDDT essentially has the same exposure pathways as a 'Dry Toilet'; the likelihood of touching soiled toilets or other surfaces in the toilet room. As with the dry toilet user-interface technology, users' defecation habits dictate the risk of exposure for subsequent users.

- For both the sitting and squatting arrangements, the floor of the UDDT (e.g. the slab or the area around the pedestal) can enhance exposure as excreta can be transferred to the hands or feet.
- The users or persons responsible for cleaning may be exposed to faeces deposited in the urine part and which must be removed.
- Normally the risk of exposure from flies or other insects are low. Poorly maintained UDDT can however attract flies that in turn serve as mechanical vectors for the transmission of diseases.
- The urine from the UDDT or from a urinal may contaminate other areas through splashing.

Epidemiological and health risk evidence
The health risks relate to individual behaviour and cleanliness of the toilet. Observational studies on behaviour in the toilets are lacking. An identified low risk exists for maintenance workers of urine plumbing.

Risk mitigation measures
The urine outlet hole should not be blocked. A UDDT should be cleaned regularly. The cleaning water should not run into either the urine or the faeces collection holes. The same holds for detergents and disinfectants. Direct contact with bare hands should be avoided when cleaning (refer for example to faeces that may have fallen into the urine part).

A separate disposal point- either built into the user interface or offset should exist for anal cleansing water. This should not contaminate the urine or faeces. Dry anal cleansing material should be disposed of in a lid-covered bin to avoid contact and flies.

User education is essential to prevent the toilet from being misused. Users should add ash, lime or similar to the faecal matter after use. If saw-dust or soil is used, the subsequent collection/storage time needs to be adjusted upwards, since die-off will be slower. The practices at the "user interface" affect the functionality and the risks in the proceeding functional groups in the system chain. Therefore the following should be adhered to:

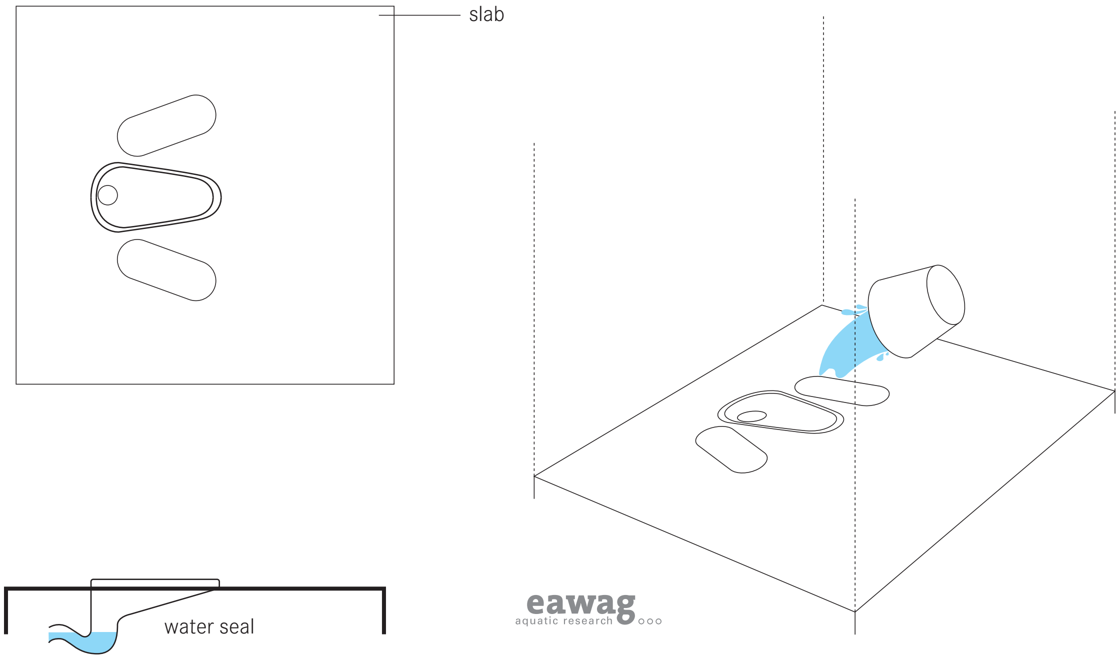
- Not throwing solid waste and detergents in the toilet
- Not adding anal cleansing water to the urine and/or faeces compartments
- Not urinating in the faeces compartment and defecating in the urine compartment
- Not forget to add ash, lime or similar to the faecal material after defecation

Risk summary
Number of exposed: 1-several depending on the number of users sharing the same toilet

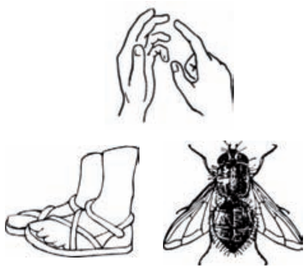
Frequency of exposure: DAILY for user (multiple contacts daily), MEDIUM-LOW for workers who clean (weekly - monthly, but higher than for the dry toilet alternatives)

Level of risk: HIGH for users of dirty toilets (LOW for clean ones and if handwashing is practiced); MEDIUM for workers who clean the toilet/ toilet room; (HIGH after incidence of diarrhoea).

Pour Flush Toilet



Exposure pathways



Risk groups

U W

Technology description

A Pour-Flush toilet is a regular pedestal or squatting toilet where water is poured in after use by the user. Normally 2-3 liters are sufficient. If freshwater is not available, greywater can alternatively be used for flushing. A U-bend below the pedestal or pan functions as a water seal to prevent insects and smells from exiting through the toilet.

Exposure pathways

The health risks relate to individual behaviour and cleanliness of the toilet similar to other user interface alternatives. Vulnerable groups such as the aged and children are always at higher risk from contact with soiled surfaces. The water-seal is an effective barrier against mosquitoes and flies entering the toilet room. If water for flushing and anal cleansing is kept in open containers in the toilet room, the risk for mosquito breeding, like *Aedes* mosquitoes (transmitting dengue) is enhanced. If contaminated water like greywater is used for flushing its quality determines if there is an additional risk due to accidental contact and ingestion.

Epidemiological and health risk evidence

The risk with unclean toilets is similarly evident for subsequent users. An elevated risk of microbial exposure through direct contact and transference to the mouth may occur if contaminated water/greywater is used for flushing. Water from the containers used for pour flushing should never be used for drinking. As for other user interface technologies, the risk of hookworm infection may occur if the squatting slab is not well maintained and cleaned.

Risk mitigation measures
Rainwater, instead of greywater, lowers the risk during pour-flushing. The seat and/or slab should be cleaned regularly to prevent the spread of organisms into, or out of the toilet room.

To prevent blockages (and therefore maintenance or overflowing toilets) dry cleansing materials, except soft paper, should not be put into the toilet. It should be collected separately in an accompanying bin with a lid to avoid contact of flies with the soiled paper (or other material). Pour-flush latrines are not suitable if it is common practice to use bulky materials, such as corncobs or stones, for anal cleansing, since this will clog the U-trap. In cultures in which anal cleansing is by water, additional water is required for this purpose.

Maintenance workers should wear the necessary protective clothes (e.g. gloves).

A vessel sized to local socio-cultural preference (normally between three and five litres capacity) should be at each toilet for flushing and cleansing purposes. Sufficient water for total household daily latrine requirements should ideally be stored in a suitable storage jar, bucket or storage tank. The storage jar should be reserved for its purpose of toilet/ latrine use. If an on-site water supply is available, a self-closing tap with separate drainage could replace the storage vessel.

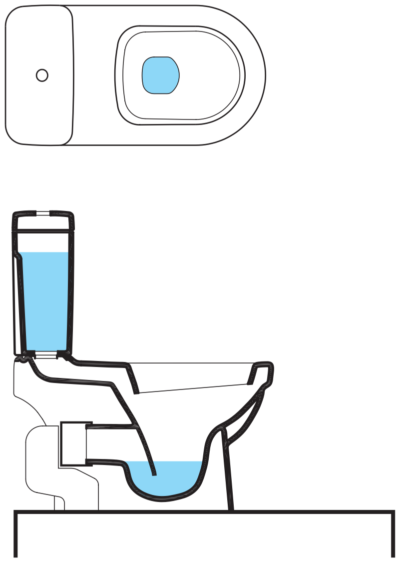
Containers or buckets used to store water for flushing should be thoroughly washed.

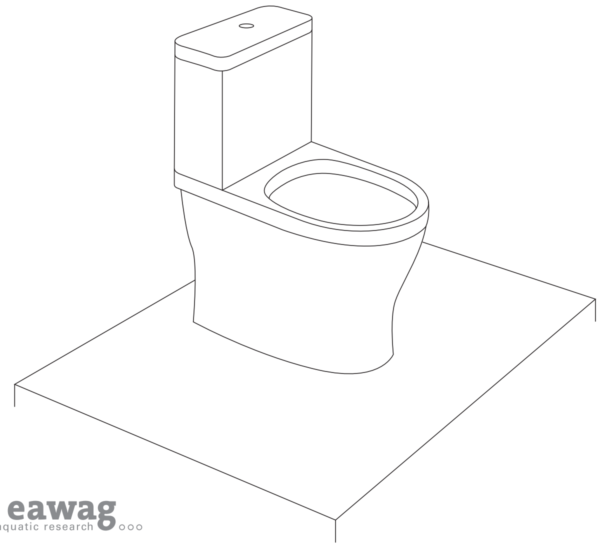
Risk summary
Number of exposed: 1-several depending on the number of users sharing the same toilet

Frequency of exposure: DAILY for user (multiple contacts daily), MEDIUM-LOW for workers who clean (weekly - monthly).

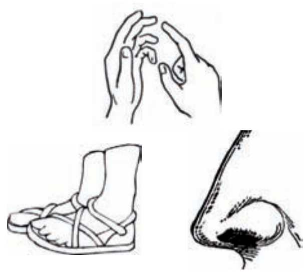
Level of risk: HIGH for users of dirty toilets (LOW for clean ones and if handwashing is practiced); MEDIUM for workers who clean the toilet/ toilet room; (HIGH after incidence of diarrhoea).

Flush Toilet





Exposure pathways



Risk groups

U W

Technology description
The flush toilet has a bowl into which the excreta are deposited and an attached water cistern that supplies the water for flushing. Both pedestal and squatting pan types exist. Depending on the model, the cistern will supply between 3 and 20 liters per flush (vacuum types exist where just 0.5 liter is needed). The problem of flies and odour are minimal. The configuration can be adapted for anal cleansing as well as different dry anal cleansing material.

Exposure pathways
The health risks relate to individual behaviour and cleanliness of the toilet through contact with soiled surface and accidental transference to the mouth, but also through aerosols. Pathogens can persist for several weeks in the bowl of a flush toilet and on different surfaces of the toilet (Gerba *et al*., 1975; Barker and Bloomfield, 2000) (Box 4). These pathogens can be ingested during a flush through aerosols (Fewtrell and Kay, 2007). Users may also ingest pathogens by touching the seats, cistern handle and lid of the toilet bowl with their hands and transfer these to the mouth. Faeces can accumulate in the toilet bowl if adequate amount of water is not assured.

Overflows from the toilet bowl can occur if the U-bend is blocked. Blockage of the U-bend may expose cleaning workers to pathogens.

In communal flush toilet facilities, some users may squat on pedestal toilets for fear of being infected. Squatting may soil the toilet lid, seat or the floor and expose subsequent users.

Epidemiological and health risk evidence
A few epidemiological studies and one quantitative microbial risk study have assessed the health risk associated with flush toilet use (Annex 8). The studies concluded that:

- Flush toilet users are 2.1 times less likely to be infected with *Ascaris* compared with dry toilet users (Asoalu *et al*., 2002).
- Flush toilet users are 1.5 – 4.2 times less likely to develop diarrhoea compared to dry toilet users (Ferrer *et al*., 2008; Azurin and Alvero, 1974).
- About 2 out of 100,000 users are likely infected with *Campylobacter* if flush water contains 0 – 0.56 *Campylobacter* /100mL (This is below the WHO acceptable risk level of 1 infection in 10,000).

Outbreak of severe acute respiratory syndrome (SARS) has been associated with aerosols generated during toilet flushing (likelihood extremely low) (Yu *et al*., 2004). Other diseases such as the herpes human papillomavirus and *Trichomonas vaginalis* have been reported from contact with soiled surfaces (likelihood extremely low).

Risk mitigation measures
Water for toilet flushing should be assured. Clean and disinfect the toilet bowl/pan, rim, handle and seat. The lid of the toilet should always be closed when the toilet is not in use.

Dry cleansing materials that may clog the toilet plumbing should be collected separately and disposed of with other solid waste.

In communal flush toilet facilities, where hygienic conditions are not assured, the squatting pedestal rather than the sitting arrangements may in some cultural settings be more appropriate.

Risk summary
Number of exposed: 1-several depending on the number of users sharing the same toilet

Frequency of exposure: DAILY for user (multiple contacts daily), MEDIUM-LOW for workers who clean (weekly - monthly)

Level of risk: HIGH for users of dirty toilets (LOW for clean ones and if handwashing is practiced); MEDIUM for workers who clean the toilet/ toilet room (MEDIUM after incidence of diarrhoea)

Box 4 : Faecal pathogen are spread to the toilet lid, seat, and other surfaces in the bathroom after flushing the toilet

Flush toilets are seen by some people as more advanced and less risky than dry alternatives. However, all toilets relate to different types of risk. One example is survival of pathogenic bacteria on surfaces, like the toilet lid and seat. If people have salmonellosis the excreted bacteria may survive on such surfaces. This was demonstrated by Barker and Bloomfield (2000) from domestic toilets in homes where family members had recently had salmonellosis. *Salmonella* persisted on the toilet bowl rim and became incorporated in adhering material in the toilet bowl surface below the water line. They could be recovered up to 4 weeks in the toilet after the diarrhoea had stopped. When *Salmonella* was artificially introduced in toilets and flushing was done, the introduced *Salmonella* could be recovered from the toilet seat and the lid and also in air samples taken directly after flushing. These introduced *Salmonella* survived below the water line for up to 50 days.

Take home message: Toilet hygiene is essential especially after diarrhoeal illness. This also include flush toilet. Proper cleaning of the toilet surfaces reduces the risk to subsequent users. Close the lid while flushing!

Source: Barker and Bloomfield, 2000

Technology	Barrier efficiency and robustness: Input pathogens	Barrier efficiency and robustness: Treatment	Barrier efficiency and robustness: Typical malfunction	Exposure pathways	Likelihood of occurrence	Diarrhoea Risk: User	Diarrhoea Risk: Worker	Diarrhoea Risk: Farmer	Diarrhoea Risk: Community	Helminths Risk: User	Helminths Risk: Worker	Helminths Risk: Farmer	Helminths Risk: Community	Risk Management *assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Dry toilet	Viruses	NA		Ingestion of excreta (E1)										--reinforced concrete or pre-fabricated plastic construction with smooth surface
	Bacteria	NA		Dermal contact (E2)										
	Protozoa	NA		Contact with flies (E3)										
	Helminths	NA												
UDDT/ urinal	Viruses	NA	-faeces clog urine collection pan -no provision for anal cleansing water -poor construction makes it difficult to clean	Ingestion of excreta (E1)										- good design to facilitate urine and faeces separation -dedicated collection point for anal-cleansing water -coated concrete or pre-fabricated plastic
	Bacteria	NA		Dermal contact (E2)										
	Protozoa	NA		Contact with flies (E3)										
	Helminths	NA		Ingestion of urine (E8)										
Pour-flush toilet	Viruses	NA	-poorly designed U-trap is prone to clogging -bulky cleansing materials cause clogging -used with insufficient water	Ingestion of excreta (E1)										-properly designed U-trap with sufficient bend angle -separate receptacle for dry-cleansing materials -fresh, rain or well-treated greywater made available
	Bacteria	NA		Dermal contact (E2)										
	Protozoa	NA		Contact with flies										
	Helminths	NA		Inhalation of aerosols (E4)										
Cistern flush toilet	Viruses	NA	-improper plumbing and/or installation -bulky cleansing materials cause clogging	Ingestion of excreta (E1)										-cover lid of when toilet is not in use or before flushing -dry anal cleansing materials should be collected separately
	Bacteria	NA		Dermal contact (E2)										
	Protozoa	NA												
	Helminths	NA		Inhalation of aerosols (E4)										

Figure 6: User interface technologies: exposure scenarios and health risk levels

NA- Not applicable
is stored in the toilet

COLLECTION AND STORAGE/TREATMENT TECHNOLOGIES

Introduction

The technologies described in this section collect, store and provide some level of treatment for the products that are introduced at the User Interface. These are directly connected to the User Interface without any intermediary technology (except for a short length of plumbing in some cases). The treatment aims to reduce the concentration of pathogenic organisms and is expressed as a barrier function.

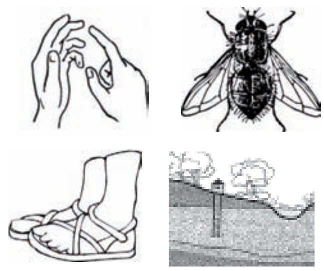
Open defaecation

Photo: T. A. Stenström

Description

Open defecation is ***not*** part of any sanitation system. However, certain habits of open defecation may relate to a reduced risk, or to reduced direct and indirect exposure through different pathways. Open defecation is practiced by billions of people mainly in developing countries. It is therefore brought up for comparative reasons. "Flying latrines" (wrap and throw) are when excreta are deposited in a bag, or wrapped in paper or similar and are thrown away or dropped at locations away from the home. This may be common in urban slums where there are inadequate toilet facilities. There are no advantages with this practice and it should be considered as open defecation. The only situation when it can be accepted for short periods of time is in an immediate emergency situation, combined with an organized collection system. In these situations commercial variants, like Peepoo bags are slightly better.

Exposure pathways



Risk groups

The safer practice also considered as open defecation is the 'cat' latrine, where a shallow hole is dug for defecation and the excreta are covered and buried several centimeters below the ground surface. A similar approach is sometimes practiced in an immediate emergency situation with shallow trenches for defecation that is covered after use.

"Open latrine" where the excreta are not covered should also be considered as open defecation. This often occurs at designated areas, usually in bushes/forest, at river/stream shores, beaches and on non-economic waste lands. Open spaces in uncompleted buildings located within residential areas are also sometimes used as 'open' latrines. 'Rotational defaecation' is sometimes practiced, where community members move from previously used and highly faecally contaminated areas to less contaminated ones to fallow and allow for the decomposition of excreta. In settings where children's faeces are not considered as harmful, indiscriminate defaecation on the ground within the compound, at the backyard of the house or in the community occurs, whilst specifically designated areas are usually used by the rest of the community.

Open defaecation is influenced by a range of socio-cultural beliefs in different regions. In rural Southern

India there is no stigma associated with open defaecation (Banda *et al*., 2007) and is considered hygienic by the users since it is perceived that the sun burns the faeces. On the contrary, the Gogo and the Rangi people of Tanzania see defecation in the open as bad because faeces attracts flies which carries faeces and deposits it on food (Almedom, 1996). The practices can influence the microbial die-off or reduce exposure, but can most often not be considered as a disease barrier.

Input and output products
Faeces, urine and cleansing materials are deposited, without targeted microbial treatment/destruction. Pathogen reduction will occur with time, and largely depends on unregulated environmental factors such as temperature, humidity (desiccation) or be due to UV irradiation in open defecation. 'Cat' latrines can be considered as partial containment, where the pathogens will be affected by the soil microbiota.

Exposure pathways
Open defaecation is the most significant environmental factor in the transmission of excreta related diseases. Various transmission and exposure pathways are associated with this. The likelihood of direct contact is the prime one, but also i) contamination of drinking water sources ii) crops and soil and iii) breeding sites of disease transmitting vectors are of concern. The degree of exposure however varies considerably for different groups as well as with population density and seasons. The likelihood of exposure is always greater in densely populated areas, where children are the most vulnerable and have a higher frequency of contact with contaminated soils than adults. The impact on surface water directly and through storm water drains will occur due to open defecation including "flying latrines" in urban areas. A higher exposure to pathogens through drinking water may also occur in the rainy season compared to the dry season. Open latrines remain the single most important risk factor for trachoma disease (Emerson *et al*., 1999). *Musca sorbens*, the fly that transmits *Chlamydia tranchomiasis* breeds predominantly in human faeces on the soil surface, but not in covered pit latrines. In a Gambian study a mean of 1426 flies/kg of human faeces on the ground were registered (Emerson *et al*., 1999).

Epidemiological and health risk evidence
Several epidemiological studies have shown the elevated disease risk of open defecation compared with containment (See Annex 5). In a cholera outbreak in Southern Tanzania, members of households practicing open defaecation were 11.4 times (95 per cent CI: 6.3 – 20.5) more likely to develop cholera than those from households with toilet facilities (Acosta *et al*., 2001). In Brazil, Gross *et al*., (1989) showed that children practicing open defaecation developed symptomatic diarrhoea to a higher degree compared to those from households using pit latrines. In rural Nigeria households defaecating in the bush had a 1.35 times higher disease incidence of *Ascaris* compared to those using pit latrines and a 2.86 higher disease incidence compared to those using flush toilets (Asoalu *et al*., 2002). A comprehensive study in East Africa, showed an incidence of diarrhoea of 42.2 per cent for household members practicing open defaecation as compared to 19.7 per cent and 20 per cent for pit and VIP latrines users respectively (Thompson *et al*., 2001).

Risk mitigation measures
Open defaecation should ***always*** be replaced by more secure sanitation systems. The users should be involved in the planning, design and construction of acceptable alternatives where maintenance and operational are integral parts. In these perspectives Community Led Total Sanitation (CLTS) has been successfully applied to significantly reduce open defaecation in areas where it is predominantly practiced (See Part 3).

Open defaecation, irrespective of the way it is practiced should never be encouraged.

Risk summary
Number of exposed: 1- several 1000 depending on the location

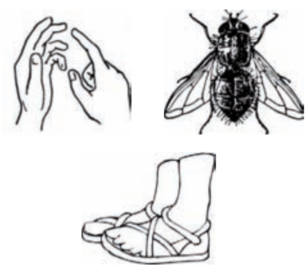
Frequency of exposure: HIGH for user (multiple contacts daily), HIGH for the community who live/pass by the site

Level of risk: HIGH for users, HIGH for the community HIGH for interlinkage with personal and food hygiene and for other communities due to contamination of water courses, crops and additional

Bucket Latrine

Photo: L Dagerskog

Exposure pathways



Risk groups

U W C

Description

A bucket latrine consists of a pedestal or seat drop hole with a bucket or pan placed in a chamber underneath. The user defecates into the bucket and when the bucket is full it is manually removed and emptied. The bucket may be placed inside a box or a chamber.

The bucket chamber has a rear door that facilitates access and emptying when the bucket is full. The buckets are normally small (25 L – 30 L), and require frequent emptying, collection, and disposal to avoid overflows. Decomposition will normally be minimal (if not secondary storage occurs) and the content should be considered as fresh faecal material with associated risks. Secondary treatment will be needed.

Input and output products

Urine, faeces and solid cleansing materials are the inputs to a bucket latrine. Anal cleansing water should be discouraged as the bucket would fill up too quickly.

Exposure pathways

The major exposure pathways, associated with the bucket latrines are related to the use and maintenance of the latrine as well as the collection and transportation of the excreta. Pathogens destruction is considered minor in the buckets.

Without regular emptying, the bucket can overflow and expose users to pathogens. If the bucket is not stable, it can tip over and spill its contents, further exposing the user and community members to a high risk. Illegal emptying in gutters may occur. Bucket latrines may also provide breeding grounds for flies that can transport infectious materials from the toilet chamber into the home environment.

Epidemiological and health risk evidence

Epidemiological investigations associated with bucket latrines as storage in households and in the community are lacking. Overflow from buckets, spillage or illegal dumping will expose for example children playing in the alleys or streets leading to significant infection risk.

Risk mitigation measures

Bucket latrines should not be promoted. Washing of buckets should be done at specifically designated sites without human contact with the washed water. Wood ash or lime can be added following each defaecation to reduce the breeding of flies and achieve an initial pathogen reduction. Flies access should be limited by coverage of the drop hole and the rear door should be securely closed.

Prolonged storage for months in lid-covered buckets will give a significant reduction of pathogens, especially if the buckets are stored in direct exposure of the sun that raises the temperature.

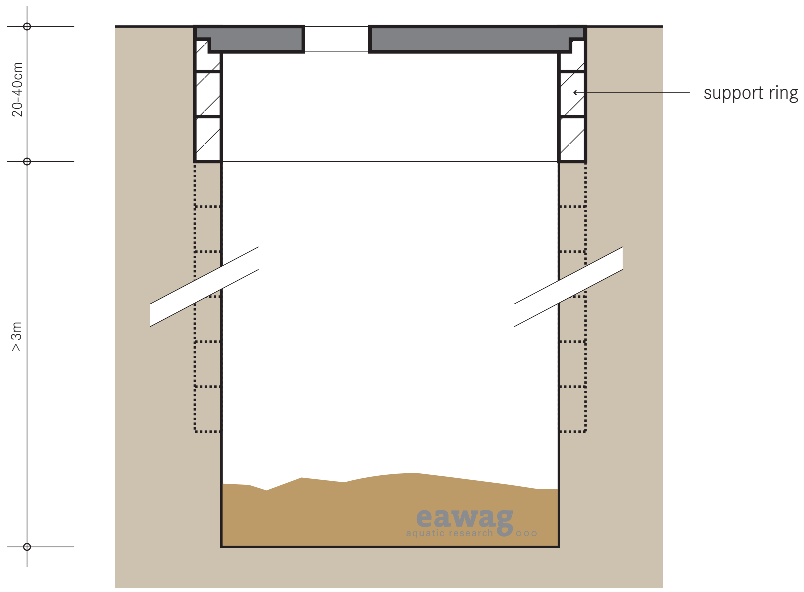
Secondary treatment is generally needed.

Risk summary
Number of exposed: 1-10 depending on the number of people sharing the toilet

Frequency of exposure: HIGH for user (multiple contacts daily), HIGH for the worker who empties the bucket, MEDIUM for the community due to spillage/ overflows

Level of risk: MEDIUM for users; MEDIUM for workers who clean the toilet/ toilet room; MEDIUM to HIGH for people emptying the toilet.

Single Pit Latrine

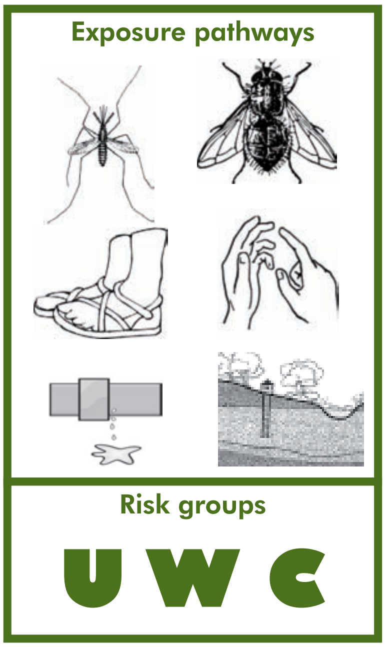


Technology description
A single pit is a shaft, dug into the earth, which is either lined with reinforcing materials (e.g. bricks) or left unlined. Lining prevents it from collapsing and provides support for the superstructure. Depending on its design and frequency of use, pit latrines can be used for up to 30 years though many are used for fewer than 5 years before they are full and must be emptied or covered.

Input and output products
The inputs includes urine, faeces, anal cleansing water or dry anal cleansing materials e.g., papers, corn cobs, corn husks or other materials. Indiscriminate dumping of garbage into pits occurs but should strongly be discouraged. The reduction of pathogenic organisms in pits relates to the storage time, filling rate, ambient temperature and moisture (from urine, anal cleansing water or seepage of surface water) and other environmental factors.

The destruction of pathogens in pit latrines is substantially higher than in bucket latrines. The die-offs rates needs to be documented more thoroughly. The outputs of the single latrine still often contain large numbers of pathogenic organisms and especially the resistant helminth eggs.

Typical malfunctioning
Pits are sometimes used as a repository for solid waste (plastic, rags and other material), which makes it difficult to empty. Pits located in flood-prone or low-lying areas are more likely to be flooded and more likely collapse.



Lining is crucial. Furthermore the risk of groundwater contamination is also high (see exposure). The pit may also overflow and spread its contents to the surrounding areas.

Exposure pathways
A high groundwater table pit latrine will pollute groundwater (mainly with viruses and bacteria).

Box 5: Nitrate contamination of groundwater occurs in areas with poorly sited and constructed pit latrines

In Francistown, Botswana, a rapid population growth in the 1970s led to an extensive development of domestic pit latrines in spite of a centralized sewage system. Subsequently, the groundwater of the town showed high levels of nitrate concentration often reaching values between 100 and 300 mg/L. Combining the results of the nitrate analyses with information on sources of nitrate contamination showed that nitrate concentrations increased in areas with pit latrines. Not a single borehole lying in or close to such areas was found to have nitrate concentration below 100 mg/L, far above the WHO guideline value. The findings support the conception that the use of pit latrines caused the serious nitrate contamination of the groundwater.

Nitrate is also a major contaminant (Box 5). The local geo- hydrological conditions (high groundwater table, fractured rocks or soil material with a high porosity) facilitate the percolation of pathogenic organisms, nitrate and dumped organic chemicals to the groundwater. These local geo-hydrological conditions and seasonality (rains or dry conditions) will be determinants for the extent of groundwater contamination.

In the event of floods, pit latrines may also serve as sources of surface water contamination. Wet pit latrines may also become profuse breeding sites for *Culex quinquefasciatus*, which in some areas are vectors of bancroftian filariasis (Maxwell *et al*., 1990). Houseflies (*Musca domestica*) can act as mechanical vectors for the transmission of diarrhoeal causing organisms and breed in wet and unvented pit latrines (Watt, 1948; Cohen, 1991; Levine *et al*., 1991; Chavasse *et al*., 1999).

Epidemiological and health risk evidence

Pit latrines will result in a reduction in diarrhoeal disease and helminths infection as compared to open defaecation (Annex 6).

- In a shanty town in Brazil children using pit latrines had 1.5 times fewer cases of diarrhoea compared to those practicing open defaecation (Gross *et al.*, 1989).
- In a clinical case-control study in Nigeria, Asoalu *et al.*, (2002) found that children using pit latrines were better safeguarded against helminths infections compared to those defaecating in the bush. The children using pit latrines were however more likely to be infected with helminths eggs than those using flush toilets.
- In a study in East Africa, the incidence of diarrhoea diseases reduced by 22.5% in households with pit latrines compared to households with no toilet facility (Thompson *et al*., 2001). Well constructed pit latrines were shown to reduce flies contact with human faeces containing *Shigella spp*. (Levine et al., 1991) with the potential for diarrhoeal disease reduction (Chavasse *et al*., 1999; Emerson *et al*., 1999).

Risk mitigation measures

A pit must be emptied or covered when it is full. It should not be used for solid waste.

Addition of lime or ash may enhance the pathogen die-off. Other material, like soil and saw-dust will reduce the wetness of the pit content but not the die-off. The pit opening should be covered with a tight lid to reduce flies.

Traditional pit latrines are not a preferred technical solution where the groundwater table is high or in flood prone areas. Raised pits or dry latrines are alternatives.

Where the risks of aquifer contamination are high, design and construction of the pit latrines are important to reduce risk. Pits should not reach the groundwater level and should leave an unconfined level of at least 2-3 meters below its bottom and the highest seasonal groundwater level. The hydrological gradient as well as the type of soil and underground rocks is important, in defining safe set-back distances. In developed countries a safety distance based on a flow time of 2-3 months are often applied.

Flies breeding in the pits can be significantly reduced with an upgrading to Ventilated Improved Pit latrines (VIPs) where a vent pipe fitted with a fly trap is installed. However, this measure will not have a big impact

Box 6: Expanded polystyrene beads reduce *Culex quinquefasciatus* breeding in wet pit latrines (Based on Maxwell, 1990)

In Zanzibar, wet pit latrines provided the main breeding places for *Culex quinquefasciatus*. Each person received about 25 000 bites per year, of which 612 were potentially infective with *Wuchereria bancrofti*. After the application of expanded polystyrene beads on all infested pits the adult mosquito population declined remarkably so that the estimated number of bites per person per year was down to about 439.

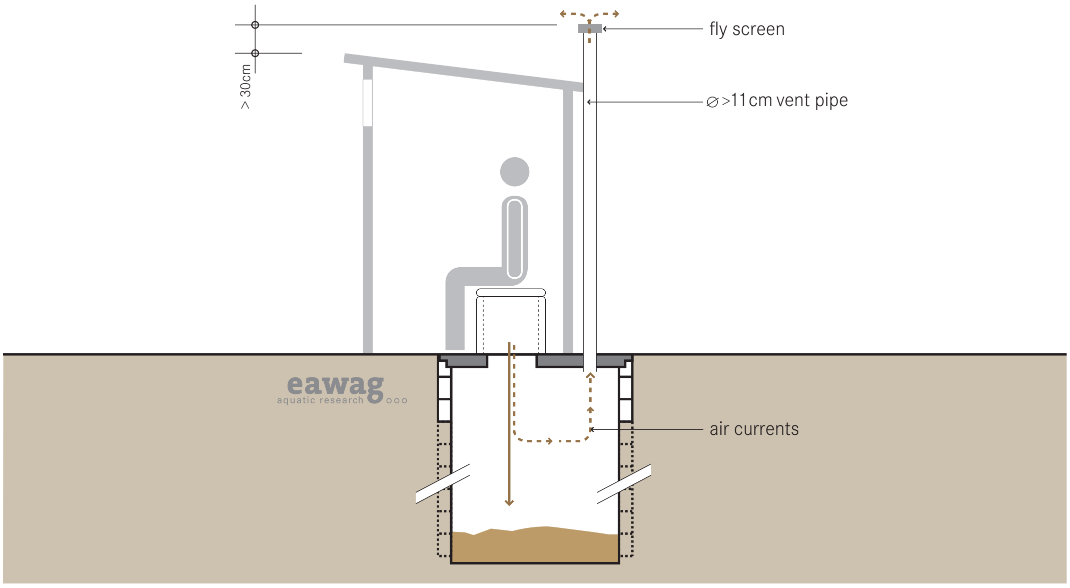
on mosquitoes breeding. Different means to control mosquitoes breeding in the pit exist. One example is given in Box 6.

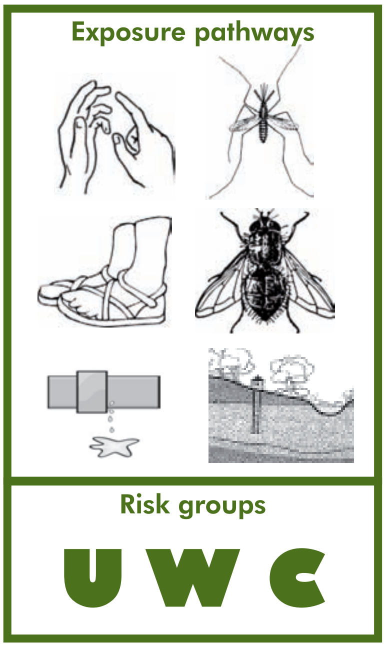
Risk summary
Number of exposed: 1-10 users, variable community members depending the density, water source, etc.

Frequency of exposure: LOW for the user (who is only affected by flies. Additional risks for direct contact see "user interface"), LOW for the community (who is only affected by potential groundwater or surface water contamination through overflows)

Level of risk: MEDIUM for the user, MEDIUM for the community

Single Ventilated Improved Pit Latrine





Technology description
VIP latrines (individual or communal) are an improvement over pit latrines due to the continuous airflow through the ventilation pipe that vents odour and acts as a trap for flies as they escape towards the light.

The pit can be lined or unlined depending on the hydro-geological conditions. Lined pits can periodically be desludged using mechanical emptying equipment such as a vacuum truck. Fly and odour reduction are the main advantages with the VIP latrines.

Input and output products
The inputs are the same as for a single pit. The output material can contain high numbers of pathogenic organisms especially parasites. An example from Accra, Ghana, showed that sludge collected from the chambers of communal VIP latrines contained about 200 – 400 helminthes eggs/g TS (Strauss *et al*., 2000). VIPs theoretically can have a faster better reduction of pathogens that single pit latrines due to better aeration.

Typical malfunctioning
Typical malfunctioning is the same as for single pits. Additionally the aeration may reduce with time if the vent pipes become clogged with spider's webs, dust and dead flies.

Exposure pathways
The same exposure pathways as exemplified for pit latrines, apply, except that fly transmission is significantly reduced. Morgan (1977) showed that the number of flies captured leaving the simple pit latrine was 54 times the number leaving the VIP latrine.

Box 7 : High Infestation rates of mosquitoes and flies exiting are associated with VIPs with no insect-proof screen

(Based on Curtis and Hawkins, 1982)

In Dar es Salaam and Gaborone Ventilated Improved Latrines showed infestation with larvae of flies (mainly *Chrysomya putoria*) and Culex mosquitoes (mainly *Cx quinquefasciatus*). The mosquitoes only occurred where the pit contents had a free water surface but the flies were found in both wet and scum covered pits. The infestation rate was much higher where the latrine vent pipe had no insect-proof screen.

If the latrine door was closed over 80% of flies and mosquitoes exit through the vent pipe. In pits with very dense mosquito infestations they also exit the pit through the drop hole. All the flies and the majority of the mosquitoes caught were trying to enter the vent pipe which indicates that odour from this source is attractive to these insects. **Maintenance of the vent-pipe of the VIP latrine is important in the control of flies**

Epidemiological and health risk evidence

- In Lesotho VIP latrines provision were related to diarrhoea morbidity in young children. Children < 5 years old from households with a latrine had 24 per cent fewer episodes of diarrhoea than those from households without a VIP latrine (odd ratio= 0.76; 95 per cent CI, 0.58 – 1.01) (Daniels *et al*., 1990).
- In East Africa, VIP latrine users were 22 per cent less likely to develop diarrhoea compared to those without toilet facilities (Thompson *et al*., 2001).

VIP latrines, generally present less risk for disease transmission than simple pit latrines (also Annex 6).

Risk mitigation measures
See Single Pit Latrines (page 28).

The vent of the VIP latrine should be properly maintained for effective removal of odour from the pit. The ventilation pipe should extend well above the roof and preferably be without 90 degree bends. In addition, the fly proof netting on top of the vent should be checked occasionally to ensure that it is not blocked or broken.

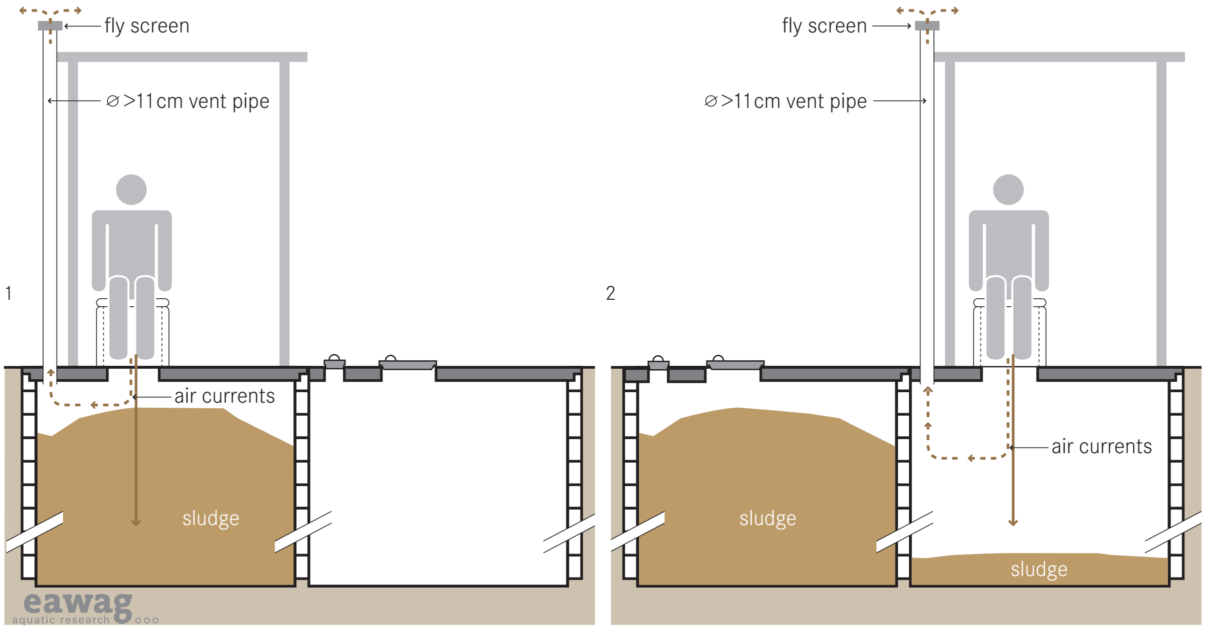
The vent pipe must be periodically cleaned, otherwise flies will escape through the toilet room and increase the exposure risk to the users (See Box 7).

Risk summary
Number of exposed: 1-10 users, variable community members depending the density, water source, etc.

Frequency of exposure: LOW for the user (who is only affected by flies. Additional risks for direct contact see "user interface"), LOW for the community (who is only affected by potential groundwater or surface water contamination through overflows)

Level of risk: MEDIUM for the user, MEDIUM for the community

Double Alternating Dry Pits

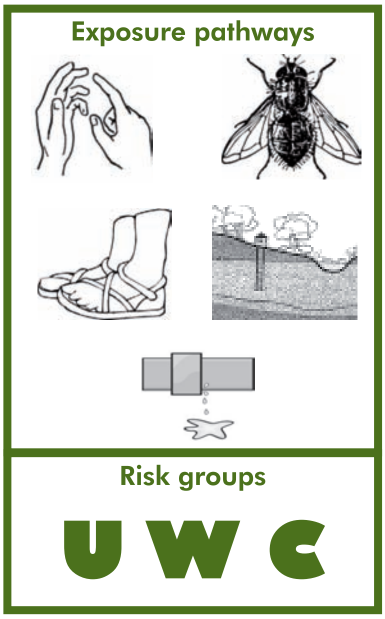


Technology description

The “double alternating dry pits” comprises two pits that are used alternately. No water is used. A fallow period of at least 1.5 - 2 years is the goal of the design, which ensures the destruction of pathogenic organisms. The depth of the pits can be reduced and relates to the alternating storage and emptying cycle. Since the two pits occupy a relatively small area and are used alternately, it may be a preferred option in certain types of peri-urban settlements.

Dry alternating pits may have different configurations for example Double VIP and Fossa Alterna further explained here.

The Double VIP consists of two, side by side, ventilated improved pits usually constructed under the same super-structure with each pit having its own squat hole or seat. A movable slab shared by both pits is an alternative. One pit is used at a time while the other is completely sealed. The structure is either provided with two ventilation pipes (one for each pit) or one fitted to the pit in use, while the hole for the ventilation pipe of the pit not in use is sealed. When the content of the pit is 30-50 cm to the top the pit is sealed, and the second pit taken into use. The pits are designed to ensure at least 1-2 years of storage. After this time or longer the content of the first pit is removed and that pit becomes operational again.



The Fossa-Alterna is similar to the double VIP but pits are shallower (1.5m) and normally include the addition of bulking material. Before the Fossa Alterna is used, the pit is lined with soil, straw, ash etc and following each defaecation, a quantity of soil is spread on top of the deposited excreta, with the aim to enhance aerobic degradation and introduce additional organisms to convert the excreta into humus.

Input and output products
Inputs into double alternating pits includes faeces, urine, dry anal cleansing material and in the case of the Fossa Alterna, bulking material. Urine and anal cleansing water can be collected separately to reduce the wetness of the material but can also be included.

Processes that reduce the pathogen load in the full covered latrine are dictated largely by temperature, residence time and pH. Biological degradation also plays a substantial role. If the pit is designed for storage duration of 2 years or more, all the pathogenic organisms in the faeces are likely to be destroyed, including helminths. For shorter storage times a reduction of most pathogens will occur, but does not ensure a full destruction.

Typical malfunctioning
The treatment will not function properly if the pits are watertight, or if they are located where groundwater or surface water intrusion may occur. Similarly the addition of water from bathing or anal cleansing may reduce the efficiency of the degradation, especially in the case of the Fossa Alterna. The pits should be properly sized for the number of users so that the material has an adequate time to degrade.

Exposure pathways
The user is largely unexposed to the contents. During the alternation, the user is likely to cover the pit which is not being used, which may lead to accidental contact and ingestion. Poor siting of the pits in areas with high water table and excessive wetness of material in the pit may lead to groundwater contamination and impact on drinking water supplies. If proper maintenance is not observed, the pits may become too full and contaminate the surrounding environment with a subsequent exposure risk to communities.

Epidemiological and health risk evidence
No epidemiological study has assessed the health risks associated with the storage of excreta in Fossa Alterna and double vault VIP. Groundwater contamination from pits is documented leading to significant infection risk through groundwater drinking water supplies.

Risk mitigation measures
With double-pit technology, the users' adherence to the practice of alternating the pits is crucial. The non-used pit chamber should be securely sealed at all times until it is ready for emptying. In the introduction phase, assistance may be needed during the first two pit changes to ensure that the complete cycle is covered. The addition of bulking materials is critical for the performance of the Fossa Alterna. The users need to ensure that the material is stored for up to 2 years or more before it is accessed. Users of the Fossa Alterna have to ensure that soil and/or ash is available at all time for addition into the toilet.

To prevent the excreta pile from forming a cone in the centre of the pit, it may need to be flattened down periodically. User education is critical to ensure that the technology is operated properly.

If proper storage times and personal hygiene practices are observed, emptying double alternating dry pits is safer and easier than single pits.

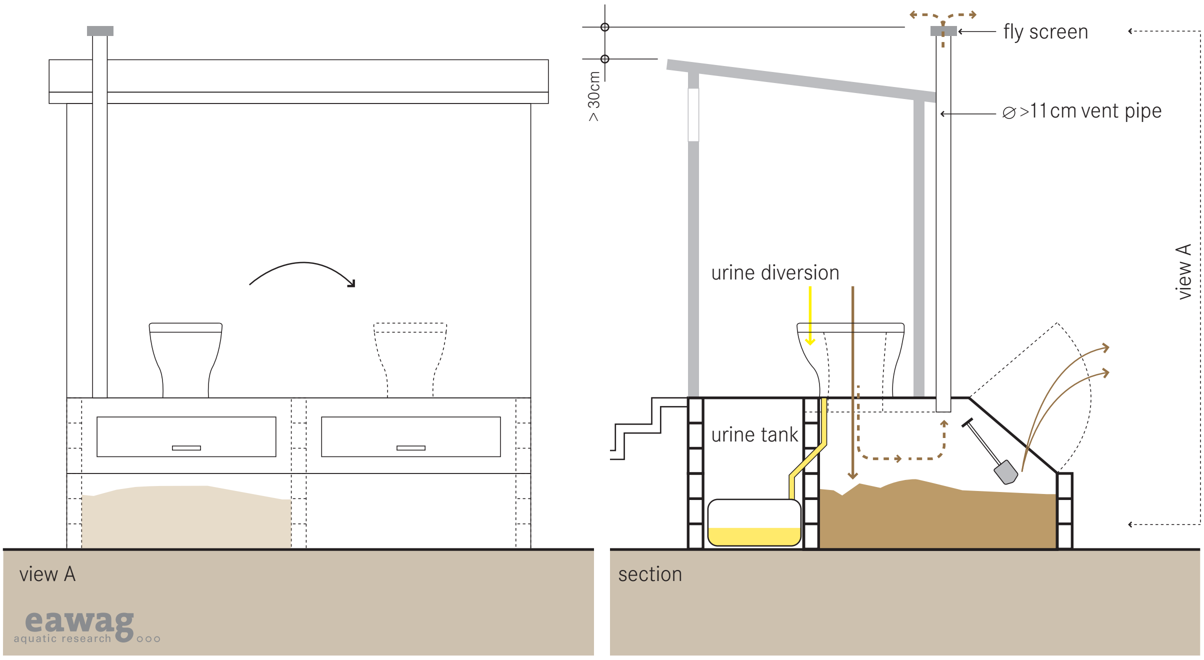
If the material is properly covered and the pit is vented, exposure to flies and other vectors is minimized considerably.

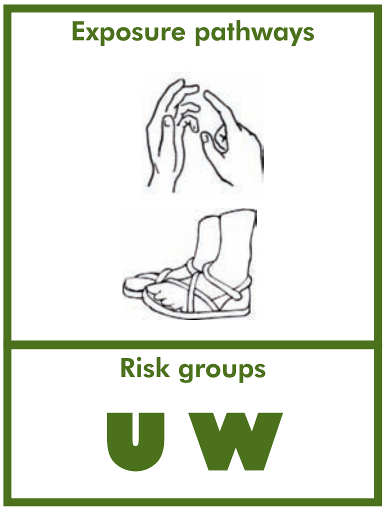
Risk summary
Number of exposed: 1-10 users, variable community members depending the density, water source, etc.

Frequency of exposure: LOW for the user (who is only affected by flies. Additional risks for direct cotact see "user interface"), LOW for the community (which is only affected by potential groundwater or surface water contamination through overflows)

Level of risk: MEDIUM for the user, MEDIUM for the community (but likely LOW if the pit is built away from a flood-prone area or near a water table)

Double Dehydration Vaults





Technology description

Dehydration vaults are used to collect, store and dehydrate (dry) faeces. Faeces will only dehydrate when the vaults are watertight to prevent external moisture from entering and when urine and anal cleansing water are diverted away from the vaults.

Input and output products

Dehydration vaults are used exclusively for faeces and covering materials such as lime, ash, or dry soil. Urine must be collected and stored separately. Temperature, pH, residence time and humidity are the main factors for the destruction of pathogens.

The addition of wood ash or lime after each excreta deposition makes the material more alkaline. If combined with low moisture content and 6-12 months of storage, reductions of up to 4 log units for viruses; 6 logs for bacteria; and a total reduction of viable protozoa and helminths can be achieved. A storage time of 1.5 – 2 years at ambient temperature (4 - 20°C and above) will eliminate bacterial pathogens and will reduce viruses and parasitic protozoa below the risk levels.

Some soil-borne ova may persist in low numbers. Tropical climates with an ambient temperature of more than 20 - 35°C and a storage duration of more than 1 year will significantly reduce viruses, bacteria and protozoa and result in inactivation of schistosome eggs (< 1 month). Inactivation of helminth eggs with a more or less complete inactivation of *Ascaris* eggs within 1 year will occur (WHO, 2006).

Some studies support this:

- Dehydrating vaults with addition of ash and temperature between

- 31-37°C, a pH of 8.5-10.3 and a moisture content of 24-55 per cent (Carlander & Westrell, 1999; Chien *et al.*, 2001) gave a total die-off of *Ascaris* and a 8 log reduction of viruses within 8 months.
- In China, Wang *et al*., (1999), mixed plant ash with faeces (ratio 1:3, pH of 9-10) and obtained a >7 log10 reduction of index viruses and faecal coliforms, and a 99 per cent reduction of *Ascaris* eggs after six months even though the temperature was low (–10°C to 10°C. Coal ash and soil amendment gave insufficient reduction. Lan *et al*., (2001) achieved inactivation of *Ascaris* within 120 days at a pH >8.
- In El Salvador, Moe & Izurieta, (2003) found that pH was the most important single factor determining inactivation of bacterial indicators and coliphages, whereas temperature was the strongest predictor for *Ascaris* die-off. A pH of 9-11 gave faster inactivation of faecal coliforms and *Ascaris* than a pH of <9. The study reports *Ascaris* viability in 40 per cent of the no solar heated urine diverting toilets, whereas viable *Ascaris* ova were not found in solar heated ones.
- In a Mexican study Redinger *et al.*, (2001) found levels of indicators similar to Class B compost (>1000 - $< 2 \times 10^6$ FC g^{-1}) in 70.6 per cent and 60.5 per cent of the systems after 3 and 6 months of storage respectively. Class A compost (<1000 FC g^{-1}) was present in only 19.4 per cent and 35.8 per cent of the toilets after 3 and 6 months of storage. Solar exposure was the most important factor for faecal coliforms destruction.

Typical malfunctioning

Water from cleaning or from anal cleansing introduced into the dehydration vault will prevent the faeces from dehydrating. Anal cleansing water should be diverted to a different container. If water is accidentally introduced into the vault, additional dry material, soil, ash, or saw dust, should be used to compensate.

Exposure pathways

At this technology interface the users are largely unexposed to the contents except during the alternation when the user is likely to cover the pit which is not being used, leading to accidental contact. Exposure to flies and other vectors is normally not of concern if the material is properly covered and the pit is vented. Bad maintenance will not result in any enhanced security over single pits or double alternating dry pits.

Epidemiological and health risk evidence

Epidemiological studies on dehydrating urine diverting toilets have generally focused on households' use of the technology without specific emphasis on the storage of the material in the vault as a potential risk factor (Annex 7). In a study performed in Durban, South Africa (Knight *et al*., 2011, submitted) it was concluded that based on multiple interventions of urine diverting toilets (without reuse) and water and hygiene inclusion a risk reduction of 41 per cent of diarrhoea episodes (adjusted Incidence Risk Ratio: 0.59 (95 per cent Confidence Interval 0.34 to 0.96; p = 0.033) was obtained. The study did not address the helminth infections. Women and children benefited particularly. This study cannot be exclusively ascribed to the collection/storage and treatment functional group as many factors including the user-interface may have accounted for the reduction of diarrhoeal disease incidence.

Risk mitigation measures

Users have to be well sensitized on the use and maintenance to reduce potential health risk.

Vaults should be made water tight and urine should be properly diverted to avoid that the faeces becomes wet which will prolong the pathogen survival and the subsequent exposure risks during emptying.

A prolonged storage time of 18 months for highland subtropical areas (17 – 20^{0}C) will reduce the risks if the product is to be applied directly from the vault; and 12 months if subsequent sun drying is to take place before handling. For low land tropical regions (28 – 30^{0}C), a storage time of 10 – 12 months is proposed for direct application; and 8 – 10 months, if subsequent sun-drying is allowed. Therefore, the vaults should be designed with the proper storage capacity based on the number of users and the desired storage time. If profuse and watery diarrhoea are common, amendments like peat, soil or other adsorbents may be necessary *in addition* to the ash or lime.

Proper use includes technical arrangements that allow for a separate wet anal cleansing. The cleansing water should not be mixed with either the urine or the faecal material and needs to be properly collected to avoid secondary exposure. Collection of stored excreta for reuse before the conditional exemplified storage time should be discouraged. In settings where the socio-cultural context do not accept contact with faeces and urine, the development of dehydrating vaults for reuse should not be considered until there has been a rigorous and systematic educational campaign. Urine diversion sanitation projects should encourage community participation in the design and implementation stages (Duncker *et al*., 2007). Issues to be addressed for acceptability and replicability are the people's perceptions and beliefs about the handling and use of human excreta, especially in crop production, the perception of human excreta as waste, and the lack of incentives for reuse in existing legislation (Esrey *et al*., 1998; Breslin and Dos Santos, 2001; Drangert *et al*., 2002; Danso *et al*., 2004; Cofie *et al*., 2005; Tsiagbey *et al*., 2005; Nawab *et al*., 2006; Duncker *et al*., 2007).

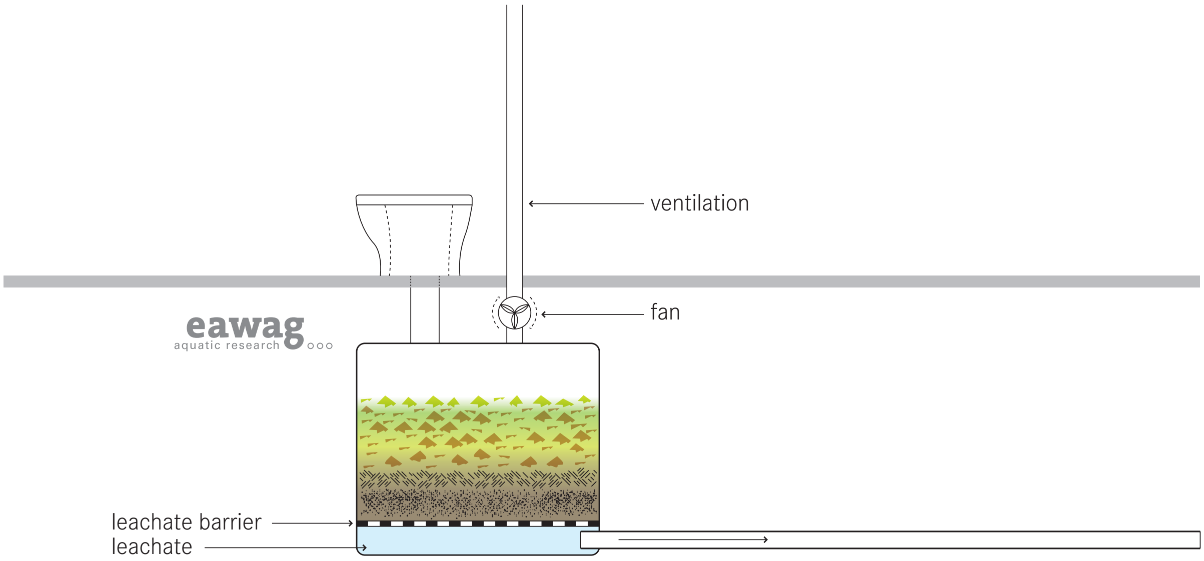
Vaults must be designed for a storage time of 1.5 - 2 years. The vaults must be used in an alternating fashion- one at a time- and not used concurrently.

Risk summary
Number of exposed: 1 worker, rarely; variable community members depending on the handling of urine collection and ablution water

Frequency of exposure: LOW (essentially never for users, and infrequently for a worker who fixes a problem) MEDIUM for community embers in relation to contaminated urine/ablution water

Level of risk: LOW for everyone, since the vaults completely contain the faeces. MEDIUM for community embers in relation to contaminated urine/ ablution water.

Composting Latrines/Chambers

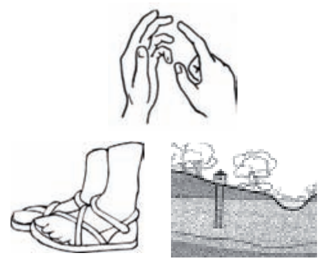


Technology description
Composting chambers are separate collection compartments designed to allow for aerobic biodegradation of excreta through the action of bacteria, worms (vermi-composting) or other organisms in an enclosed chamber. The biodegradation is enhanced through the addition of organic or bulking materials, such as vegetables scraps, wood shavings, corn or coconut husks, wood ash etc to improve oxygenation and the carbon to nitrogen ratio of the mixture with excreta. The compost chambers are designed either for batch and continuous fed. They can be of different design configurations with additional features for heating (solar or electricity) and urine diversion.

The composting process in the vaults depends on the oxygen supply for aerobic conditions and temperature, moisture and an optimum carbon to nitrogen ratio. The latrine composting process is usually mesophilic, in contrast to secondary composting that sometimes are thermophilic. The mesophilic composting process functions acceptably well in a temperature range of 20-30 °C with an optimum temperature between 28-30 °C (Burrows, 2003). A proper carbon to nitrogen ratio of 30:1 is essential as well as a moisture content of 40-70 per cent with an optimum level of 60 per cent (USEPA, 1999).

External heating has been applied to enhance the process for example through solar heating.

Exposure pathways



Risk groups

U W C

Input and output products
Inputs for the composting chamber may include some or all of the following: faeces, urine, dry anal cleansing material and organic household or garden waste. Reduction of pathogens in the composting chamber is primarily by aerobic degradation. If high temperatures (>50°C), typical of thermophilic aerobic composting are achieved, all pathogenic organisms would be eliminated in some days (Epstein, 1997). However, thermophilic conditions are rarely achieved in composting toilet chambers. Feachem *et al*., (1983) suggest the composted

material should be stored for at least 3 months before collection. Longer storage duration is especially needed in settings where helminths are endemic.

In the temperature enhancement with solar heated compost chambers the effect is a combination of temperature and biodegradation. Solar heating will result in complete elimination of all pathogenic organisms if the temperature is high enough. The effect is due to the temperature range and storage time.

Typical malfunctioning
A typical malfunction in composting chambers is a too high moisture content (for example too much urine), which may cause anaerobic conditions. Too dry conditions will also slow down the biological degradation process. For efficient and effective composting, the correct balance of nutrients, moisture and temperature is essential for the degrading organisms. Composting thus need proper skill and operation to works without problems.

Exposure pathways
The exposure from a composting chamber is minimal, though care should be taken when pushing down the pile and adding material to the chamber. The contact with the material is the most critical from a health point of view. Leachate from non-contained composting chambers may contaminate the surrounding environment. In thermophilic composting actinomycetes and fungi are among the organisms that function as decomposers. These organisms are spore-forming and the spores may function as allergens for sensitive individuals when inhaled.

Epidemiological and health risk evidence
There is currently a lack of epidemiological evidence from small-scale and on-site composting systems.

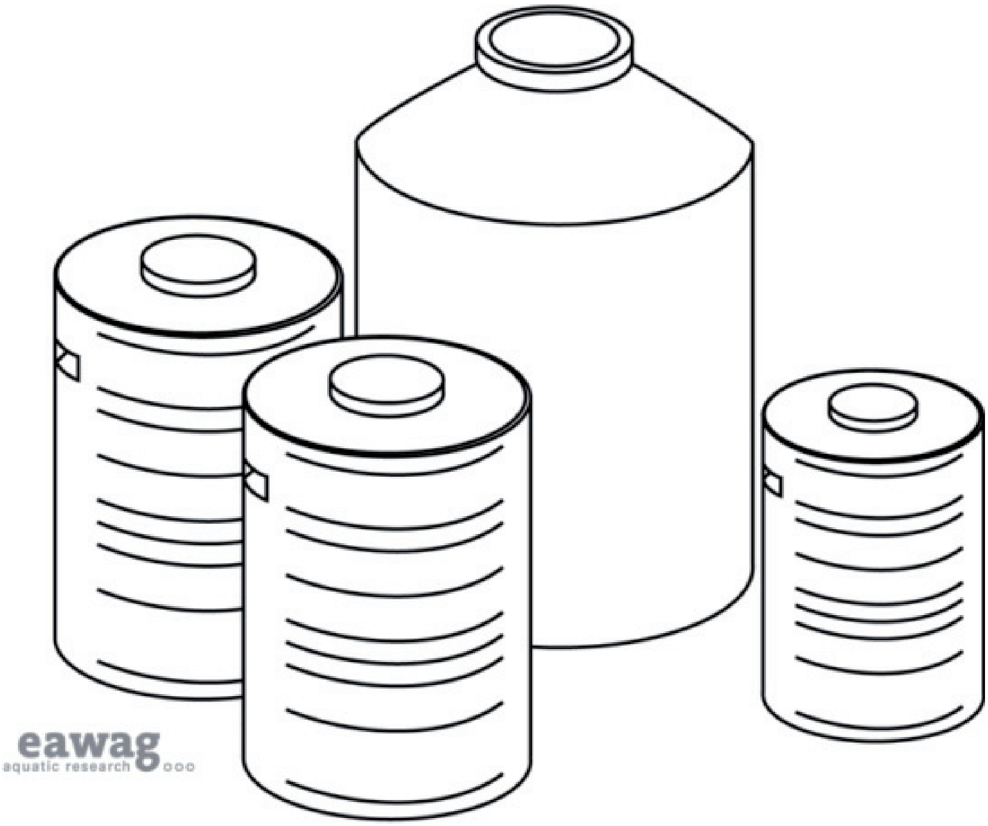
Risk mitigation measures
The ability of users to consistently monitor and maintain the composting material, i.e. adding organic and bulking material, is critical. The barrier efficacy of the compost chambers depends largely on the ability of users to maintain optimum temperature, moisture, Carbon-Nitrogen ratio, pH etc. The vaults of the latrines should be constructed water-tight to minimize the risk of polluting the surrounding environment including groundwater. Where anal cleansing with water is practiced, a separate tank for the collection of anal cleansing water should be installed as the compost should not be too wet.

Risk summary
Number of exposed: 1 to several workers, rarely

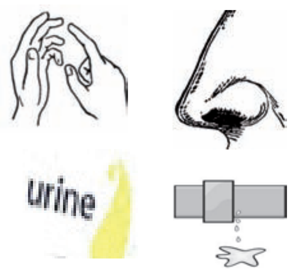
Frequency of exposure: LOW (essentially never for users, and infrequently for a worker who fixes a problem)

Level of risk: LOW for everyone, since the vaults completely contain the excreta

Urine Storage Tank



Exposure pathways



Risk groups

U W

Technology description

A wide range of technologies for the storage of urine exists. These include rigid plastic or cement tanks of different sizes for large scale systems, or expandable ones of rubber or plastic. The size is determined by the volume that needs to be collected and the corresponding storage time.

Input and output products

Excreted urine generally contains microorganisms from the uninary tract. Freshly excreted urine from healthy individuals may contain 10,000 bacteria/ mL (Tortora *et al*., 1992). The pathogens traditionally known to be excreted in urine are *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi* and *Schistosoma haematobium* (Feachem *et al*., 1983). In urine diverting toilets, some faeces may be misplaced and end up in the urine collection tank. The amount is due to the behavior of the users. Urine may also contain antibiotics and metabolites from medication. It will also contain excreted hormones.

For research validation the amount of coprostanol (a chemical compound produced in gut from the conversion of cholesterol) excreted in faeces has been used as a measure of the faecal contamination of urine stored in tanks of urine diversion toilet (Höglund *et al*., 1998).

The die-off of pathogenic organisms in stored urine is largely a function of storage time, temperature, pH and the presence of ammonia. During storage, urea in urine degrades rapidly to ammonia and carbon dioxide. This results in a pH rise and an increase in ammonium concentration which acts as an inactivating agent for pathogens in the stored urine. Gram-negative bacteria (eg. *E. coli* and *Salmonella*) are rapidly inactivated (time for 90 per cent reduction, $T_{90} < 5$ days) while Gram-positive (e g faecal streptococci) are more persistent. Similarly, rotavirus and *index bacteriophages* were not inactivated in urine at low temperature (5^0 C), whereas at 20^0C their T_{90}-values were 35 and 71 days, respectively. *Cryptosporidium* oocysts were less persistent with a T_{90} (1 log reduction) of 29 days at 4^0C (Höglund *et al*., 2001).

Typical malfunctioning

Large tanks should be water-tight. The use of metal should be minimized so as to avoid corrosion. Fitted taps should be well fixed but easily replaceable in case of clogging or need of replacement (e.g. not cast in concrete). Smaller collection vessels should preferably have an overflow device.

Exposure pathways

Exposure may occur through direct contact followed by accidental ingestion during tank maintenance, at time of collection or due to overflow at the storage tanks or collection vessel.

Epidemiological and health risk evidence

Storage does not result in health risks if the tanks does not leak or overflow. Health risks related to the further handling and evidence is given in "Human-Powered Emptying and Transport" (page 55).

In accidental contact unstored urine will, based on the faecal cross-contamination result in a high rotavirus infection risk (10^{-1}), but is much less and below the risk threshold for *Cryptosporidium* (10^{-5}), *Campylobacter* (10^{-4}) and Hepatitis A. In developing countries the health risk for Hepatitis A and bacterial infections associated with the ingestion of unstored urine may be high because of the relatively high incidence of these pathogens in the population compared to European conditions which was the base of the above study. The infection risk associated with the accidental ingestion of urine stored for 1 and 6 months was generally low for all the pathogenic organisms except rotavirus.

Risk mitigation measures

When urine is collected into a tank, the inlet should be at or near the bottom of the tank to avoid splashing and minimize ammonia volatilization. The urine tank should be sealed. The urine collection container should ensure that overflow does not occur, which may also lead to accidental direct contact.

It is important to adapt storage conditions to potential cross contamination at the user interface. Storage at ambient temperature is a viable treatment option for urine. Recommended storage time at temperatures of 4-20°C varies between one and six months for large-scale systems depending on the type of crop to be fertilized (See Annex 7). For single households, urine could be applied to any crop without storage as long as one month passes between fertilization and harvest.

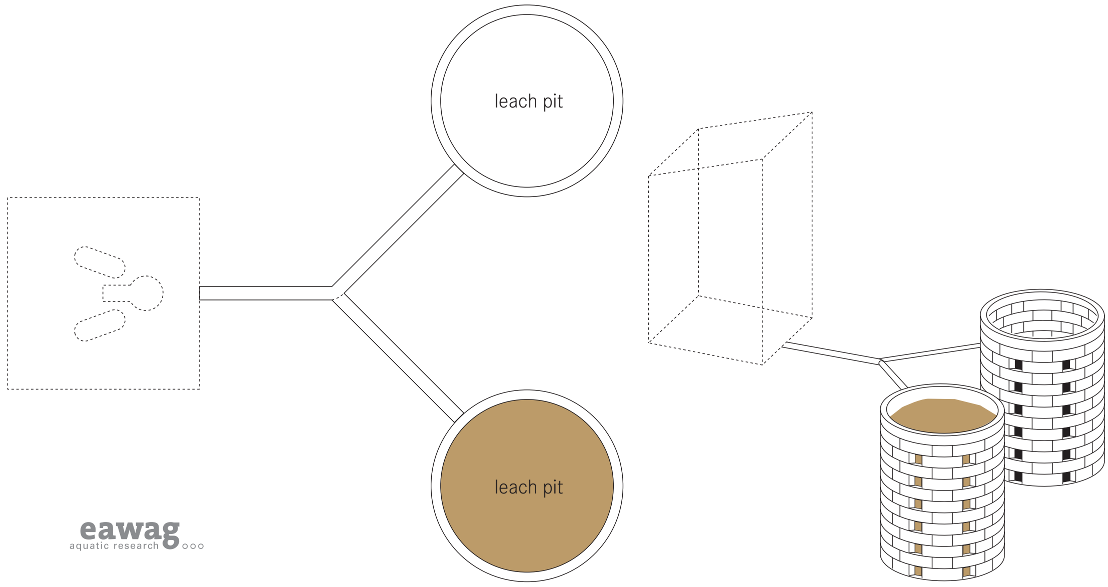
Risk summary

Number of exposed: 1 worker, rarely, 1-2 collector/s; Several community members/children if urine collection vessel overflow frequently

Frequency of exposure: LOW (essentially never for users, and infrequently for a worker who fixes a problem); MEDIUM for community members if collection vessel overflow

Level of risk: LOW for everyone, since the tanks completely contain the urine; MEDIUM if vessel overflows and the feacal cross-contamination is documented.

Twin Pits Pour with Flush



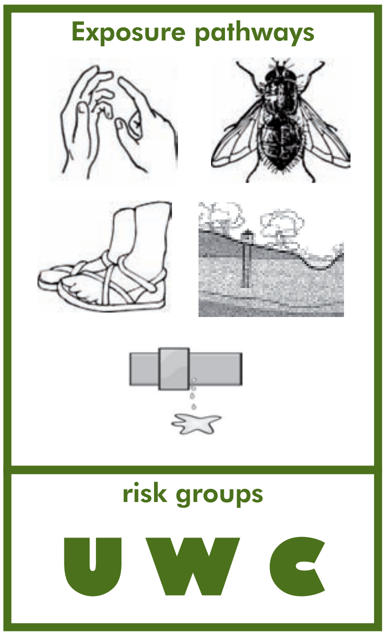
Technology description

The double pit pour flush toilet is based on the design concept of the double vault VIP latrines. The Twin Pits Pour Flush technology function for the: i) storage and digestion of the solid content of the wastewater; and ii) infiltration unit of liquid. The infiltration of the liquid is enhanced if the pits are lined with a honey-comb, brickwork that provides stability but allow the liquid to leach into the surrounding soil. The leach pits can be installed directly under the superstructure, or at a distance away, connected to the pour-flush toilet with plumbing.

When the first pit is full, usually after 1-2 years, the second pit is put into use. The first pit is sealed until, the second pit is full. By the time the second pit is full, the excreta in the first pit would have decomposed enough for the content to be collected for disposal whereafter the pit can be taken into service again.

Input and output products

Inputs into the pit may include excreta, anal cleansing water and greywater though dry cleansing materials should be excluded. Excreta flushed into the pits undergo degradation, mainly anaerobic. The two pits are used in alternation to allow the content in the one not in use to drain, reduce in volume, and degrade. The long storage time of up to 2 years in the alternating pits, would lead to elimination of most of the pathogenic organisms of viral, bacterial and protozoan origins while a fraction of the more persistent parasitic helminthes may remain (Mara, 1985).



Typical malfunctioning

Too shallow pits will not provide sufficient treatment time to the excreta. Pits located in soil with insufficient absorptive capacity, will rapidly fill up as the rate of accumulation will exceed the rate of infiltration. Excessive use of dry cleansing materials will clog the walls of the pit and prevent the liquid from infiltrating properly.

Exposure pathways
A major contamination route of health concern is through groundwater. The extent of the unsaturated zone under the pits determines the risk of contamination over short or long distances in addition to the hydrological flow, nature and type of soil and its porosity and the underlying rocks. The transport of helminths and to some extent protozoa are considered a minor problem due to their larger size than bacteria or viruses, which will result in a larger retention in the soil. (Foster *et al.*, 1993). Smaller bacteria and viruses can be transported over a long distance.

Maintenance workers not wearing protective clothes will also be exposed. Problems may also occur with fly breeding and subsequent transmission.

Epidemiological and health risk evidence

- In a prospective cohort study in the Philippines, members of a community using improved pour-flush toilet, were 3.1 times less likely to develop cholera compared to those with no toilet facilities (Azurin and Alvaro, 1974).
- A quantitative microbial risk assessment combined with hydro-geological transport models based on a case study in Kerala, India shows that wells could be considerably contaminated with rotavirus, *Cryptosporidium*, Hepatitis A and *E. coli* (EHEC) and lead to significant infection risk if proper set back distances between pour flush pit latrines and drinking water wells are not maintained (Molin *et al.*, 2010) (Box 8).

Risk mitigation measures
Users or workers who are blocking or opening the outlets of the pits should wear protective clothes.

Leach pits should be located, so that potential groundwater contamination is avoided. This refers to safe horizontal and vertical set back distances and hydraulic loading. Set back distances should be based on the local hydro-geological conditions. Pour-flush latrines may be upgraded to a septic tank with a drainage field or soak-away, or may be connected to a small sewerage system. The technology should only be used in areas with adequate water for flushing. The design of the U-trap should be done so that blocking or clogging is avoided.

The distance between the two pits should account for the liquid leakage and not percolate into the pit not in use. It has been suggested that the distance between the two pits should not be less than the depth of a pit (Franceys *et al.*, 1992). If the pits are built adjacent to each other, the dividing wall should be non-porous.

A vessel sized to local socio-cultural preference (normally between three and five litres capacity) should be at each toilet for flushing and cleansing purposes. Sufficient water for total household daily latrine requirements should ideally be stored in a suitable storage jar, bucket or storage tank. The storage jar should be reserved for its purpose of toilet/latrine use. If an on-site water supply is available, a self-closing tap with separate drainage could replace the storage vessel.

Risk summary
Number of exposed: variable

Frequency of exposure: LOW for the community, depending on the location of the water source and potential for groundwater contamination). HIGH if groundwater contamination may occur.

Level of risk: LOW - HIGH for the community (depending on the location of the water source and potential for groundwater contamination).

Box 8: Pour flush latrine and set-back distances in Kerala, India

(Based on Molin *et al.*, 2010)

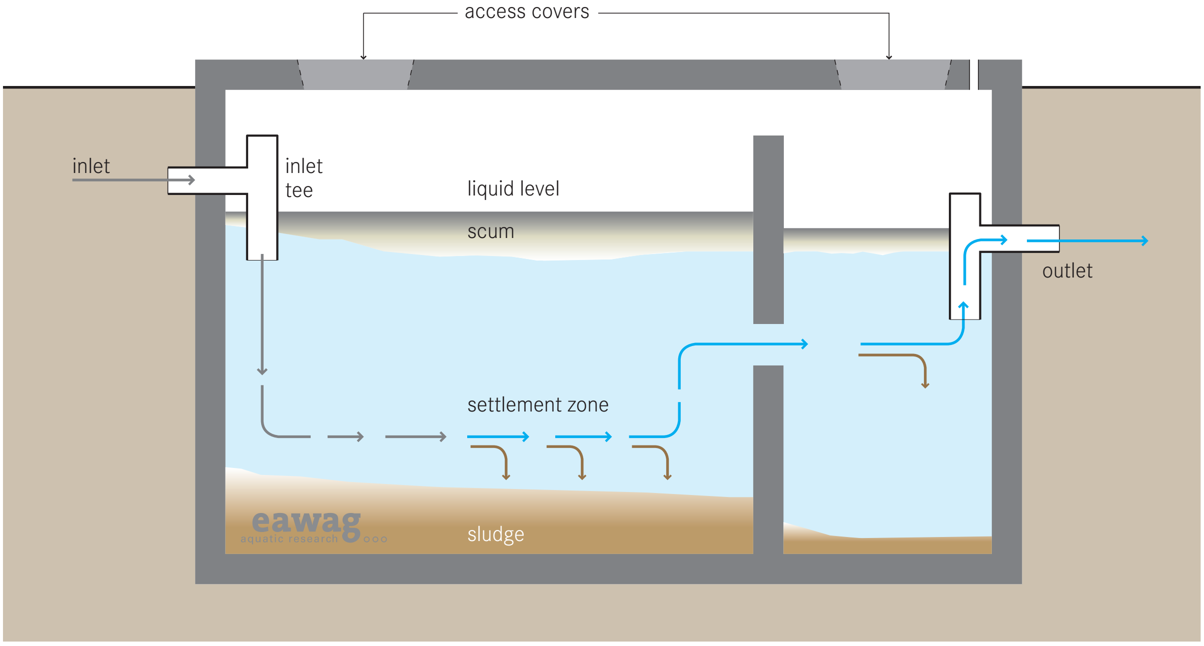
Kerala in south-west India is part of the tropic humid with monsoons area.

Open dug wells is an important source of drinking water and are lined with cement or laterite bricks, and extract 500 – 800 l/day. The density of wells is 270 open wells/km^2 in the coastal area.

The minimum distance between pour-flush toilets and wells has been reduced from 15m to 9m. The annual infection risk between the latrines and wells was modelled with reference to these specific set-back distances. The limit for safe set-back distances under the prevailing hydro-geological conditions varied for the modeled pathogens with *E. coli* at 8m, rotavirus at 26m, *Cryptosporidium* at 40m and Hepatitis A at 80m.

Take home messages: Pour flush latrines may highly impact the risk of groundwater contamination affecting nearby wells. Safety distances cannot just be set based on *E. coli* as an indicator. Hydro-geological conditions and flow must be considered. Risk modeling will give a more full-covered picture of the risk related to different pathogenic groups.

Conventional and Improved Septic Tanks



Technology description
A septic tank is a watertight chamber used for the storage and treatment of blackwater and/or greywater. The settling of particles and anaerobic degradation that will occur reduce the solids and organics content, but only moderately affect the microbial reduction. The formed sludge has to be collected for disposal. Regular desludging of the tank is critical for proper functioning.

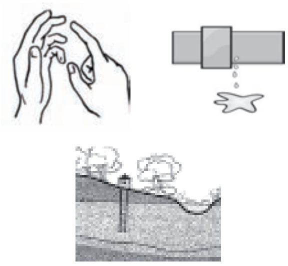
A septic tank should have at least 2 chambers. A variant with more chambers for increased settling and sludge contact is called an Anaerobic Baffled Reactor (ABR) and uses the same processes of settling and anaerobic digestion. By increasing the number of chambers and forcing the liquid to flow through the accumulated sludge a further reduction of nutrients and organic load is achieved as compared to a conventional septic tank.

An anaerobic filter is a further adaptation that incorporates a filter media (e.g. crushed rock or preformed plastic) into a final chamber. After passing the first chamber the wastewater is forced to flow up through the filter as a final polishing step.

Input and output products
The input for the septic tank consists of urine, faeces, flush water, dry-anal cleansing material, anal cleansing water and/or greywater. In the tank, a significant amount of the solid matter in the influent settles. Optimally a septic tank is capable of removing 80 per cent of the suspended solids (Majumber *et al*., 1969) that undergo further degradation by anaerobic digestion. The rate of digestion increases with temperature, a maximum rate being achieved at about 35 °C (Franceys *et al*., 1992). Removal of pathogens varies and largely depends on the removal of suspended solids.

Majumber *et al*., (1969) reported an 80-90 per cent removal of hookworm and *Ascaris* eggs. A maximum of 1-log *E. coli* removal has been reported but itis usually lower. The reference value given by WHO is less than

Exposure pathways



Risk groups

U W C

0.5 log (WHO, 2006-2). Faechem *et al*., (1983) gave a 0 – 2 log removal range for all pathogenic organisms provided that the system is functioning under normal conditions.

In Nigeria, 46 per cent and 40 per cent reductions of faecal coliforms from septic tanks receiving blackwater and greywater respectively were reported (Burubai *et al*., 2007). In Australia, the performance of 200 residential and public septic tanks had higher average concentrations of thermotolerant coliform bacteria than communal systems (Charles *et al*., 2005). The concentration of pathogens in the effluent of septic is always high.

Typical malfunctioning
Septic tanks must be water-tight. When they leak or allow ground water to infiltrate, their performance is compromised. If the septic tank is under designed, the treatment efficiency will be low and in the worst case the blackwater will flow directly out without settling or undergoing any treatment.

Exposure pathways
Exposure is in theory low and relates mainly to "emptying". In addition, exposure is related to technical factors like failures in the septic tank due to overloading, poor construction and poor maintenance (i.e., infrequent desludging). In the literature a clear differentiation is not always made for soak-pits or with linked infiltration units which may have higher impact on groundwater. This remains a major contamination route for leaking septic tanks. Septic tanks have been associated with ground water contamination that has, resulted in disease outbreaks with enteric microorganisms (Fong *et al*., 2007; Falkland, 1991). The contamination risk is enhanced during events of extreme precipitation (flooding). This was for example shown by Fong *et al*., (2007) for septic tanks located in the South Bass Island, Ohio, and subsequent well contamination during events of extreme precipitation.

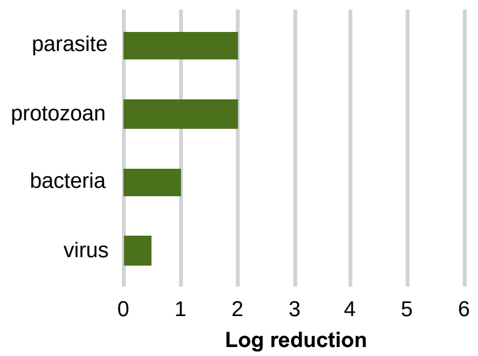


Figure 7: Reduction of pathogens in an optimally functional septic tank (WHO, 2006)

Besides groundwater contamination, septic tanks may also provide breeding sites for mosquitoes including *Culex pipiens* (Cetin *et al*., 2006), *Culex quinquefasciatus* and *Aedes albopictus* (Chang *et al*., 1993; Charlwood, 1994). Domestic septic tanks in Ipoh, Malaysia were found to serve as breeding sites for *C. quinquefasciatus* and *Aedes albopictus* (Lam, 1989). In another study in Malaysia, *A. albopictus* was found to be breeding in 38 per cent of the septic tanks surveyed in housing areas in Kuching, Sarawak (Chang, 1993).

Epidemiological and health risk evidence
Accidental ingestion of the influent and effluent from septic tanks can result in significant infection risk.

- Heistad et al., (2009) estimated a high rotavirus infection risk (>10^{-4} per annum) for children accidentally ingesting 1-2 mL of the effluent of a septic tank receiving wastewater from single households in Norway.
- Yates and Yates (1988) have implicated septic tanks in outbreaks of gastroenteritis, Hepatitis A and Typhoid (Annex 9).
- A study conducted by Borchardt *et al*., (2003) in central Wisconsin also found an association between septic tank densities per acre and endemic diarrhoeal illness of viral and unknown aetiology in children. Viral diarrhoea was associated with the number of holding tank septic systems in a 640-acre section surrounding the case residence [adjusted odds ratio (AOR), 1.08; and bacterial diarrhoea was associated with the number of holding tanks per 40-acre quarter-quarter section (AOR, 1.22). Diarrhoea of unknown aetiology was independently associated with drinking from a household well contaminated with fecal enterococci (AOR, 6.18; 95 per cent CI, 1.22-31.46; p = 0.028).
- In another study at the White Mountain Apache reservation, the presence of a septic tank within a household was identified as a major cause of rotavirus diarrhoea (Menon *et al*., 1990).

Disease outbreaks associated with inadequately sited or maintained, overloaded and malfunctioning septic tanks have been summarised (Craun, 1984; 1985) and an example is given in Box 9.

Risk mitigation measures
A septic tank (or ABR or Anaerobic filter) should be buried, and not easily accessible, except for desludging. In general, the user should have very little contact with the septic tank. Harsh chemicals (e.g. cleaning or industrial chemicals) should not be introduced in the inlet. This may inhibit the active biological sludge degradation.

Box 9: A dormitory septic system causes severe waterborne disease outbreak

(Based on CDC, 1999)

A mixed agents outbreak in 1999 in the US was associated with attendance at the Washington County Fair. The investigation showed that the outbreak probably resulted from contamination of a well from a septic system on the fairground. Another suspected source was manure stored in a nearby area. A total of 781 people were affected. Of these, 127 cases of *E. coli* infection and 45 cases of *Campylobacter jejuni* were confirmed, with 2 deaths and 71 people hospitalized. Haemolytic uraemic syndrome, a severe complication of *E. coli* O157:H7 infection that can lead to kidney failure was developed in 14 people.

A case-control study concluded that consumption of beverages sold by vendors supplied with unchlorinated water from the well was a key risk factor for patients. *E. coli* O157:H7 was found in water samples. *E. coli* O157:H7 was also found in the suspected septic system. The discharge area of that septic system was approx. 12 m from the well and tests showed a hydraulic connection. Tests did not identify *Campylobacter* in samples from the septic system or the well.

Take home message: Epidemiological investigations are valuable both to document the causal relationship, in this case the most likely connection between a septic system and a well, to exclude potential other sources. Evidence based documentation is valuable to relate to for situation analysis in similar type of areas.

The installation of the septic tank for the removal of suspended solids through sedimentation is best achieved under quiescent conditions. The residence time in the tank is affected by factors like tank volume, geometry, and compartmentalization. To prevent groundwater contamination, the tank should be water tight and the tank joints (at the inlet, outlet, inspection points and risers) properly sealed. The tanks should be periodically desludged. The system is therefore not appropriate in areas with poor road access (e.g. in remote area, on steep slopes, or in dense urban slums). The frequency of desludging largely depends on the number of users and size of the tank, but in general, desludging is made at least every 3 to 5 years. Advanced systems are available to provide continuous monitoring and data storage of changes in sludge depth, scum or grease layer thickness, liquid level, and temperature in the tank.

Mosquitoes breeding in septic tank have been controlled using expanded polystyrene beads (EPSB). A field trial in household septic tanks in Sarawak showed a 100 per cent and 68.7 per cent reduction of *Culex auinauefasciatus* and *Aedes albopictus* respectively one week after treatment. No adult mosquitoes were caught one month after treatment. A reduction in mosquito biting rates was reported by 87.3 per cent of respondents. All households regarded the EPSB treatment as effective. This study has reduced the relatively high infestation rate of *A. albopictus* in the septic tanks to 16-20 per cent. The EPSB treatment was regarded as feasible and practical (Chang *et al*., 1995).

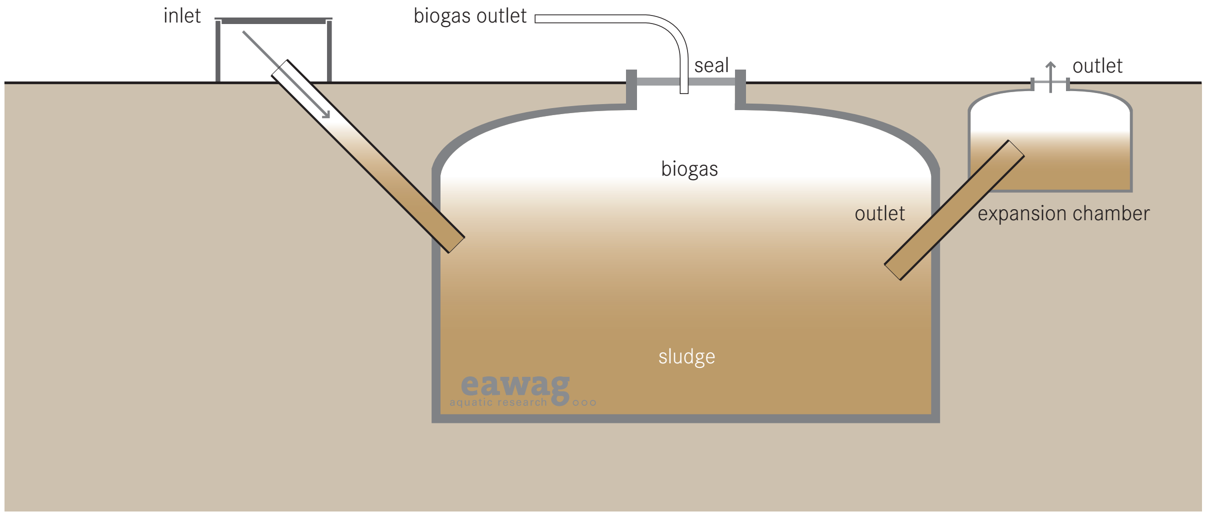
Where the septic tank also treats greywater, excessive use of fat or oil from the kitchen will affect the functionality of the septic tank. A grease trap should always be installed before the liquid enters the tank, to prevent clogging, which ultimately may cause overflowing or backflows.

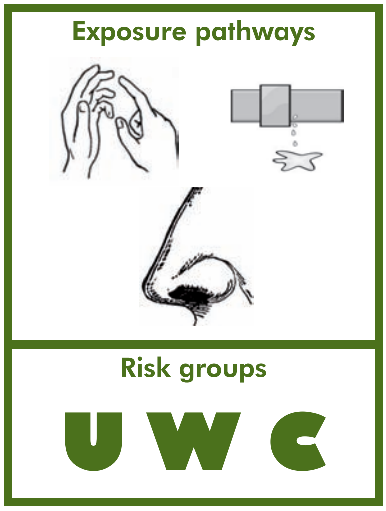
Risk summary
Number of exposed: variable

Frequency of exposure: LOW (depending on incidents of overflow or leaks) and prevailing groundwater conditions.

Level of risk: LOW-MEDIUM for users, LOW -MEDIUM for community

Anaerobic Biogas reactor





Technology description
An Anaerobic Biogas Reactor produces both a digested slurry which can be used as a soil amendment and biogas which can be used for energy. 'Biogas' is a mix of methane, carbon dioxide and other trace gases.

The biogas reactor can be built above or below ground, depending on the soil, groundwater, and temperature conditions. Prefabricated tanks or brick-constructed chambers can be sized depending on space, resources and the volume of waste generated. Biogas reactors can be built as fixed dome or floating dome reactors. In the fixed dome reactor, the volume of the reactor is constant. As gas is generated, it exerts pressure and displaces the slurry upward into an expansion chamber. When the gas is removed, the slurry flows back down into the reactor. In a floating dome reactor, the dome will rise and fall with the production and withdrawal of gas.

The hydraulic retention time (HRT) in the reactor should be a minimum of 15 days in hot climates and 25 days in temperate climates. For material with a potential high pathogenic input, a retention time of 60 days should be considered. Normally, biogas reactors are not heated in developing countries, but may be so in industrialized ones to ensure pathogen destruction.

Input and output products
Human and animal excreta, blackwater, greywater and organic waste are all suitable products for the biogas reactor. Many biogas reactors are directly connected to indoor (public or private) toilets with an additional access point for organic materials. The inputs may contain large numbers of pathogenic organisms depending on the input source and location. The destruction of pathogens in the anerobic digester depends on a number of factors; temperature, hydraulic retention time, pH, volatile fatty acids (VFA), batch or continuous digestion, the pathogen of concern and available nutrients (Keaney *et al*., 1993a; Farrah and Bitton, 1983). The temperature digestion process, mesophilic (30 – 38^{0}C) or themophilic (50 - 60^{0}C) combined with time is the most important factor for

pathogen destruction. Thermophilic temperatures are particularly effective.

Pathogens are rapidly destroyed; in a few hours to days; in thermophilic reactors, and weeks in mesophilic once. In a continuous thermophilic biogas reactor receiving manure no viable *Ascaris* eggs and *Salmonella* were found after 24 hours (Plym-Forshell, 1995).

More than 3 log units of *Cryptosporidium* oocysts were inactivated in an anerobic digester after 10 days at 37°C, 4 days at 47°C, and 2 days at 55°C. The corresponding time for *Ascaris* egg inactivation was less than 75 per cent after 10 days (37°C), 95 per cent in 2 days (47°C) and more than 3 logs in 1 hour (55°C) (Kato *et al*., 2003). Thermophilic temperature conditions are rarely achieved in biogas reactors without additional heating.

Most of the 35,640 biogas digesters in Himachal Pradesh, India, operated in the lower mesophilic range (16 – 24°C) for or below (Kalia and Kanwar, 1989). Here, hydraulic retention time will be the most important factor for pathogen destruction. In an anaerobic batch digester operating at room temperature (18 - 25°C), the time for the complete inactivation of *E. coli* and *Salmonella typhi* was 20 days (Kumar *et al*., 1999).

The reduction time required for inactivation may vary within wide ranges due to the organism in question. The days required for a 1 log removal was for *E.coli* (77 days), *Salmonella typhimurium* (35 days), Yersinia enterocolitica (18 days), *Listeria monocytogens* (29 days) and *Campylobacter jejuni* (438 days) in a batch-fed anerobic digestor operating at 28°C (Kearney et.al, 1993b). Cholera bacteria die off more rapidly and were below detectable limits within 20 days (Kunte *et al*., 2000). *Streptococcus faecalis* persisted longer than all the pathogenic bacteria tested (Kumar *et al*., 1999) and will thus serve as a functional conservative indicator for pathogenic bacteria.

However, coliphages were found to be more capable of surviving than faecal coliforms and faecal streptococci under mesophilic anaerobic conditions in a full-scale biogas plant that mainly digested cow manure.

Typical malfunctioning

The biogas reactor is efficient but sensitive, and must be carefully built and operated. To prevent dangerous leaks of gas, the gas piping must be well constructed and sealed. The gas lines also collect moisture, and the water must be drained out otherwise it will cause blockages of the gas flow.

To prevent clogging, the connecting pipe from the toilets to the reactor should slope of at least 6o degrees, and no chemicals or harsh soaps should be added.

Exposure pathways

The user can be exposed to the gas if there are leaks. Contact with the slurry is the most dangerous exposure pathway. Workers maintaining the reactor may accidentally be exposed to both untreated and treated sludge. Because the slurry is free-flowing (and does not need to be emptied manually), it is often allowed to pour out of the reactor into an open holding tank or directly onto the land, sometimes directly to agricultural areas. Even if partially treated the slurry is unsafe and any type of exposure (including using it as fertilizer for crops) should be avoided. If the reactor is well buried, the user should not come in contact with the reactor or risk any danger of falling in.

Epidemiological and health risk evidence

Feed materials that have been pasteurized (treated at temperatures above 70°C) will not pose any significant health risk while the accidental ingestion of small amounts of mesophilic treated sludge and especially with limited hydraulic retention time can result in significant infection risks. Also, the microbial health risks associated with the inhalation of gas from a biogas plant is negligible compared to the handling of feed material and product of the reactor (Vinnerås *et al*., 2006).

A well-designed and operated slurry management technology should reduce the risk to most users, except the person (people) who are transferring the sludge to the field.

Risk mitigation measures

Biogas plants operating under mesophilic conditions should, at best, be used as pre- or post treatment technologies and not as the only technology for excreta treatment.Temperature and residence time are critical to the performance of the biogas reactor. To assure that safe products are obtained from the digester, the sludge has to be heated to at least 50 - 55°C. In situations where both the heating and hydraulic retention time cannot be fulfilled, it is important that product is treated further before disposal.

Risk summary
Number of exposed: 1-10 depending on the number of users

Frequency of exposure: HIGH-MEDIUM for the user, depending on the slurry production and outlets., LOW-MEDIUM for the community, depending on slurry containment

Level of risk: MEDIUM for the user, and for the community

Technology	Barrier efficiency and robustness			Exposure pathways	Likelihood of occurrence	Diarrhoea Risk				Helminths Risk				Risk Management
	Input pathogens	Treat-ment	Typical malfunction			User	Worker	Farmer	Community	User	Worker	Farmer	Community	*assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Open defeca-tion	Viruses	0		Ingestion of excreta (E1)										-should not be practiced -if practiced, area should be clearly marked and contained -area should be away from water source
	Bacteria	0		Dermal contact (E2)										
	Protozoa	0		Contact with flies (E3)										
	Helminths	0		Surface water contami-nation (E5)										
Bucket latrine	Viruses	0	- overflowing/ leaking -tipping over -not cleaned regularly	Ingestion of excreta (E1)										- empty regularly -locate and fix bucket firmly and contain in a stable box -clean and disinfect bucket after emptying
	Bacteria	0		Dermal contact (E2)										
	Protozoa	0		-contact with flies (E3)										
	Helminths	0		Contact with overflow-ing/leaking contents (E6)										
Single pit	Viruses		-excessive flies and mosquitoes -built in unsuit-able area -unstable and prone to collapse	Dermal contact (E2)										-install vent -circular with lining -site where there is a low groundwater table, low risk of flooding
	Bacteria			Contact with flies (E3)										
	Protozoa			Falling into pit (E7)										
	Helminths			Surface/groundwater contamination (E5)										
				Contact with overflow-ing/leaking contents (E6)										
Single VIP	Viruses		-excessive flies and mosquitoes -built in unsuit-able area -unstable and prone to collapse	Dermal contact (E2)										- keep toilet room dark - ensure vent is high enough and in direct sun-light -uncover toilet to allow airflow -circular pit with lining -site where there is a low groundwater table, low risk of flooding
	Bacteria			Contact with flies (E3)										
	Protozoa			Falling into pit (E4)										
				Surface/groundwater contamination (E5)										
	Helminths			Contact with overflow-ing/leaking contents (E6)										

Figure 8: Collection and storage/treatment: exposure scenarios and health risk levels

Technology	Barrier efficiency and robustness: Input pathogens	Treat-ment	Typical malfunction	Exposure pathways	Likelihood of occurrence	Diarrhoea Risk: User	Worker	Farmer	Community	Helminths Risk: User	Worker	Farmer	Community	Risk Management
														*assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Double alternating dry pits	Viruses	4	-material is too wet -insufficient oxygen for aerobic degradation	Ingestion of excreta (E1)										-install vent -addition of organic/ bulking material -locate away from surface water
	Bacteria	6		Dermal contact (E2)										
				Contact with flies (E3)										
	Protozoa	1-2		Contaminated ground-water/surface water (E5)										
	Helminths	1-2		Contact with overflowing and leaking content (E6)										
Double dehydration vaults	Viruses	4	-Faeces are too wet and do not dry	Ingestion of dehydrating material (E1)										-water-tight chambers away from surface water -additional desiccation material
	Bacteria	6												
	Protozoa	1-2		Dermal contact (E2)										
	Helminths	1-2												
Composting latrines	Viruses		-anaerobic conditions, inadequate temperature	Ingestion of composting material (E1)										-leachate collection system, separation of urine, installation of vent, better ratio of organics: excreta
	Bacteria			-Dermal contact (E2)										
	Protozoa			Contaminated ground-water/surface water (E5)										
	Helminths													
Twin pit pour flush	Viruses		-Filling is too rapid -liquid does not infiltrate -Liquid infiltrates into groundwater	Ingestion of stored material (E1)										-design based on soil type (proper site analysis) -better design capacity (i.e. amount of water used, number of users -separate collection of dry cleansing material -appropriate pit lining
	Bacteria			Dermal contact (E2)										
	Protozoa			Contact with flies (E3)										
				Contaminated ground-water/surface water (E5)										
	Helminths			Contact with overflowing and leaking content (E6)										

Figure 8 (cont): Collection and storage/treatment: exposure scenarios and health risk levels

Technology	Barrier efficiency and robustness			Exposure pathways	Likelihood of occurrence	Diarrhoea Risk				Helminths Risk				Risk Management
	Input pathogens	Treat-ment	Typical malfunction			User	Worker	Farmer	Community	User	Worker	Farmer	Community	*assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Conven-tional and improved septic tanks	Viruses	0.5	-overflowing/ leaking -inadequate treatment	Ingestion of wastewa-ter (E1)										- proper pre-treatment (grease trap) -separate collection of dry cleansing material -avoid use of harsh chemi-cals -construct chamber to be water-tight
	Bacteria	1		Contaminated ground-water/surface water (E4)										
	Protozoa	2												
	Helminths	2		Contact with overflowing and leaking content (E6)										
Biogas reac-tors	Viruses		-faeces clog urine collection pan -no provi-sion for anal cleansing water -poor construc-tion makes it difficult to clean	Ingestion of digested material (E1)										- containment technology for effluent - high quality reactor con-struction (gas and water tight) - high quality piping con-struction for gas -regular use of gas (to pre-vent excessive accumula-tion)
	Bacteria			Contact with overflowing and leaking content (E6)										
	Protozoa													
	Helminths			Inhalation of aerosols (E 5)										
Urine stor-age tank	Viruses		-insufficiently sized tank -poorly located tank, with improper seal-ing -poorly con-nected to UDDT or urinal	-inhalation of urine aerosol (E4)										-high quality concrete or plastic construction that will not crack -tight fitting lid -connection from urine source should be under liquid surface
	Bacteria			-contact with overflow-ing/leaking contents (E 6)										
	Protozoa													
	Helminths			Ingestion of stored urine (E8)										

Figure 8 (cont): Collection and storage/treatment: exposure scenarios and health risk levels

CONVEYANCE TECHNOLOGIES

Introduction

Depending on the collection and storage/treatment technology, emptying can either be done manually or through different mechanical means. It further relates to pipe conveyance with water in pipes. A collection and storage/treatment technology helps prevent faecal pollution of household surroundings.

The manual emptying of faecal material from toilet pits most often gives the highest exposure to faecal pathogens of the conveyance alternatives. Proper protective measures should always be taken and should always be complied with if the task is commissioned to private or municipal enterprise.

- Always wear protective clothing (overalls), disposable gloves, masks and boots
- Always wash hands with soap after the emptying exercise
- Always restrict the clothing for the specific work purpose and never use the clothes in households, markets or public places.
- Emptying equipments should further be properly cleaned after usage and reserved solely for the purpose of emptying.

Hygiene and Behaviour

Hygiene and behavioural aspects relate to the full chain of activities from emptying pits, collection chambers or tanks and transporting the content to disposal sites.

Workers need to adhere to good hygiene habits while working and understand how contamination may occur and how this relates to their work. An employer or contractor normally has a formal responsibility to ensure that hygienic precautions and instructions are followed, and that these are included in proper management procedures.

In congested peri-urban areas and city centers the accessibility into the area for motorized emptying and transportation is often limited or not possible. In such conditions, manual emptying and transportation may be the only option. Land to empty the wastes are also unavailable or highly limited in these congested areas.

Behavioural aspects also relate to the individual owners of toilets and their willingness to take on the emptying practices or employ contractors to do the work. Their willingness is then a function of the labour and costs involved as well as the perceived offence in relation to smell, appearance and risk of contracting disease. From a hygiene perspective the risk is always greater the less treatment that has been applied. Thus, a bucket latrine or a single pit always poses a greater risk than if the material has been stored for a prolonged period (e g twin pits, in dehydrating vaults or likewise). Similarly the risk is always greater if no treatment has been applied compared to treatment that then poses less risk (like pH elevation with lime and ash, thermal treatment or solar irradiation). Independently individual reasons and perceptions also play a role in this regard (Box 10).

Factors relate both to cost and tradition. It is cheaper with manual emptying than with motorized emptying and transportation.

In poor communities, workers have little or no protective gear and do not follow basic hygiene and safety

Box 10: Objections to emptying the UDDT vault by individual toilet owners.

- We do not want to work with excreta!
- The municipality must take the excreta away!
- It is not easy to dispose of the contents of the vault!
- The emptying of the vault is not easy!
- Nobody is willing to empty the vault and handle the faeces!
- We will hire people to empty the vault!

Message: The individual behaviour may often refer to practicalities, costs or a feeling that the task is somebody else business.

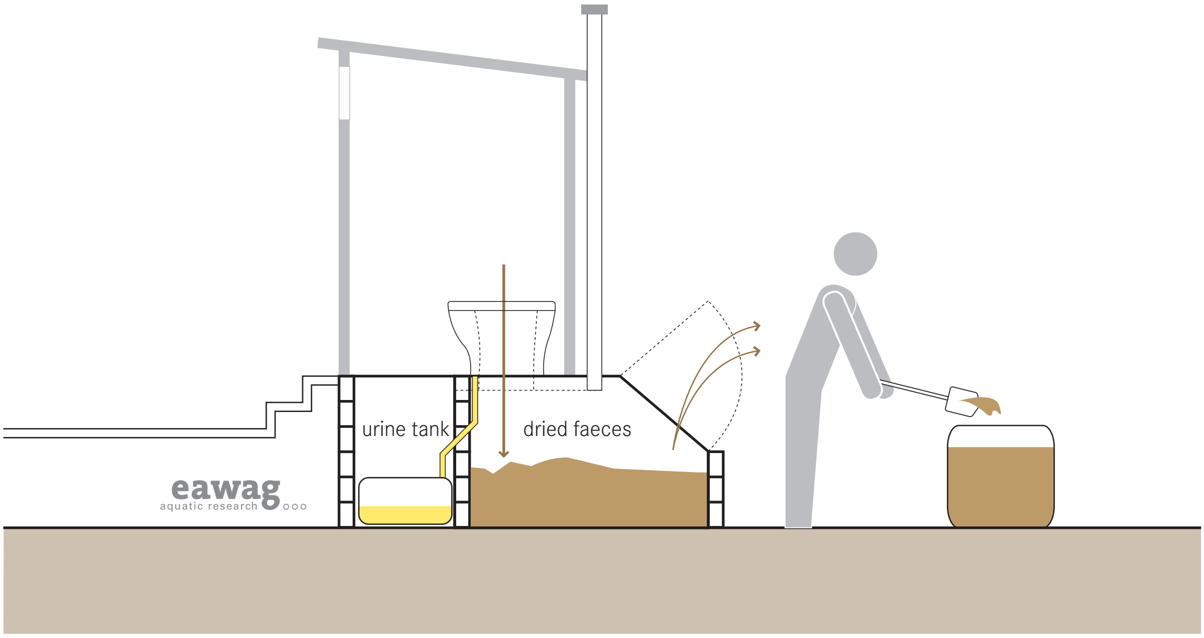
Source: Duncker *et al.*, 2006.

precautions (exposure relates both to the direct work as well as secondary exposure during subsequent eating and drinking).

Those involved in manual emptying and transportation are directly exposed to disease causing pathogens, where poor hygiene habits as well as poor safety measures exacerbate the exposure situation. Additionally, entire communities may be exposed through spillage on the ground where the job is carried out or along the transportation path.

In some societies direct contact and work with faecal material are stigmatized or refered to specific tribes, both positively and negatively. The 'Bhaca' ethnic group in South Africa are eagerly sought after in the whole of the Republic as attendants at sewage treatment works (Mbambisa and Selkirk, 1990), while particular ethnic group such as the 'Munchi' peoplein Cameroon, and Dalits of India handle night soil more as part of a tradition or for economic reasons.

Human-Powered Emptying and Transport



Technology description
Human-powered emptying and transport refers to the different ways in which people manually empty and/ or transport sludge, septage or urine. Human-powered emptying of faecal material and transport from pits and tanks can include several different means and technologies:

- Jerry cans or similar for the transportation of urine (plastic containers containing approx. 20 L).
- Buckets and shovels used for emptying Dehydration Vaults, Fossa Alternas or Twin Pits for Pour Flush. This would also apply to the transportation of full buckets from a bucket latrine.
- A hand-pump specifically designed for sludge (e.g. the Pooh-Pump or Gulper) which can be used for septic tanks or lined pits. This is similar to a water pump- with a handle on top and a spout on the side- but is portable and much wider to facilitate the movement of thick sludge.

A portable, manually operated pump (e.g. the MAPET: Manual Pit Emptying Technology) which can be used for pits or septic tanks. This is a hand-wound pump connected to a hose and a chamber where the sucked up sludge is collected.

Exposure pathways

Risk groups

U W C

Typical malfunctioning
The malfunctions associated with manual emptying technologies are mainly associated with the pits, chambers or tanks that are being emptied and to a lesser extent the emptying itself. Additionally, garbage wrongly deposited in the pit, like plastics, rags, etc.

will add to the difficulties in emptying and can in addition force the workers to manually remove these. Urine collection containers may be broken or leak. The MAPET alternative of manual emptying is partly mechanical and will require maintenance, new parts, and occasional repair.

Exposure pathways

Emptying and transportation of urine storage containers from UDTs can result in accidental contact and subsequent ingestion of small amounts of urine.

Manual emptying and transport of the contents of bucket and pit latrines is an unpleasant task and a significant pathway for disease transmission through accidental direct contact and secondary oral transmission.

Direct contact with excreta is likely to occur when the emptied material is transported to the disposal site. Compared to the pit latrine, Manual emptying of Dehydration Vaults, Fossa Alternas and Twin Pits for Pour Flush is less unpleasant and pose less risk than from pit latrines as the material is either relatively decomposed or treated on-site prior to emptying. During manual transport the waste can spill over and contaminate the surrounding environment and expose the community members, especially children. A typical case of pit latrine emptying highlighting various potential exposure pathways is presented in Box 11. Manual emptying of bucket latrine contents will also result in significant exposure of untreated excreta with subsequent high health hazards.

Dried faeces from double vault latrines must be removed with a shovel. When dry and powder-like, persons emptying and transporting the vault material may also be exposed to airborne particles.

Epidemiological and health risk evidence

Excess infection risk of excreta related diseases have been reported among workers engaged in the emptying of pit and bucket latrines.

Rulin (1997) showed that farmers emptying pit and bucket latrines were 1.9 times more likely to be infected with Hepatitis A virus compared to workers engaged

Box 11: Manual emptying of pits in Kibera (Adapted from Eales, 2005)

Kibera, the slum in Nairobi' with more than 500,000 residents, lies on less than 4% of the city surface area. It is said to be the most densely populated settlement on the continent. Residents lives, mainly as tenants, in rows of single-room wattle-and-daub or corrugated iron structures. Internal road access is virtually absent; dwellings are linked by narrow alleys. Two sewer lines pass through the settlement, but most residents use simple pit toilets, shared by many households. A few public toilets/community ablution blocks exist.

Regular pit emptying are critically important in this context of high residential density and extreme loading on individual toilets. There are some mechanical emptying services, but parts of the settlement are simply inaccessible to desludging vehicles. Manual pit emptying is therefore essential in Kibera, but this work is stigmatised and poorly paid, and those who do the work are vulnerable to physical attack and disease.

In Kibera, manual pit emptiers work at night, by torchlight, sometimes standing waste-deep in human excrement. The emptiers had no protective clothing, gloves, boots or face-masks. They sometimes use plastic bags over their hands instead of gloves and shovels. One man showed us the cuts on his hands and feet from glass and metal in the sludge.

The job is generally done by men, working in teams of two to four. Sometimes they begin by pouring paraffin into the pit to override the smell of the excreta. The waste is removed using a bucket on a rope, and the contents are then transferred to a 100 litre drum. Thereafter, the drum may have to be carried 50 or 100 metres to a handcart, which is used to wheel the waste to a disposal site. The waste is disposed of by emptying it into the sewer system (where there is no structure obstructing the manhole cover), dumping it in a stream, or transferring it to a mechanical desludger for disposal elsewhere. Some spillage is inevitable, and it is the combination of smell and spillage which can prompt assault by local residents.

Where the pit waste has solidified, it can be liquefied and stirred and then removed with a bucket. Where it has hardened ("it gets like concrete," said one pit emptier) it must be dug out with a shovel. Here the pit emptier stands inside the pit, filling a bucket on a rope which then gets hauled up and emptied into the drum.

Message: The description illustrate the common direct risks of exposure that the workers are exposed to and the indirect contamination and subsequent exposure that results for community members and downstream communities.

in non-excreta related activities. Hygiene education reduced the risk. Workers with some hygiene education were 5.6 times less likely to be infected with Hepatitis A compared to those with no hygiene education.

The health risk associated with the accidental ingestion of urine, compared to other exposure pathways is generally low; but may be of concern for viruses. (Höglund, 2001).The infection risk associated with the accidental ingestion of urine stored for 1 and 6 months was generally low for all the pathogenic organisms except rotavirus.

In developing countries the health risk for Hepatitis A and also bacterial infections associated with the ingestion of unstored urine may be high due to a higher incidence in the population compared to Europe.

Risk mitigation measures.
People who empty and transport excreta should never enter the pits and tanks. Long handled shovels, long suction hoses and other implements should be used when sludge or excreta is difficult to access.

Personal protection equipment as well as good hygiene practices is necessary in manual emptying and transport of excreta. Boots, gloves, clothing that covers the whole body, and when possible, a face mask are essential, as are washing facilities and practices. Hand disinfectants are sometimes used.

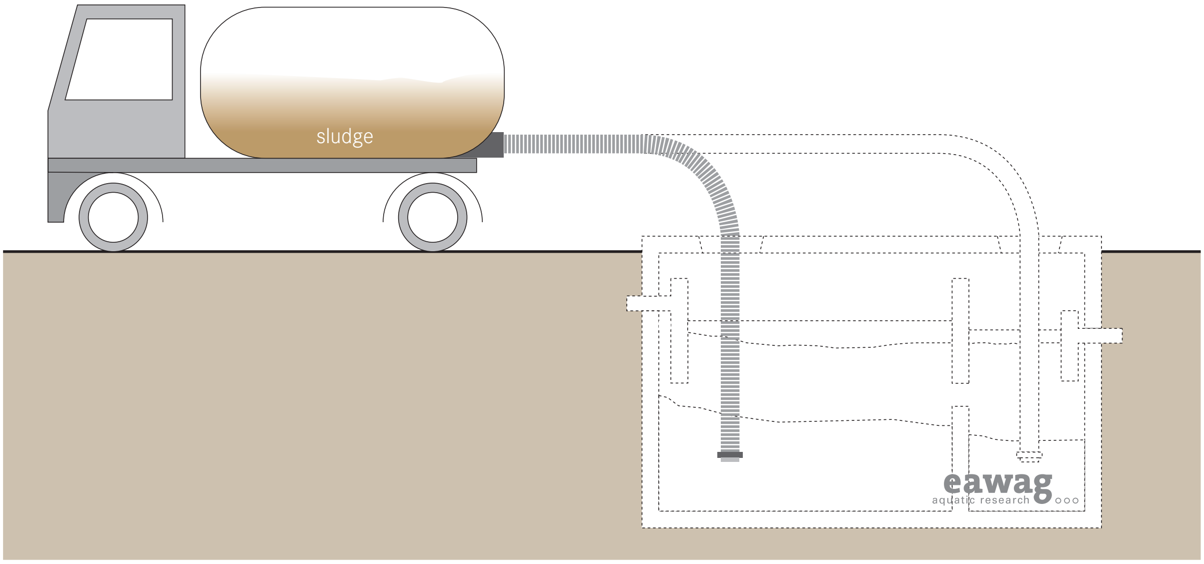
Technologies that are based on long-term storage on-site are preferable from a health point-of-view. For example, the Fossa Alterna presents a lower infection risk compared to pit latrines and would be a safer alternative in areas with frequent pit emptying. Where there is enough land for latrine construction, single pits should be covered when they are full, and be left for about 2 years for their contents to degrade before being emptied.

Risk summary
Number of exposed: 1-3 workers

Frequency of exposure: HIGH for the worker, LOW for the user, MEDIUM for the community (depending on how often emptying takes place and secondary exposure)

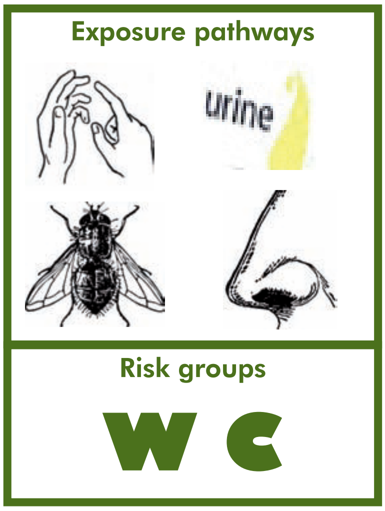
Level of risk: HIGH for the worker, MEDIUM for the user who can be exposed during the process, MEDIUM for the community who may be exposed during transport. HIGH if indiscriminate dumping occurs.

Motorized Emptying and Transport Technologies



Technology description
Motorized Emptying and Transport refers to a truck or a vehicle equipped with a motorized pump and a storage tank for emptying and transporting faecal sludge, blackwater or urine. A worker is required to operate the pump and manoeuvre the hose, but does not lift or transport the sludge.

A pump is connected to a hose that is lowered down into a tank or pit and content is pumped up into the holding tank or the truck. Generally, the storage capacity of a vacuum tanker is between 3000 and 10,000 L. Multiple truckloads may be required to fully empty a large tank or pit.



Typical malfunctioning
Vacuum trucks are expensive and are seldom locally manufactured. New and spare parts may be difficult to find locally.

As with manual emptying techniques, the problems associated with the mechanical pumps are mostly due to blockages which originate in the pits or tanks that are being emptied. Access is often a problem.

Exposure pathways
For the worker, Motorized Emptying and Transport is much safer than manual emptying, though it still poses many opportunities for exposure to pathogens. The truck operator may be sprayed with sludge and the surrounding may accidentally be contaminated during the emptying operation. Furthermore, the access before emptying involves several manual operations in opening and closing the collection chambers and connecting hoses and pumps, which involve direct contact and exposure. The example in Box 12 accounts for emptying and transport in Tamale, Ghana and the potential exposure pathways for pathogenic organisms and risk groups involved. Workers, as well as their family members, may be exposed. It further points out the needs for proper supervision and management that are lacking. Community members may also be at risk due to spillage at the emptying site and along the streets during transportation of the sludge to the disposal.

Epidemiological and health risk evidence
Significant infection risk may result from the exposure pathways as exemplified in the Box 11 both for the workers, their families and community members.

Risk mitigation measures
People who empty and transport excreta should never enter into pits and tanks. Long handled shovels, long suction hoses and other implements should be used when sludge or excreta is difficult to access.

As with manual desludging and transport, personal protection equipment is also essential during motorized emptying and transport for health risk reduction. Boots, gloves, clothing that covers the whole body, and when possible, a face mask should be used. The work should be done within a supervision and management structure and the workers educated on the potential health risk associated with the activity and given practical guidelines on risk reduction measures. This should also include secondary effects on community members and families.

Risk summary
Number of exposed: 1-5 workers

Frequency of exposure: HIGH for the worker, LOW for the user, MEDIUM for the community (depending on how often emptying takes place in the town) and for family members.

Level of risk: HIGH for the worker, MEDIUM for the user who can be exposed during the process, MEDIUM for the community who may be exposed during emptying and transport, as well as for family members.

Box 12: 'We drink soda'-the perception of health precaution by sludge workers.

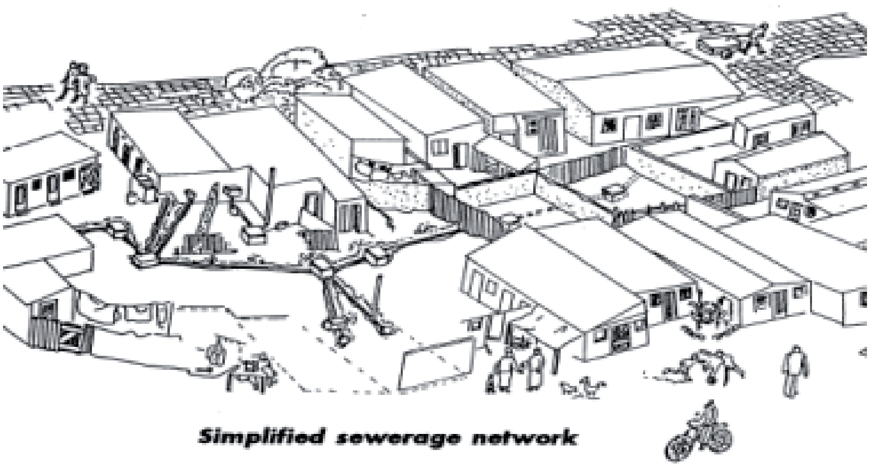
Tamale (population approx 250,000 people) located in Northern Ghana mainly has on-site toilet facilities. The emptying is carried out with suction trucks by the local Authority's Waste Department Unit, the Prison Service and Private companies. The average volume of the suction truck tanks is 3000L. Desludging with the suction truck is done for a fee. A team of three workers are mainly involved; the driver and two labourers. None of them usually wear protective clothes. They claim that protective clothes slow down their work and that the activity does not involve any significant health risk except gas emitted from the tanks and the intense odour associated with it. Any disease transmission is not considered.

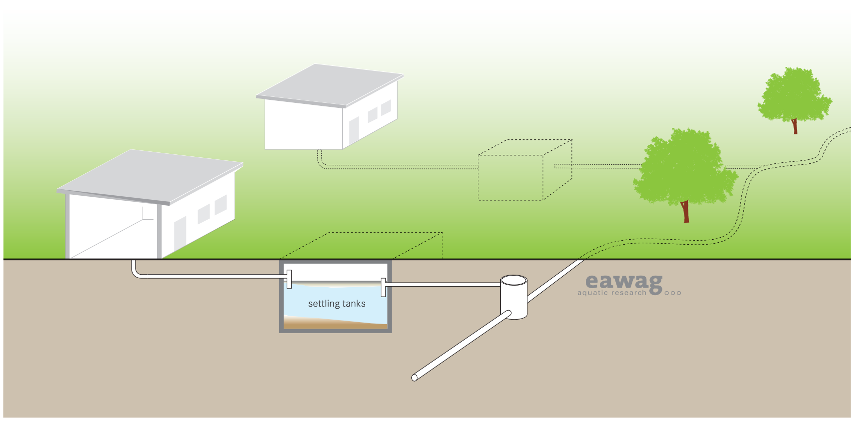
The driver operate the vacuum pump while the two labourers remove/break the slab on the septic tank, and then put the hose connected to the vacuum tank into the sludge tank. Following desludging, the soiled hose is washed with water and broom by the two labourers with their bare hands within the compound of the toilet facility where children also play. Thereafter, they wash their hands with water without soap. The filled tank is driven through the streets of Tamale to the outskirt of the town where the content is discharged at a waste stabilization pond for further treatment (mainly in the wet season) or on farms for soil fertilization (in the dry season).

After the day's desludging exercise (i.e., after several tanks have been desludged), the workers drink soda. This "*helps to get rid of the gas and odour they have accumulated in their stomachs during the days work*" they claim. They do not change their working clothes, but go home in them. At home, the soiled clothes are washed by the girl child or wife in containers that are also used for fetching drinking water.

Conclusions: From a health perspective the activity both involve obvious direct exposure risks for the workers, potential exposure of community members due to spillage and exposure of family members due to the clothing practices. It is obvious that this municipality/company driven activity is lacking a clear supervision/management and that several of the potential risks could easily be counteracted by risk mitigation, "*We drink soda*" is the individual perception that is far from the management solution!

Simplified and Solids-Free Sewer Technologies



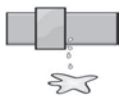
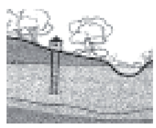


Technology description
Simplified and Solids-Free Sewers are versions of conventional sewers that are generally less costly, of a smaller diameter than conventional sewers and with decentralized operation.

The smaller diameter pipes are normally laid at a shallower depth and at a flatter gradient than conventional sewers. Because the sewers are mainly communal, they are often referred to as condominial sewers. At times, the community connects to the main sewer system line if existing.

A solids-free sewer is a network of small-diameter pipes that transport solids-free or pre-treated wastewater (such as septic tank or settling tank effluent) to a treatment facility for further treatment or to a discharge point. Solids-free sewers are alternatively called settled small-bore, small diameter, variable-grade gravity or septic tank effluent gravity sewers.

Exposure pathways

Risk Groups

W C

A solids-free sewer network requires that the wastewater is pre-treated by an interceptor, septic or settling tank to remove the settleable particles that could clog small pipes.

Typical malfunctioning
Simplified and solids-free sewers require more maintenance than conventional sewers. The homeowner, a CBO or a privately company would most often be responsible for the maintenance and to counteract any eventual clogging. The maintenance is crucial in counteracting malfunctions. An interceptor tank must precede each household connection so that solidsclogging of the sewer is reduced.

Due to the shallow construction heavy vehicles or accidents could crack or break small-diameter sewer pipes, resulting in leakages.

Exposure pathways
In theory the users should never come in contact with the sewer or the effluent that it carries. The interceptor tank should be regularly emptied of the settled solids and sludge, but that can be performed by a professional emptier. Exposure will occur during maintenance work and as a result of breaks or leakage

Epidemiological and health risk evidence
There is currently a lack of health risk evidence for this technology. Future research should focus on the vulnerability of these systems during extreme events as well as frequency of leakage and breaks and their relationships to exposure of communities. When the sewer is water tight, it poses little risk to either the environment or to humans or animals.

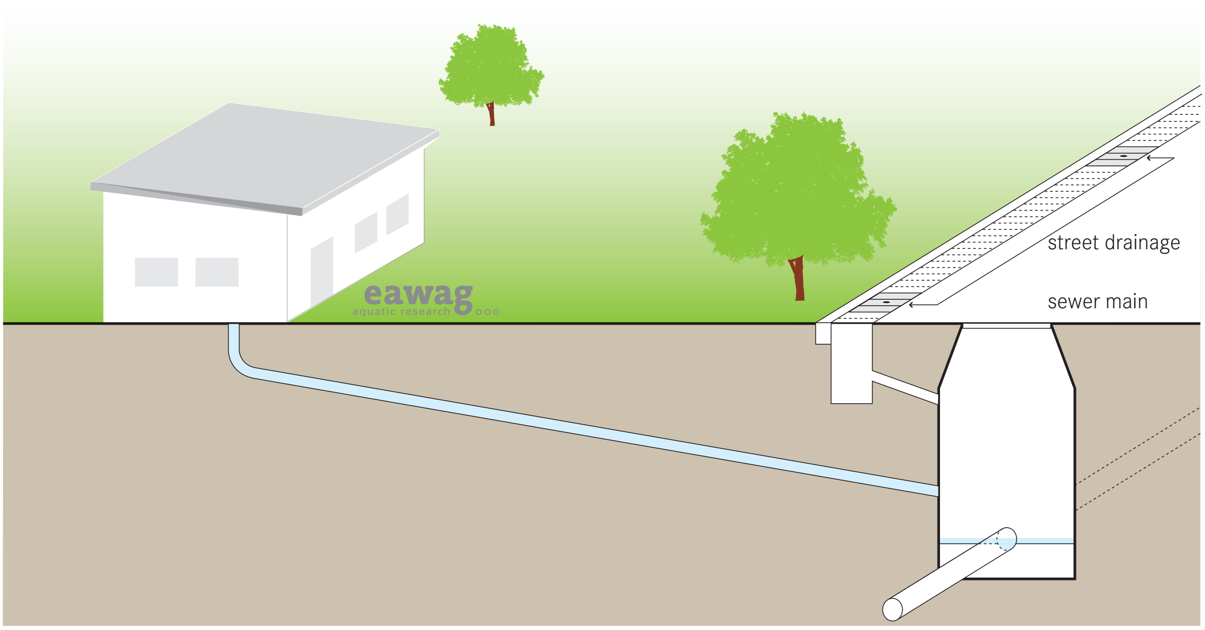
Risk mitigation measures
Risk mitigation relates to the prevention of cracked and/or leaking pipes. Parts that need to pass through areas where heavy equipment or vehicles pass should be reinforced. If maintenance is needed, the worker should use appropriate personal protection and hygiene measures.

Risk summary
Number of exposed: Maintenance workers

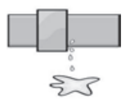
Frequency of exposure: LOW for the worker; LOW for communities (breaks)

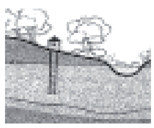
Level of risk: MEDIUM for the maintenance workers, MEDIUM for communities during breaks.

Conventional Gravity Sewers Technologies



Exposure pathways





Risk groups

W C

Technology description

Conventional Gravity Sewers are large networks of underground pipes that convey blackwater, greywater and stormwater from individual households to a centralized treatment facility using gravity (and pumps where necessary). Typically, the network is subdivided into primary (the main sewer lines), secondary and tertiary (sewer lines at the neighbourhood and household level). This type of sewer does not require pre-treatment or storage of wastewater. Therefore, the sewer must be designed to maintain self-cleansing velocity (i.e. a flow that prevent solids to accumulate) generally 0.6-0.75 m/s. A constant downhill gradient must occur along the length of the sewer.

Typical malfunctioning

Most gravity sewers are overdesigned and rarely clog. Malfunction occurs if there is insufficient water or an insufficient gradient. Manholes (e.g. access points) need to be positioned at gradient changes and junctions to allow inspection and maintenance. When pumps are needed they may be prone to failure without proper maintenance.

Exposure pathways

Conventional sewers are normally maintained by specialized city workers. With proper management "risk-at-work" is limited. Residents and community members should never come in contact with the wastewater carried by sewers. Rats and other vermin occasionally inhabit sewers and are potentially secondary transmitters of disease.

Secondary effects may relate to the proximity of the sewer network if laid in the same trenches as water distribution lines. Secondary cross-contamination of drinking water may occur where the sewer lines are leaking and when an overpressure is not maintained in the drinking water lines. Cross-contamination is further more likely in the events of flooding and during maintenance of the sewer network. Schulz and Kroeger (1982), for example, found a higher level of *Ascaris* eggs in the vicinity of inspection chambers due to a deficient sewer and sewage overflow over the streets in the rainy season. They concluded that the deficient sewerage network could expose the population to a much greater health hazard compared to if they had simple but clean latrines.

Leaking sewers can also contaminate groundwater.

Epidemiological and health risk evidence
Excreta related diseases can be reduced significantly with a sewer network, by reduced direct exposure to pathogens in the public domain.

In a cross-sectional study performed in the city of Salvador, Brazil, children (5-14 years) living in areas without sewers were 1.7 and 1.2 times more likely to be infected with *Ascaris* and *Trichuris* compared to those living in areas without. The relative risk for hookworm infection was 2.7 times higher for the children living in the sewerless area compared to those with sewers. This shows the importance of a sewer network as a barrier preventing direct contact within the public domain.

An expansion of the sewer network to more households also decreased the prevalence of diarrhoea disease among children (Barreto *et al*., 2007). After the sewer intervention diarrhoea prevalence was reduced by 21 per cent (95 per cent CI: 18 - 25 per cent)-from 9.2 (9 – 9.5) days per child/year before the intervention to 7.3 (7.0 – 7.5) days per child/year.

However, significant health risks can result from sewers if they are not properly constructed and well maintained. In Gaza, children (0-5 years) in an area with a poorly constructed piped sewerage were four times more likely to be infected with *Ascaris* during winter flooding compared to those in areas without a sewer network. The sewered streets were more contaminated with Ascaris than the unsewered streets (Smith, 1993).

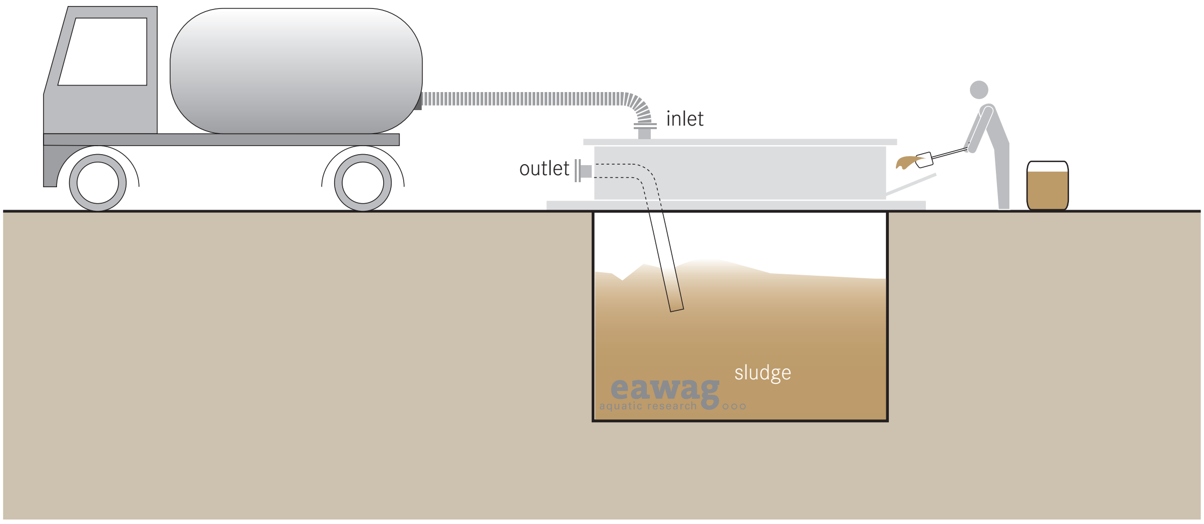
Risk mitigation measures.
Sewer lines should have manholes with heavy lids to prevent entry. Sewer leaks result from a combination of cracked pipes, opened or displaced pipe joints, root intrusion, pipe deformation, sewer collapse, reverse gradients, silting, blockages, poorly constructed connections and abandoned laterals left unsealed (Misstear *et al*., 1996). Pipes should be laid below ground and so that physical damage does not occur. Separate pipes for surface water drainage reduce the risks of overflow, as do periodical cleaning and monitoring for blockages.

Risk summary
Number of exposed: 1-several workers

Frequency of exposure: HIGH for the worker, LOW for the user, LOW for the community (depending on how often breaks occur)

Level of risk: MEDIUM for the worker (due to precautions at work), LOW - MEDIUM for the community (due to faults and proper maintenance)

Transfer and Sewer Discharge Station Technologies



Technology description

Transfer and Sewer Discharge Stations are points where sludge can be withheld when it cannot be easily transported to a specialized treatment facility. Transfer stations normally are underground holding-tanks that must be emptied by vacuum trucks, whereas a sewer discharge station is a point along the main sewer line that can be legally accessed. The sludge that is emptied into the transfer station is thereafter flowing to a centralized treatment facility through the sewer. By providing transfer and/or sewer discharge stations, sludge is prevented from being dumped illegally. It further reduces the travel distance to a dedicated facility.

Typical malfunctioning

Transfer stations must be emptied regularly to prevent overflow, and sewer discharge stations may require pumps to enhance the sludge flow.

If the opening or access point is not convenient or well-designed, the potential for spills and poor transfer is enhanced. The access point for both mechanical and manual emptying must be taken into account to minimize spillage and contamination of the surrounding grounds.

Exposure pathways

The area around the station should be well maintained to prevent smell, flies and direct contact. Spillage during dumping sludge at the station may otherwise become an exposure point in the area.

Epidemiological and health risk evidence

So far, no study has assessed the health risk associated with either of the two technologies.

Risk mitigation measures.

The stations should be kept clean, minimize spill and be designed for easy access. Workers should be appropriately protected. Since a goal of the stations is to minimize transport distance they normally are within the urban centres. There, they should be properly fenced and not in direct vicinity of homes.

Risk summary
Number of exposed: variable- depending on the number of workers using the facility

Frequency of exposure: HIGH for the worker, LOW for the community (depending on siting and site protection)

Level of risk: HIGH for the worker, LOW for the community (depend on siting).

Technology	Barrier efficiency and robustness			Exposure pathways	Likelihood of occurrence	Diarrhoea Risk				Helminths Risk				Risk Management
	Input pathogens	Treat-ment	Typical malfunction			User	Worker	Farmer	Community	User	Worker	Farmer	Community	*assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Human-powered emptying and trans-port	Viruses	NA	-spills and contact with excreta are inevitable as part of this work (the risk depends on the material) -worst case is entering or falling into a pit	Ingestion of material from bucket (E1)										-personal protection, including boots, gloves, overalls and a face mask -washing hands (and body) after emptying activities -washing equipment (e.g. shovel) after emptying activity
				Ingestion of material from pit and VIP pit (E1)										
				Ingestion of stored material from alternating dry pit (E1)§										
	Bacteria	NA		Ingestion of material from dehydrating vaults(E1)§										
	Protozoa	NA		Ingestion of composted material (E1)§										
				Ingestion of stored material from pour flush pit (E1)§										
	Helminths	NA		Ingestion of material from septic tank (E1)										
				Ingestion of digested biogas reactor material (E1)										
				Inhalation of urine aerosol (E.4)										
				Ingestion of urine (8)										
				Inhalation of aerosol from biogas reactor (E4)										
Motorized emptying and trans-port	Viruses	NA	-spills and contact with excreta are inevitable as part of this work -worst case is entering or falling into a pit	Ingestion of material from pit and VIP pit (E1)										-personal protection, including boots, gloves, overalls and a face mask -washing hands (and body) after emptying activities -washing equipment (e.g. shovel) after emptying activity
				Ingestion of material from septic tank (E1)										
	Bacteria	NA		Inhalation of urine aerosol (E 4)										
	Protozoa	NA		Ingestion of urine (8)										
	Helminths	NA		Ingestion of digested biogas reactor material (E1)										

Figure 9: Collection and storage/treatment: exposure scenarios and health risk levels

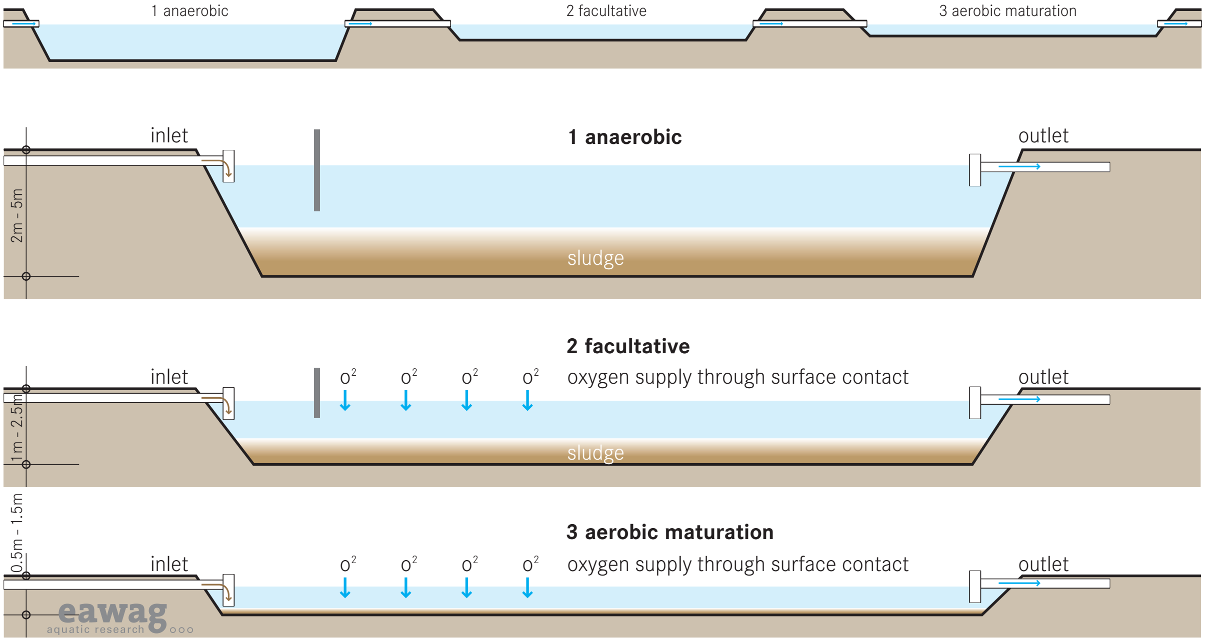
Technology	Barrier efficiency and robustness: Input pathogens	Treat-ment	Typical malfunction	Exposure pathways	Likelihood of occurrence	Diarrhoea Risk: User	Worker	Farmer	Community	Helminths Risk: User	Worker	Farmer	Community	Risk Management
Simplified and sewer Technologies	Viruses	NA	-fats, grease, garbage etc may clog the sewer and must be removed manually -the sewer is broken or cracked and leaks	Ingestion of wastewater (E1)										-efficient pre-treatment and screening with grease trap -proper depth and location of sewer to prevent contact
	Bacteria	NA		Contaminated groundwater/surface water (E5)										
	Protozoa	NA		Contact with overflowing/leaking contents (E6)										
	Helminths	NA												
Conventional Gravity Sewers	Viruses	NA	-sewer is broken or cracked and leaks	Ingestion of wastewater (E1)										-efficient pre-treatment and screening with grease trap -proper depth and location of sewer to prevent contact
	Bacteria	NA		Ingestion of contaminated groundwater/ surface water (E5)										
	Protozoa	NA												
	Helminths	NA		contact with overflowing/leaking contents (E6)										
PTransfer and Sewer Discharge Station	Viruses	NA	-the opening is poorly located, difficult to access and results in spills and poor sludge transfer	Ingestion of sludge (E1)										-good design to facilitate sludge transfer -located conveniently for emptiers but not too close to residential area
	Bacteria	NA		Inhalation of aerosols (E4)										
	Protozoa	NA		Contact with overflowing/leaking contents (E6)										
	Helminths	NA												

(SEMI)-CENTRALIZED TREATMENT TECHNOLOGIES

Introduction

(Semi-) centralized treatment technologies are normally designed to accommodate increased volumes of waste and provide improved removal of nutrients, organics and/or pathogens than household-centered collection and storage technologies. The technologies in this section serve large groups of houses, small communities and in some cases, cities. The differentiation between semi-centralized or centralized depends on the design of the technology, the number of people served, and the management model that is employed.

Waste Stabilization Ponds & Aerated Ponds

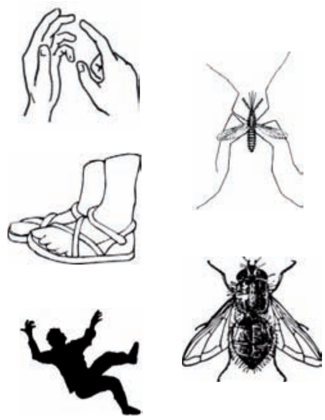


Technology description

Waste stabilisation ponds (WSPs) are used for wastewater treatment in settings where there is sufficient land and with a temperate or tropical climate (Mara, 1997; Horan, 1990). The standard design is a series of ponds: anaerobic; facultative and maturation. The anaerobic pond acts as pretreatment for the reduction of suspended solids and BOD. Anaerobic ponds are dimensioned to have a hydraulic retention time of 1 -7 days and a depth of 2 - 5 meters. The facultative ponds, has a hydraulic retention time of 10 – 40 days and depths of 1 – 1.5 meters. Both aerobic and anaerobic processes, that significantly reduce BOD, take place in the ponds. The final maturation ponds are for the polishing of the wastewater and have a hydraulic retention time of 5 – 10 days and depths of 1 – 5 meters (Faechem *et al.*, 1983). Well-operated waste stabilisation ponds produce high quality effluent with limited health risk. They often have lower operating costs than other alternatives (Mara, 1997).

Aerobic ponds are an alternative used where space is more limited. Aerobic degradation is also more complete than anaerobic. Mechanical aerators can be used to produce aerobic conditions in a deep pond, but will most often need electrical energy to introduce air into the pond.

Exposure pathways



Risk groups

W C

Oxidation ditches are based on a similar concept of open-air treatment. Essentially, an oval canal is used to circulate the water, and in the process aerate it through weirs and/or mechanical aeration. This technology requires more energy inputs.

Input and output products

Wastewater, greywater and/or faecal sludge can be inputs to WSPs. The removal of pathogens is a function of factors including residence time, sedimentation, temperature, sunlight, pH, predation and adsorption. Helminthes and to a lesser extent protozoan oo(cysts) are removed by sedimentation (and will accumulate in the pond sludge) while a main mechanism for viruses removal is by adsorption to solids. Bacteria are mainly removed or inactivated by a combination of factors including temperature, pH, light intensity and dissolved oxygen concentration. In Annex 2, the pathogen reduction efficacy of some waste stabilization pond studies is summarized.

An example is the study by Mahassen *et al*., (2008) from Egypt with anaerobic, facultative and maturation ponds in two series, receiving domestic wastewater. The microbial reduction was approx 80 per cent for *E. coli,* 97 per cent for faecal streptococci, 98 per cent for *Salmonella* and 90 per cent for *Listeria*. Coliphages and rotaviruses were reduced by 50 and 99.7 per cent respectively. Feachem *et al*., (1983) reported a much higher reduction; up to 6 log units of bacteria, 5 log units of viruses and 100 per cent of protozoa and helminths ova. Shuval *et al*., (1986) found that stabilization ponds with a hydraulic retention time of 20 days completely removed helminth ova. Summary maximum reduction values from WHO (2006) is given in Fig 10. This is based on a collation of data from different studies. Depending on the number of ponds in series and operational conditions, stabilization ponds can remove 1- 4 log unit of viruses; 1 -6 log units of bacteria; 1-4 log unit of protozoa and 1-3 log unit of helminths.

In Choconta, Columbia, a waste stabilization pond consisting of two facultative ponds in series found a high variability in the reduction of bacteria indicators (0.3 – 4.7 log units) and viruses (1- 4.6 log units) (Campos *et al*., 2002). Parasite eggs were reduced on average by 94 per cent and 99.9 per cent in the anaerobic and facultative ponds respectively in a Brazilian study. No eggs were found in effluent from the second maturation pond (Stott *et al*., 2003).

Typical malfunctioning

Overloading and hydraulic short-circuiting are typical malfunctions of WSPs. If the pond is under-designed, and/or overloaded, insufficient settling and/or inactivation time for the organisms will result. Similarly, if the pond is poorly designed and influent short-circuits through the pond (the retention time is shorter than the design value), the resulting treatment will be insufficient. Scum, garbage and large particles should be removed from the wastewater prior to entering the pond to prevent malfunction. Invasive species (both plants and micro-organisms) may disrupt the treatment efficiency of the pond. Ponds can become breeding grounds for mosquitoes. Chemical waste may cause inhibition of the anaerobic and aerobic degradation functions.

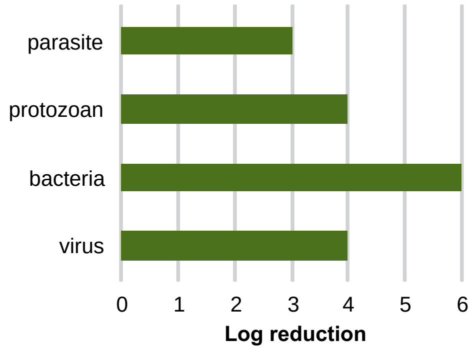


Figure 10: Maximum reduction of pathogens in an optimally functional waste stabilisation pond* (Based on WHO, 2006)

[* May be significantly lower. Depends on type of climate zone, retention time and number of ponds.]

Exposure pathways

Workers operating a waste stabilization pond can be exposed to the wastewater. Community members, particularly children living nearby may similarly use the water and be exposed in different ways (e.g. playing and swimming) if these ponds are not enclosed. Such incidents often relate to poor community awareness on the health impact of wastewater ponds.

The risks of groundwater contamination (microbial or chemical (particularly nitrate) exists if the ponds are not properly sited. In Lima, Peru, penetration of indicator bacteria beneath waste stabilisation ponds of over 15 m has been noted, although the majority was removed in the top 3 m of the unsaturated zone (Geake *et al*., 1987).

Stabilization ponds may also act as breeding sites for mosquitoes as shown in several independent studies. In Pakistan a waste stabilization pond was identified as the major breeding site for *Culex* and *Anopheles* species known for their public health significance (Mukhtar *et al*., 2004). Also the surrounding wastewater irrigation systems were a major cause of vector mosquitoes breeding (Mukhtar *et al*., 2003). *Cx. quinquefasciatus* have been implicated as a vectors of West Nile virus (Burney and Munir 1966, Peiris and Amerasinghe 1994) while *Cx. tritaeniorhynchus* and *Cx. pseudovishnui* are vectors of Japanese encephalitis and of West Nile virus (Barnett 1967, Amerasinghe and Ariyasena 1990, Peiris and Amerasinghe 1994). Carlson *et al*., (1986) and Carlson and Knight (1987) recorded extremely high populations of *Culex quinquefasciatus* and *Culex nigripalpus* in WSP in Florida, while midges (*Chironomus zealandicus*) bred profusely in a waste stabilization pond in Aukland (also creating odour nuisance for nearby communities) (Lawty *et al*., 1996).

Poorly treated stabilization pond effluent may also be discharged into surface water bodies, affecting communities that use the water sources for drinking and household purposes.

Epidemiological and health risk evidence
The health risks associated with the use of the effluent of waste stabilization ponds have been evaluated in several epidemiological studies (Annex 11) and mainly demonstrate significant helminth and viral infection risks when the effluent of poorly maintained WSPs are reused for irrigation. This may affect both farmers and consumers of the wastewater irrigated produce. Poorly maintained ponds can also increase the incidence of mosquito related diseases as exemplified from Nigeria, where residents living < 300m from the WSPs were 3.4 times more likely to suffer from malaria compared to those living >300m away (Aguwamba, 2001).

Risk mitigation measures
Workers at stabilization ponds should wear protective clothing. Community members, especially children, should be prevented from entering the area preferably through fencing.

A specific lining, a clay barrier, polyethylene and/or vinyl sheet has been used in smaller ponds to limit groundwater impact during pond construction (WHO, 1987). In settings where there is a significant aquifer used as source of drinking water, the location of stabilization pond should be preceded by proper site investigation to avoid groundwater contamination.

Mosquitoe breeding may be reduced by removal of floating matter and vegetation. Cracks in the pond structure should be repaired. These simple measures have been very effective in reducing mosquitoes breeding in waste stabilization pond in Pakistan (Ensink *et al*., 2007).

The ponds should not be sited close to houses to minimize the nuisance of smell and possible vectors (e.g. mosquitoes).

Community member and farmer sensitization may be effective in children's access for recreation and for farmers to adopt risk reduction measures. Otherwise the situation may be similar as encountered in Pakistan, where local farmers preferred the use of untreated wastewater as a source of nutrients instead of the WSP treated water.

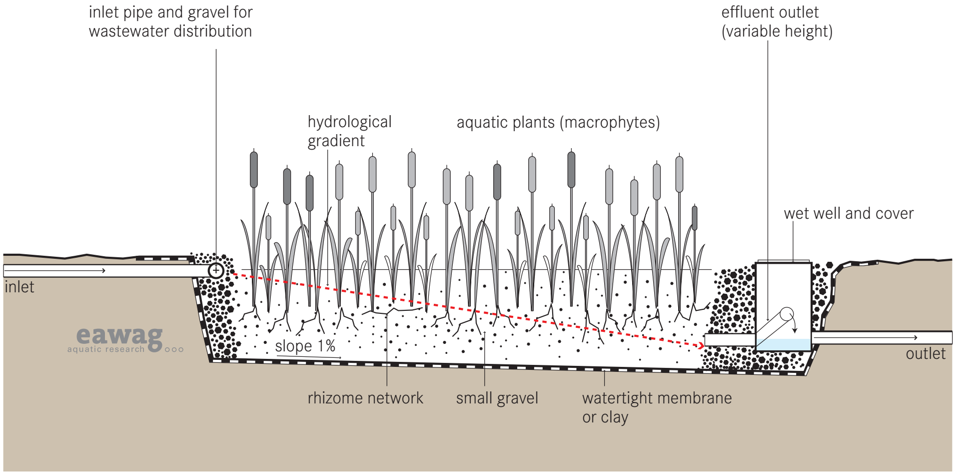
Risk summary
Number of exposed: 1-3 workers; several thousand in the rare event of groundwater contamination or crop contamination

Frequency of exposure: MEDIUM for the worker, depending on the maintenance required, LOW for the community and consumers

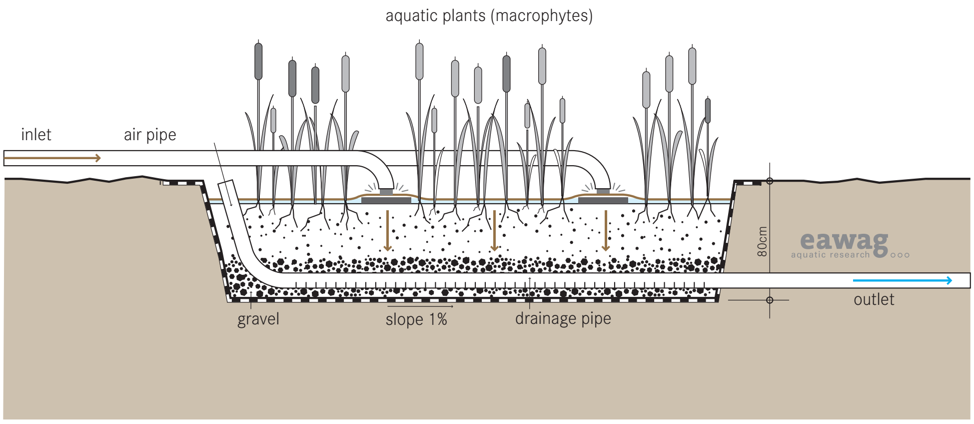
Level of risk: MEDIUM for the workers, MEDIUM (to LOW) for the community, depending on the construction and location of the pond

Constructed Wetlands

Horizontal sub-surface flow constructed wetland



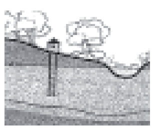
Vertical flow constructed wetland



Technology description
Constructed wetlands are designed in many variations. These include horizontal surface, and horizontal and vertical subsurface flow wetlands. The technologies aim to replicate the naturally occurring processes of wetlands, marshes or swamps, resulting in particle settling, pathogens reduction and utilization of nutrients by organisms or plants with a convertion to biomass.

Input and output products
Constructed wetland can be used for the treatment blackwater and/or greywater which has undergone proper pre-sedimentation. In small-scale system a grease-trap is important. The wetland combines chemical, physical and biological processes for the removal of pathogenic organisms and nutrients. A well constructed and operated wetland is capable of reducing viruses by 1-2 log unit;

Exposure pathways



Risk groups

W C

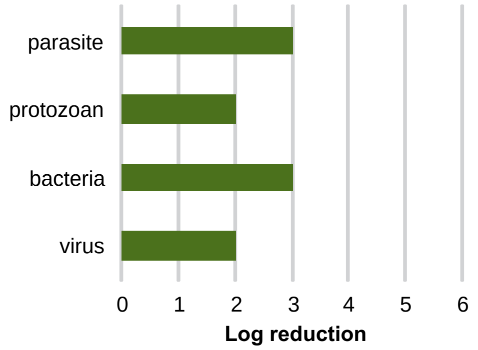


Figure 11: Maximum reduction of pathogens in an optimally functional constructed wetland* (WHO, 2006)

[*Depends on type of wetland, filter material, retention time and vegetation.]

bacteria, 0.5-3 log unit; protozoan (oo) cysts, 0.5-2 log units and helminth eggs, 1-3 log unit (WHO, 2006).

Selected studies that have evaluated the pathogen or indicator removal efficacy are summarized (Annex 3).

Typical malfunctioning
If the filter media (e.g. sand or gravel) becomes clogged, the constructed wetland will fail to achieve the desired degree of treatment. This is partly counteracted by pre-settlement. Chemicals in the wastewater can damage or kill the natural processes and organisms essential for a functioning wetland. If the wetland is not well-designed, invasive species and undesirable vectors (e.g. mosquitoes) may become problematic.

Exposure pathways
The exposure pathways relate to accidental ingestion and the risk is always higher at the inlet than at the outlet.

Surface-flow constructed wetlands generally relate to a higher risk than sub-surface flow ones. Theformer are similar to stabilization ponds, with the exception that mosquito breeding and the subsequent vector transmission is substantially higher. In some developed countries surface-flow wetlands have been combined with public recreational areas. This enhances the risk of public direct contact.

Subsurface flow wetlands generally have a high level of security, and may be combined with root resorption beds for nutrient recovery. They normally exclude the possibilities of direct contact, will not facilitate mosquito breeding and when combined with root resorption will have limited impact on groundwater. The potential hazard points are at their inlet and outlets, which should be the focus for critical exposure point assessments.

Epidemiological and health risk evidence
Westrell (2004) made a quantitatively assessment of the health risk associated with the use of a surface constructed wetland for the treatment of the effluent of a wastewater treatment plant in Sweden. The assessment addressed two exposure scenarios: i) unintentional contact at the inlet of the wetland and ii) children playing at the outlet of the wetland. Among the pathogenic organisms assessed, only exposure to rotavirus and adenovirus under the two scenarios (10^{-1} to 10^{-3}) was above the WHO tolerable health risk (Annex 10).

A similar assessment for a subsurface constructed wetland treating wastewater from a single household was undertaken in Norway (Heistad *et al*., 2009) The treatment comprised a septic tank, a pretreatment biofilter unit and an upflow constructed wetland operated for almost 5 years. This study also assessed the potential health risk associated with the consumption of lettuce salad irrigated with the effluent of the constructed wetland in addition to the Westrell (2004) exposure scenarios. All the exposures led to significant rotavirus infection risk above the WHO tolerable risk level.

Risk mitigation measures
For surface-flow wetlands, instructions should inform people about contact hazards with the water.

Filter materials should be well selected to avoid clogging and ponding.

In settings where mosquitoes are a nuisance or major health problem, free surface flow constructed wetland should be avoided. The construction of the wetland should also be preceeded by a thorough hydro-geological investigation in vulnerable areas to prevent any potential contamination through groundwater.

Risk summary
Number of exposed: 1-3 workers. Community based on design of surface flow wetlands

Frequency of exposure: LOW for the worker (depending on the maintenance activities), LOW for the community

Level of risk: MEDIUM for the worker at surface flow wetlands at the inlet part. LOW at the outlet, MEDIUM for the community (depending on the design and location) for surface flow wetlands; LOW for subsurface flow wetlands.

Conventional Wastewater Treatment
(including Activated Sludge)

© Lindsay Banks/flickr

Technology description
A 'Conventional' Wastewater treatment facility is usually centralized and based on a multi-stage process to remove solids, nutrients and pathogens. Primary treatment consists of mechanical screening and sedimentation; secondary treatment is a biological aerobic step where a reduction of pathogens is achieved and further enhanced in chemical flocculation and different filtration processes, (partly also in a tertiary treatment). Enhanced treatment may also include special treatment steps aimed at further reduction of specific nutrients before discharge (e.g. phosphorus or nitrogen). In some countries a final disinfection of the effluent is done.

Input and output products
The effectiveness of each treatment process and combination of processes at reducing pathogens varies depending on the type of pathogens and the train of treatment processes. Table 3 gives ranges of pathogen reduction for some of the available processes (WHO, 2006).

Typical malfunctioning
Conventional wastewater treatment plants require a significant level of energy to operate pumps, supply air, and monitor the treatment. Without energy and skilled workers, the treatment processes may malfunction. All of the alternative treatment processes require thorough process control and management.

Exposure pathways
Household members connected to the wastewater treatment plant via the sewer network are rarely directly exposed to pathogens present in the wastewater. Exposure occurs after the outlet. However, wastewater workers may be exposed by inhalation of aerosols and gases, by dermal contact, and by oral ingestion. All

Table 3: Pathogen removal efficiency of different wastewater treatment processes

Treatment process	Removal efficiency (log reduction)			
	Viruses	Bacteria	Protozoan (oo) cysts	Helminth eggs
Primary treatment				
Primary sedimentation	0 -1	0 -1	0 – 1	0 - <1
Chemically enhanced primary treatment	1 – 2	1 – 2	1 – 2	1 – 3
Anaerobic upflow sludge blanket reactors	0 – 1	0.5 – 1.5	0 -1	0.5 – 1
Secondary treatment				
Activated sludge + secondary sedimentation	0-2	1-2	0-1	1-<2
Trickling filters + secondary sedimentation	0-2	1-2	0-1	1-2
Aerated lagoon + settling pond	1 -2	1 -2	0 -2	1 -3
Tertiary treatment				
Coagulation/flocculation	1 -3	0 -1	1-3	2
High rate granular or slow rate sand filtration	1 -3	0-3	0-3	1-3
Dual media filtration	1-3	0-1	1-3	2-3
Membranes	2.5->6	3.5 ->6	>6	>3
Disinfection				
Chlorination (free chlorine)	1-3	2-6	0-1.5	0-<1
Ozonation	3-6	2-6	1-2	0-2
Ultraviolet radiation	1 - >3	2->4	>3	0

Source: WHO (2006)

faecal pathogens may occur in the wastewater. In a study of two wastewater treatment plants in Italy, a marked variation of pathogen concentration in aerosols between different treatment steps and seasons was found (Fracchia *et al*., 2006). In particular, mechanical aeration of the sewage inflows posed the greatest health hazard.

The highest concentrations of bioaerosols are associated with the aeration tank (secondary treatment) and sludge pressing units (Rylander and Lundholm, 1979). Kudlinski (1995) found the highest concentration of airborne viable Gram-negative bacteria (used as an index of contamination) at the belt press and sludge collection. In a Swedish study, Westrell *et al*., (2004) identified exposure to aerosols at the pre-aeration tank and the belt press as the most significant exposure points to pathogenic organisms.

The main risks from a wastewater treatment plant is however not at the plant itself but is related to the concentration in the outlet and the type of recipient and related activities that occur.

Epidemiological and health risk evidence

Some studies where high occupational health risk for workers of wastewater treatment plants has been found are summarized in Annex 12. Disease symptoms for workers relate to the respiratory system, gastrointestinal system, and the skin and eyes.

In the US, wastewater treatment workers had higher prevalence of headache, respiratory infections (1.4 times higher) and enteric disease symptoms (12.7 times higher) than the controls (Khuder *et al*., 1998). A significant relationship with respiratory infections (p=0.52), or skin symptoms (p=0.09) were not found.

In Copenhagen cohorts of 591 wastewater and 1545 water supply workers were followed and compared in terms of cause of specific mortality and cancer incidence from 1965 to 1998 (Hansen *et al*., 2003). Wastewater workers' mortality exceeded the controls (water supply workers) (relative risk (RR) = 1.25, 95 per cent CI: 1.03 – 1.51) and an excess cancer incidence was also recorded for the wastewater workers (RR= 1.27, 95 per cent CI: 0.97 to 1.67). Primary liver cancer was especially noted among the wastewater workers compared to the water supply workers (RR= 8.9, 95 per cent CI: 1.5 – 51.5). In a US study the cancer mortality for wastewater treatment plant workers was slightly higher than that of the general population SMR = 1.19, 95 per cent CI = 0.79-1.7) (Lafleur and Vena, 1991).

This was however not seen in a 9-year cohort study involving employees of all the wastewater treatment plants in Sweden where it was concluded that wastewater workers did not have an increased risk of cancer (Friis *et al*., 1999). No relation between cancer incidence and level of sewage exposure was found.

The level of antibodies in the blood is an indication of exposure. Canadian wastewater workers were 6 times more likely to be infected with Leptospira spp compared to the non-wastewater workers (de Serres *et al*., 1995). .

In a QMRA assessment of viral, protozoan and bacterial infection risks among workers operating the pre-aeration and the belt press an enhanced risk was found for all the pathogen groups (Westrell *et al*., 2004). Epidemiological studies have investigated the viral infection risk for wastewater treatment plant workers with variable results. In a cross-sectional epidemiological survey, no excess infection risk for hepatitis A virus was found among wastewater treatment workers in a large city in the United States (Trout *et al*., 2000). Cadilhac *et al*., (1996), in France, found that an adjusted odds ratio for Hepatitis A sero-positivity was 2.2 times greater in sewage workers compared to non-sewage workers. Similar results were found in a study in Singapore with 2.2 time's higher sero-prevalence than that of non-sewage workers (Heng *et al*., 1994). The need for vaccination of wastewater workers against Hepatitis A was reiterated in an epidemiological survey in Canada even though the sero-prevalence among wastewater workers compared to the controls was not significant (de Serres *et al*., 1995).

Risk mitigation measures

Wastewater treatment plant workers have to wear protective clothes during the operation and maintenance of the facility.

Most 'conventional' wastewater treatment technologies require some level of mechanical and/or electrical inputs to function properly: rotating spray arms on trickling filters, aeration pumps in activated sludge, ozone generators for ozonation, etc. When specialized equipment is required, skilled operation and maintenance is essential. Equipment, and indeed the wastewater, must be carefully monitored by technicians who understand the complex processes at work so that they can optimize the equipment and settings. Skilled staff, well-maintained equipment, trained mechanics and an availability of spare parts are essential for the-function of the wastewater treatment plant.

Risk summary

Number of exposed: One - several workers

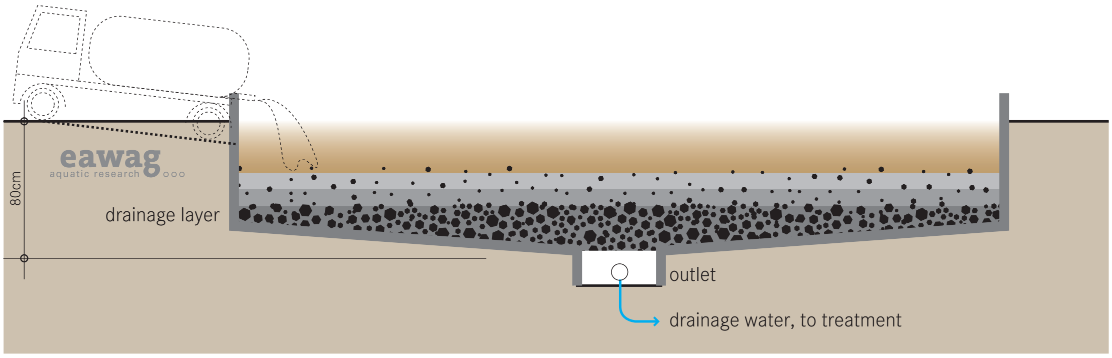
Frequency of exposure: LOW for the worker

Level of risk: LOW - MEDIUM for the worker, LOW-HIGH for the community (depending on the effluent and type of recipient)

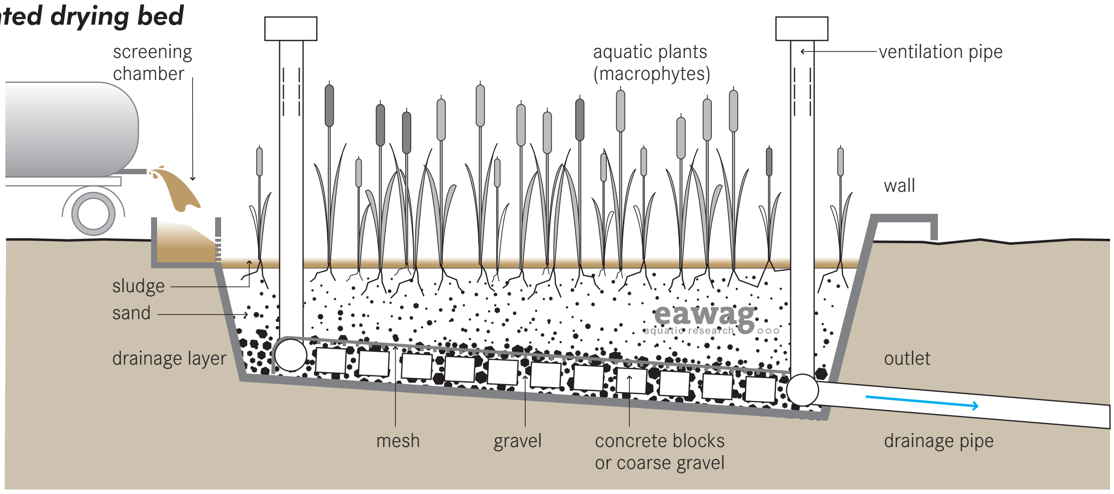
Faecal sludge Treatment Technologies

Faecal sludge Treatment Technologies for the treatment of sludge, septage and/or biosolids have high input concentration of both nutrients and pathogens. Several different treatment technologies exist. Here, Sedimentation/Thickening Ponds, Unplanted Drying Beds, Planted Drying Beds, and Co-composting but not more energy-intensive technologies like incineration are considered.

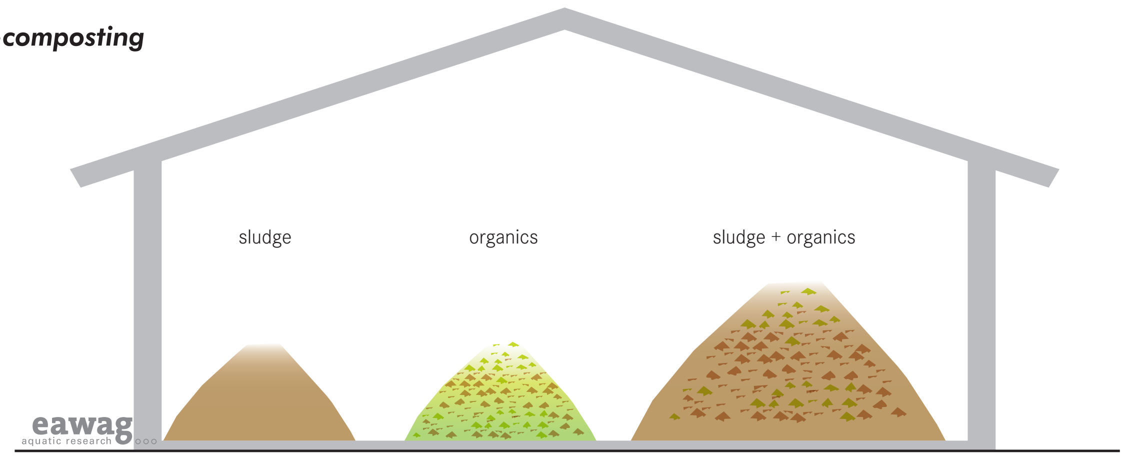
Unplanted drying beds



Planted drying bed



Co-composting



Technology description

Sedimentation or Thickening Ponds are simple settling ponds that allow the sludge to dewater and thicken. The effluent water is treated separately, while the thickened sludge can be treated in a subsequent technology step. The thickened sludge can be applied to a planted/unplanted drying bed or treated by co-composting.

An unplanted drying bed is a simple, permeable bed that, when loaded with sludge, allows the sludge to dry by facilitating the liquid to percolate down through the bed, where it is collected, treated or eventually evaporated. Approximately 50-80 per cent of the sludge volume drains off as liquid. The sludge however, is not stabilized or decomposed.

A planted drying bed is similar to an unplanted one with the benefit of increased liquid uptake in plants and transpiration. The advantage 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.

Co-composting is the controlled aerobic degradation of organics using more than one feedstock (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 products, the benefits of each can be used to optimize the process and the finished compost product.

Input and Output Products

The input faecal sludge is generally differentiated into high strength (originating from latrines and unsewered public toilets) and low strength (originating from septic tanks). High strength sludge is rich in organics and has not undergone significant degradation. Low-strength sludge has undergone significant anaerobic degradation and is more easily dewatered. In order to be properly dried, high strength sludges must first be stabilized, which may be done anaerobically in Settling/Thickening Ponds. 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 pathogen reduction efficacy of the range of faecal sludge treatment technologies largely depends on their design configuration and the type (strength) of sludge being treated. Annex 4A-C exemplify the treatment efficiencies of the different sludge treatment technologies presented here.

Typical malfunctioning

Overloading of any sludge treatment technology will reduce its performance both in relation to the nutrients and pathogens reduction. Too much sludge in a settling pond, or insufficient time for proper settling, will negatively impact the possibilities for secondary treatment. Similarly, if too much sludge is applied to a drying bed- either too often or in layers that are too thick, proper dewatering will not occur. If this is a planted bed, the growth of the plants will be negatively impacted.

Large areas of drying or settling sludge, inevitably attract flies and/or mosquitoes, depending on the sludge quality, and act as significant vector pathways for exposure.

Exposure pathways

Workers at sludge treatment facilities have a high risk of exposure from both the pathogens in the sludge, and from the vectors which it may attract. Sludge workers are exposed to pathogens while transferring the sludge (e.g. applying it to a drying bed, or mix a co-composting pile) by direct contact and indirectly through aerosols and contamination of clothes and skin. Workers may also be exposed at the discharge points.

Sludge workers are also exposed while transferring or spreading the sludge. Additionally they may be cut by glass or other sharp edges that may occur in the sludge, which may also give rise to skin infections.

Compost workers may also be exposed to the airborne spores of thermophilic fungi and actinomycetes that proliferate during the composting process. For instance, *A. fumigatus* thrives well at 45^{o}C or higher temperatures at compost sites (Millner *et al*., 1977). *Aspergillus spp*. has been shown to cause diseases in both immunecompetent and immune-compromised individuals through the inhalation of the small airborne spores (2.5-3.0 µ for *A. fumigates*). The dust from composting sites may contain significant quantities of LPS derived from gram negative microorganisms in sludge (Clark *et al*., 1983) known for clinical symptoms including headache, nasal and eye irritation, chest tightness and fever (Matsby and Rylander, 1978).

High concentrations of pathogens and *Ascaris* and other helminthes have been found on sampled face masks worn by workers, which illustrate the risk of exposure.

Compost that is inadequately stored may be dispersed by strong winds thus exposing community members living in the immediate surroundings as well as the workers of the plant.

Environmental contamination may result from open air storage of compost. Runoffs from the compost pile may contaminate surface water used for recreation or drinking by community members. Community members and especially children should not have access to the facility.

Also, depending on the sludge quality, large areas of drying or settling sludge, inevitably attract flies that can act as mechanical vectors in the transmission of diseases.

Epidemiological and health risk evidence
Work-related health complaints and diseases of compost workers and organic waste collectors were investigated in a cross sectional study and compared with control subjects (Bunger *et al*., 2000). Compost workers had significantly more respiratory disease (p=0.003) and skin symptoms (p=0.02) than the control subjects, but organic waste collectors did not differ from those of the control group.

In another study workers at a compost plant for household refuse and wastewater sludge reported significantly higher frequency of nausea, headache, fever or diarrhoea than a control group of water treatment plant employees (Lundholm and Rylander, 1980). These symptoms were mainly attributed to the presence of endotoxins in the compost. Clark *et al*., (1984) carried out a comprehensive study to assess the health risk associated with composting sludge with solid waste at 9 composting plants in the United States, which clearly showed a higher health risk for the compost workers. The findings were the following:

- Excess nasal, ear and skin infections among compost workers.
- Higher frequency of symptoms of burning eyes and skin irritation among compost workers.
- Evidence of higher white blood cell counts in compost workers
- Higher antibody levels to endotoxins in compost worker

Risk mitigation measures
For workers at sludge treatment facilities, there is no better risk mitigation measure than personal protection and good hygiene practices. High boots, full body protection and face masks should be used. To prevent exposure of local communities the facility should be located so that odours and dust are not affecting these. Contamination of local water sources by liquid run-off should be prevented. A fence should surround the work area to prevent children and others from entering and getting in contact with the sludge.

For worksites in composting and wastewater treatment plants, specific airborne microbial contamination limits are sometimes set, but only for a few agents such as endotoxins and allergens. Limit values up to 10^4 CFU/m^3 for culturable bacteria, 10^3 CFU/m^3 for Gram-negative bacteria and 10^3 CFU/m^3 have been suggested (Malmros, 1990; Oppliger *et al*., 2005).

Risk summary
Number of exposed: 1-20 workers, large number of community members due to location and local fencing off

Frequency of exposure: HIGH for the worker, LOW for the community

Level of risk: HIGH for the worker, MEDIUM for the community depending on the design

Technology	Barrier efficiency and robustness: Input pathogens	Treatment	Typical malfunction	Exposure pathways	Likelihood of occurrence	Diarrhoea Risk: User	Worker	Farmer	Community	Helminths Risk: User	Worker	Farmer	Community	Risk Management *assuming that standard hygiene behaviour and practices are followed (including handwashing, toilet cleaning, etc.)
WSponds	Viruses	1-4	-flies, other vectors and odours become a nuisance -improper design produces low quality effluent	Ingestion of wastewater (E1)										-properly designed ponds can produce high quality effluent, with few odours or vectors -a fence prevents contact by the public
	Bacteria	1-6		Contact with flies/mosquitoes (E3)										
	Protozoa	1-4		Ingestion of contaminated surface water (E5)										
	Helminths	1-3		Ingestion of wastewater by falling in (swimming) (E7)										
Constructed wetlands	Viruses	1-2	-flies, other vectors and odours become a nuisance -improper design produces low quality effluent -filter media (in subsurface flow designs) clogs	Ingestion of influent water (E1)										-properly designed wetlands can produce high quality effluent, with few odours or vectors -a fence prevents contact by the public -proper pre-treatment (grease trap and screening) prevents clogging
	Bacteria	0.5-3		Ingestion of effluent (E1)										
	Protozoa	0.5-2		Ingestion of contaminated groundwater/surface water (E5)										
	Helminths	1-3												
Conventional wastewater treatment	Viruses	0- >6	-electronic malfunctions (e.g. pumps, aerators) -over or under-loading of process -presence of toxic or agressive mcroorganisms impede treatment	Ingestion of wastewater (E1)										-proper design -process monitoring -trained staff
	Bacteria	0- >6		Inhalation of aerosols (E2)										
	Protozoa	0- >6												
	Helminths	0- >3		Ingestion of contaminated groundwater/ surface water										
Sedimentation / thickening pond	Viruses	2-3	-sludge transfer, spreading and handling is always high risk and depending on the technology the opportunities for malfunction vary, though extreme care should always be taken.	Ingestion of wastewater (E1)										-regular cleaning of transfer points and equipment -fences and barriers to prevent vectors and humans from entering area -personal protection for workers -appropriate location, not near residential area
	Bacteria	2-3		Dermal contact										
	Protozoa	NA		Contact with flies (E3)										
	Helminths	<1 – 3		Contact with wastewater from falling in (E7)										

Figure 12: Semi-centralized treatment technologies: exposure scenarios and health risk

Technology	Barrier efficiency and robustness			Exposure pathways	Likelihood of occurrence	Diarrhoea Risk				Helminths Risk				Risk Management
	Input pathogens	Treatment	Typical malfunction			User	Worker	Farmer	Community	User	Worker	Farmer	Community	*assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Planted or unplanted drying bed	Viruses	1- <6		Ingestion of raw sludge (E1)										---reinforced concrete or pre-fabricated plastic construction with smooth surface
	Bacteria			Ingestion of dewatered sludge (E1)										
	Protozoa			Dermal contact (E2)										
	Helminths	1-3		Contact with flies (E3)										
Co-composting	Viruses	2- <6	-faeces clog urine collection pan -no provision for anal cleansing water -poor construction makes it difficult to clean	Ingestion of raw sludge (E1)										- good design to facilitate urine and faeces separation -dedicated collection point for anal-cleansing water -coated concrete or pre-fabricated plastic
	Bacteria	1.8- <6		Ingestion of composted material (E1)										
	Protozoa	2.5		Dermal contact (E2)										
				Contact with flies/ (E3)										
	Helminths	1-2		Inhalation of aerosols/particles (E4)										
				Ingestion of contaminated groundwater/ surface water (E5)										

Figure 12 (cont): Semi-centralized treatment technologies: exposure scenarios and health risk

REUSE AND DISPOSAL

Introduction

To reduce disease transmission the products of sanitation technologies have either to be safely disposed of or safely reused. When the product contains toxic compounds that may affect the environment or is detrimental to human or animal health it needs to be safely disposed. Safe reuse may be appropriate and beneficial when the product contains nutrients that can be used as fertilizers, water for irrigation or when the product can be used to generate energy, without comprising human health or be detrimental to the environment. The reuse is thus part of the sustainable development concept.

The safe reuse within a management context is the main objective of "the WHO guidelines for the safe reuse of human excreta, wastewater and greywater in agriculture" (WHO, 2006). The guidelines aims to protect human health within an integrated preventive management framework encapsulating both technical and non-technical (handling) barriers that progressively reduce health hazards from the point of wastewater/ excreta generation through the farm to the fork (WHO, 2006). They further accounts for the beneficial use of the nutrient and water resources from municipal and domestic wastes.

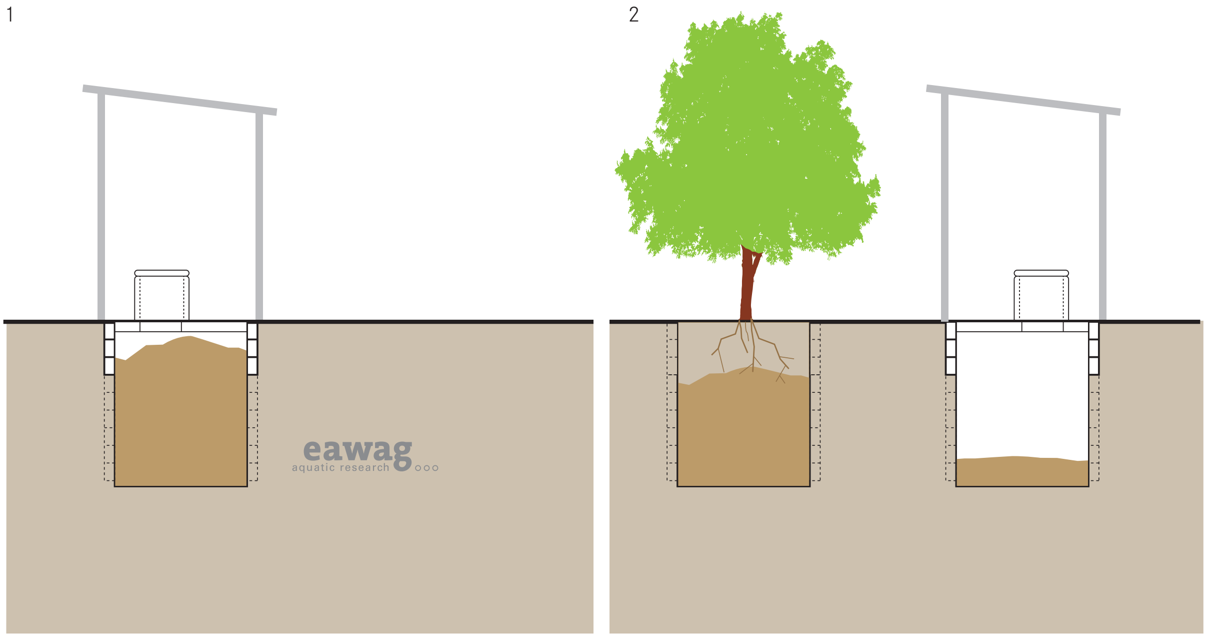
Hygiene and behaviour

Human excreta have been used in agriculture and aquaculture in Asian countries especially in China and Japan for thousands of years. The use of human excreta reflects an economic appreciation of soil fertility. This has evolved in response to the need to feed large populations with limited land availability, which makes it a necessity to use all fertilizing resources available (WHO, 2006-4). According to Strauss and Blumenthal (1990), the East Calcutta sewage fisheries are the largest of their kind in the world with up to 5000 ha of ponds, the effluent from which is additionally used to irrigate an area of 6500 ha downstream. Some social norms and ethnic beliefs warn against the intentional handling and use of raw or fresh and treated human excreta and greywater in agriculture and aquaculture and look at products fertilized with excreta and greywater as tainted or defiled. This is the situation e.g. among the 'Bamileke', 'Banwa' and 'Bakweri' tribes in Cameroon. This is also the case according to Koranic edict, where excreta are regarded as containing impurities (*najassa*) and can only be used when the impurities are removed (WHO, 2006-4).

The social feasibility of changing certain behaviour in order to introduce excreta or wastewater use schemes can only be assessed with a prior understanding of cultural and traditional values attached to practices that appear to be social preferences yet which facilitate disease transmission (Mara and Cairncross, 1989). The shift towards widespread use of human excreta and greywater, either as an informed choice or as a resource necessity, needs to take into account the prevailing social context and physical environment. To mainstream the development of nutrient reuse, concerted efforts are needed in the policy arena of national and local governments, in particular within the sectors of health, environment and agriculture. Also, the whole area of awareness-raising among farmers and consumers about sanitation systems is necessary in order to create a better understanding and greater demand for more sustainable solutions (Rosemarin *et al*., 2008).

Additionally, a barrier efficiency may be postulated for individual workers in relation to crop production, but the effect on the market and consumer levels may be minimal if a few do not adopt the practices. These drive the risk. The non-treatment options are mainly practices that prevent direct contact and/or progressively reduce the health hazard if generally adhered to as a practice in addition to the treatment of wastewater/excreta.

Fill and Cover/Arborloo



Technology description

The 'Arborloo' is a shallow pit that is filled with excreta and organic material, covered with soil and planted with a tree or plant (vegetable or ornamental). This ensures the utilization of parts of the nutrients in the pit.

The production of pumpkin was doubled by planting the seeds in Arborloo pits (Simpson-Hebert, 2006). In Ethiopia many users of Arborloo pits have chosen to plant pumpkin rather than trees and in Zimbabwe, tomatoes are grown as an alternative (Morgan, 2007). In Niassa, Mozambique trees, pumpkins, and a range of vegetables have been planted in abandoned pit toilets (Breslin and Dos Santos, 2001). The planting of banana trees in pit latrines is a common practice in Malawi.

Alternatively, a pit can be used for the disposal of excreta/sludge taken from a different technology. This has been practiced with the contents from bucket latrines where the content of the buckets are covered with a layer of soil and left for about 2 years for the destruction of pathogenic organisms (Feachem *et. al*, 1983).

Exposure pathways

In the Aborloo the exposure to pathogens is small if the pit is properly covered. Exposure occurs during the planting of the tree for the persons involved in the activity, but users do not come in contact with the faecal material. Exposure may also occur in water logged areas through groundwater contamination.

Epidemiological and health risk evidence

To date, there are no epidemiological or health risk data to describe the health impact of this disposal/reuse technology.

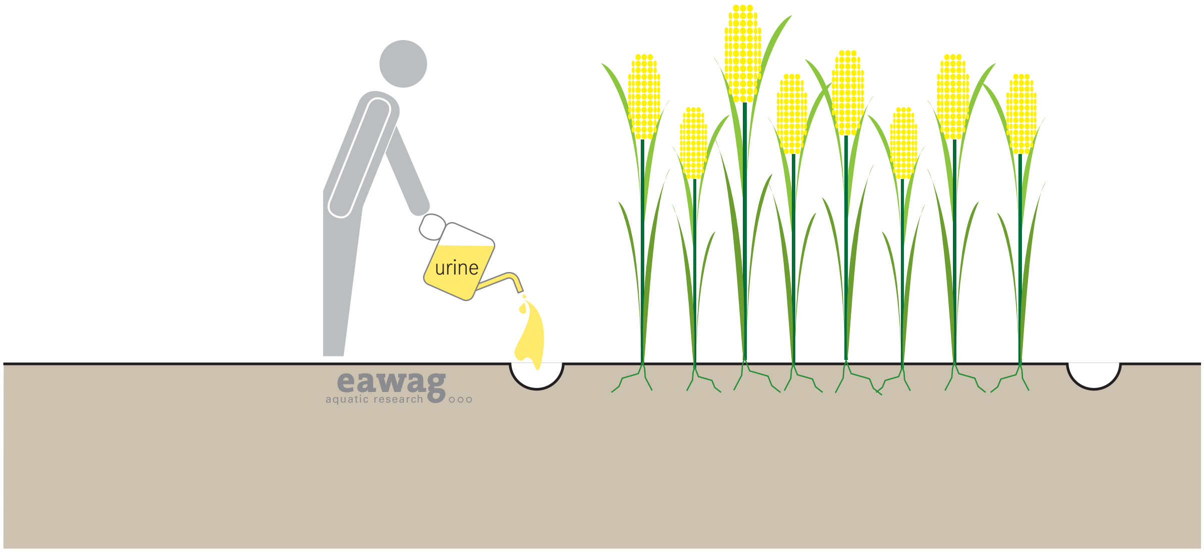
Risk mitigation measures
When a pit is filled, regardless of whether or not plants or a tree is planted on top, it should be well covered to avoid contact with the buried excreta. With time, the contents will degrade and reduce in volume. Additional filling should then be made with soil and not with additional excreta or garbage.

Risk summary
Number of exposed: 1-3 during planting

Frequency of exposure: LOW for the user and the planters.

Level of risk: LOW for the user; MEDIUM for the planters.

Application of Urine



Technology description

Urine may be safely disposed of through infiltration, or preferably used as a fertilizer for crop production. Urine contains the majority of nutrients that are excreted from humans. The concentration of nutrients in urine varies depending on diet, gender, climate and water intake. Out of the total amounts excreted by humans, roughly 80 per cent of nitrogen, 60 per cent of potassium and 55 per cent of phosphorus of is excreted with urine. The health related parts of the reuse guidelines for urine are based on storage time and temperature. Because of its high pH, stored urine should not be applied directly on green leafy plants surfaces. Rather, it should be:

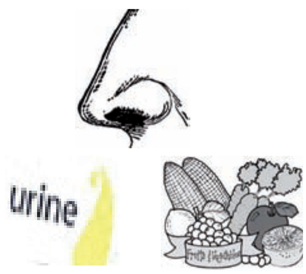
- mixed undiluted into soil before planting;
- poured into shallow furrows and covered immediately (once or twice during the growing season); and
- diluted several times and used frequently (twice weekly) poured around plants.

Roughly a square meter of cropland can be fertilized with one day's urine from 1 person (1 to 1.5L). A comprehensive summary on the use of urine in Crop Production is available as a SuSanA/SEI document (Richert *et al*., 2010).

Exposure pathways

A few pathogenic bacteria (like *Salmonella typhi*) or parasites (like *Schistosoma haematobium*) can be excreted with the urine. Direct contact with fresh urine may transmit the former through the oral route and the indirect spread of the latter through an intermediate snail host if poured into surface water. Significant health hazards may be present in the use of urine due to faecal cross-contamination at the user interface. The disposal or reuse practice and storage conditions of the urine will determine the extent of exposure to the diluted faecal microorganisms. Exposure to these organisms may occur during the disposal or application of the stored urine in the field through accidental ingestion of the urine from contaminated hands and through inhalation if spray irrigation is used in large scale application. Mainly the farmers/field workers are at risk of exposure. Consumers of crops fertilized with urine may also be exposed to pathogens if faecal cross-contamination has occurred and storage, application and with-holding time practices are not adhered to.

Exposure pathways



Risk groups

F C

Epidemiological and health risk evidence

The infection risk associated with urine application largely depends on the urine storage time as well as the application method used. In a screening level QMRA assessment accidental ingestion of urine during the handling of stored and unstored urine as well as the consumption of lettuce fertilized with urine were assessed (Höglund, 2001). Faecal contamination was the source of health hazards. Accidental ingestion of unstored urine resulted in a high infection risk (0.56) for rotavirus whereas the risk of infection from bacteria and protozoa were approximately 1:10,000. After 6 months of storage at 20°C, the risk of viral infection by accidental ingestion of 1 mL of urine was < 10^{-3}. Consumption of lettuce contaminated with urine resulted in risk levels far better than the tolerable level stated by WHO (< 10^{-7} after 4 weeks) withholding period between fertilizing and harvesting.

An estimate of the infection risks for bacteria and protozoan through aerosols during urine spray irrigation for people living within an area of 100 m was extremely low within the WHO tolerable infection risk. However, the risk of rotavirus infection was high for unstored urine and urine stored at 4°C but was significantly reduced if the urine was stored at 20°C or above before spraying (Hoglund *et al*., 2001).

It is generally accepted that if urine is stored for at least 1 month, it will be acceptably 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. A substantial die-off will however occur in the field.

Risk mitigation measures

Risk mitigation partly depends on the storage duration of the urine. In Table 4 the suggested recommendations for the application of urine in large systems is summarized where the urine mixture is used to fertilize crops that will be consumed by individuals other than members of the household from whom the urine was collected. The six-month stored urine can be applied safely to all range of crops including those eaten uncooked. The household generated urine can be applied to sites of cultivation for all crops during planting. It is important that it is applied directly to the soil before or during planting and sprinkler irrigation avoided. To ensure maximum destruction of potential pathogens on the fertilized crops (ie. vegetables eaten raw), the application of urine should be halted not less than one month before harvesting.

Urine should be applied close to the ground or worked into the soil. In large scale urine application systems, techniques such as band spreading with a boom with trailing hoses creates practically no aerosols, and the use of a spread plate forms drops large enough to quickly settle on the ground.

For maximum protection for workers and farmers, urine disposal or application should be undertaken with protective clothing irrespective of the storage duration.

Risk summary

Number of exposed: variable number of farmers; large number of consumers of crops

Frequency of exposure: LOW (the majority of the urine used will be safe)

Level of risk: LOW for both farmers and consumers if recommendations are adhered to.

Table 4: Recommended storage urine application

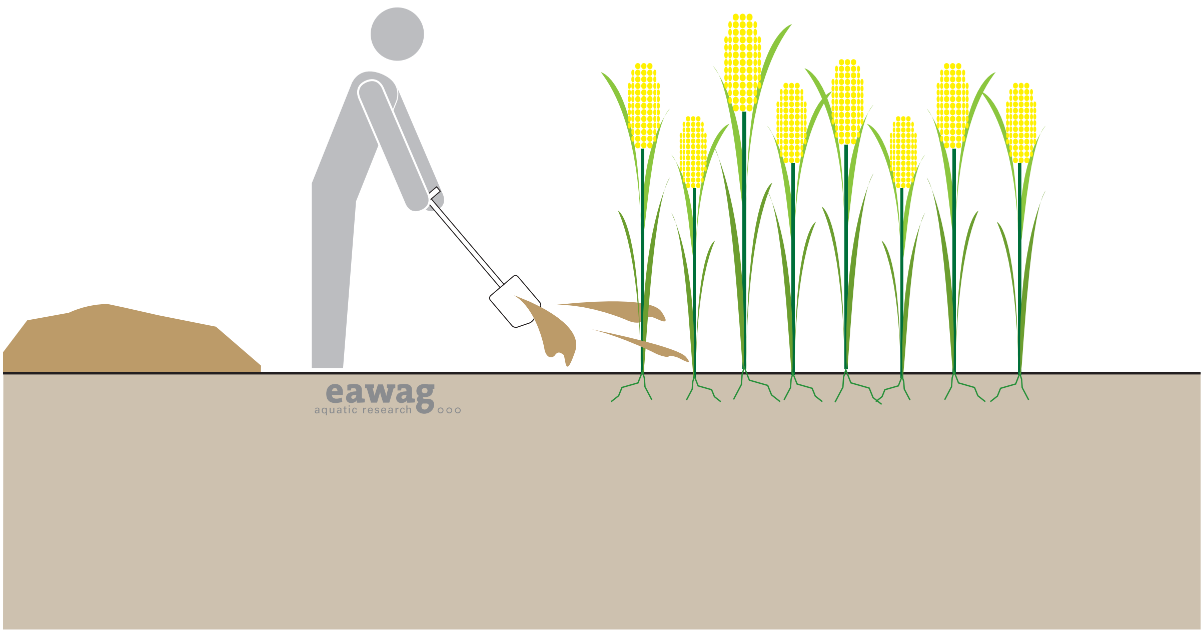
Storage temp	Storage time	Possible pathogen in the urine mixture	Recommended crops
4°C	> 1 month	Viruses, protozoa	Food and fodder crops that are to be processed
4°C	> 6 months	Viruses	Food crops that are to be processed [c]
20°C	> 1 month	Viruses	food crops that are to be processed, fodder crops [c]
20°C	> 6 months	Probably none	all crops [d]

Adapted from Hoglund (2001)

c Not grasslands for production of fodder. Use of straw is also discouraged.

d For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible part grow above the soil surface.

Application of Dehydrated Faeces



Exposure pathways

Risk groups

F C

Technology description
Faeces stored in the absence of moisture (i.e. urine) and without intrusion of water (i. e rainwater) will dehydrate but not decompose. Dehydration means that the moisture naturally present in the faeces partly evaporates and/or is absorbed by the addition of a drying material (e.g. ash, sawdust, lime). After dehydration, faeces have reduced in volume by about 75 per cent and appear as a humus-like substance. The shells and carcasses of worms and insects that also dehydrate will remain in the dried faeces. The dehydrated faeces may be buried in pits, or incorporated into the soil on farms for crop production as a fertilizer and soil conditioner if pre-treatment requisites are adhered to. For agricultural application, the material should be worked into the soil before planting or sowing.

Exposure pathways
Faeces stored for at least 12 to 18 months will result in minimum risk for all pathogens with the potential exception of some parasites. Accidental ingestion of small amounts of dehydrated faeces (i e from contaminated hands) may occur during field application. The main exposure, however, occurs after contact with the crops grown.

The exposure risk is small if storage and pre-treatment recommendations are followed, but can be substantial if this is not the case. The risk is smaller for crops with long rotation time, with crops not consumed raw or not in contact with the ground than for vegetables eaten raw or from fruits picked from the ground. The risk from airborne particles is normally low.

Epidemiological and health risk evidence
High infection risks have been estimated in a quantitative microbial risk assessment in relation to the incorporation of dehydrated faeces into soil or accidental contact in the gardens (Westrell, 2004). For fresh unstored faeces

the annual risk for rotavirus infection was 4 out of 100 persons while 12 months of storage reduced the risk to less than 4 out of 10,000 exposed persons. The risk for *Ascaris* infection still remained high.

The infection risks from *Salmonella* and *Ascaris* associated with the consumption of spinach or carrots grown in soil amended with dehydrated faeces were estimated in a South African study (Jimenez *et al*.2007). The *Salmonella* infection risk with application rates of 19 to 37.5 ton/ha was above the acceptable WHO tolerable risk level. For helminths, 2 to 9 out of 100 people were likely to develop helminthiasis from a single consumption of spinach grown in soil amended with 1.3 to 37.5 ton of dehydrated faeces/ha (or 0.18 - 5.1 helminth ova/cm^2) while for carrots the infection risks ranged from 6 x 10^{-3} to 1 x 10^{-2} for an application rates of 7 to 35 ton of dehydrated faeces /ha (Jimenez *et al*., 2007).

In El-Salvador, infections were higher in households where solids from dehydrating vaults were used in agriculture than when it remained in pits. Members of households where dehydrated faeces from urine diverting toilets were buried in the yard after storage were 8.3 times more likely to be infected with *Ascaris* (CI = 2.1-31.8, $P < 0.001$), and 3.7 times more likely to be infected with *Trichuris* (CI = 1.6-8.7, $P = 0.002$). Prevalence of hookworm, *Giardia* and *E. histolytica*, however, were significantly lower for members of households who buried dehydrated faeces than for pit latrine users. Reuse in agriculture or on household gardens did not show an enhanced risk. It was concluded that the burial of the content of the dehydration toilets in the backyard led to an elevated helminthes' infection risk.

Similar higher incidence of *Ascaris* infections were found in Vietnam for households using urine diverting toilets as compared to those without, Prevalence of hookworm among households with the latrines was however lower resulting in an odd ratio of 0.87 (0.39-1.96) (Yajima *et al*., 2008). Yajima *et al*., (2008) concluded that the dehydrating latrines may not provide enough health risk barrier where the content from these latrines is used in agriculture for the production of vegetables eaten raw. However, neither the treatment efficacy of the latrines was assessed, nor the storage time. In an earlier study in the Yon So Commune of Vietnam, Trang *et al*., (2007a) found that some farmers were applying 1 month old dehydrated faeces from their dehydrating toilets in their farms. Among these farmers and their family members a significant enhanced helminth risk, with an overall risk ratio of 1.82 (95 per cent CI: 0.94 -3.05) was found.

Risk mitigation measures

Faeces that are dried and stored between 2 and 20°C should be stored for between 1.5 to 2 years before being used in areas where helminth infections are prevalent. At higher temperatures (i.e. > 20°C) storage of one year is recommended to inactivate *Ascaris* eggs. A shorter storage time of at least six months is required if the stored faeces have a pH of about 9 (i.e. lime will increase the pH of the faeces) (WHO Guidelines, 2006).

The dried faeces should be fully mixed into the soil. Personal hygiene should be adhered to, with hand washing and exchange of clothes after applying (or burying) the dried faeces.

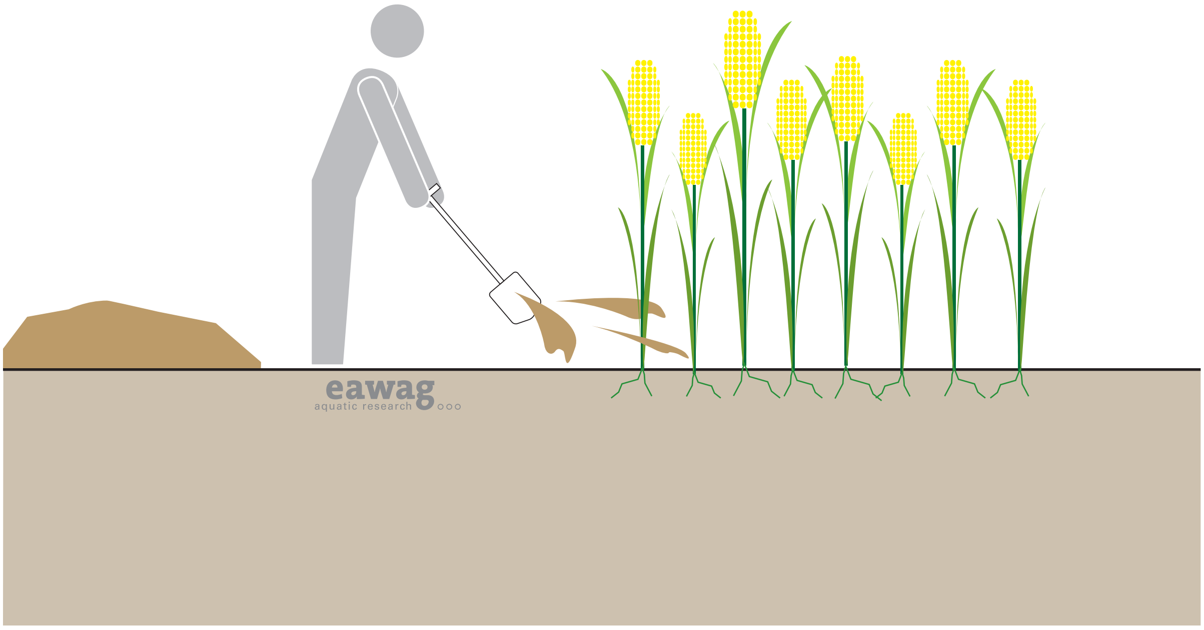
Risk summary

Number of exposed: variable number of farmers and consumers of fertilized crops

Frequency of exposure: LOW for farmers, HIGH for consumers

Level of risk: LOW for the farmers and consumers if storage guidelines are followed. MEDIUM for the farmers and the consumers, if treatment is to short (HIGH for helminth infections).

Application of Compost/Eco-Humus



Technology description
Compost is the product from composting toilets or from secondary treatment, where organic household and garden waste are treated together with excreta. The product can, if properly treated, be applied in the field for crop production and as a soil conditioner or buried in a pit if there is no need for reuse. 'EcoHumus' is an equivalent term for the material removed from a Fossa Alterna (P Morgan, pers. com.). Thermophilic composting generates heat (50 to 80°C) which kills the majority of pathogens present in a short time, while a mesophilic composting is less efficient in its pathogen reduction.

Product from mesophilic composting should therefore not be directly applied to crops eaten uncooked. Secondary treatment of products from mesophilic composting can be applied for enhanced security, including further storage, drying beds and/or thermophilic co-composting.

Exposure pathways
For compost and 'eco-humus' the same transmission pathways apply as for dehydrated faeces. Health hazards associated with the disposal or reuse of well treated compost and eco-humus will be the same as for well-treated dehydrated faeces. Thermophilic composting will render the safest product. Mesophilic compost or compost directly from "the compost chamber of the toilets" applied directly to crops is not considered safe.

Exposure pathways

Risk groups

F C

Epidemiological and health risk evidence
Watanabe *et al.*, (2002) assessed the health risk associated with the consumption of vegetables fertilised with compost prepared from a mixture of sewage sludge and solid waste. Lettuce was the crop selected for the risk evaluation. An average daily consumption of 11.5 g-wet lettuce was assumed, as well as a 90 per

cent (1 log reduction) of the pathogens due to washing before consumption. Given average concentrations of pathogenic bacteria or virus in the compost from 10^{-1}-10^{2} CFU or PFU/g-wet of lettuce. The risk of *Salmonella spp* was higher and above the WHO tolerable annual infection risk, compared to the *E.coli* O157:H7 and Poliovirus 1 annual infection risks.

Risk mitigation measures
Farmer should take care of any sharp object that may be be included if household garbage is included in the mixture. If the compost is directly removed from a Fossa Alterna or a Composting Chamber after insufficient time or mesophilic composting is applied secondary treatment should be considered before application to crops.

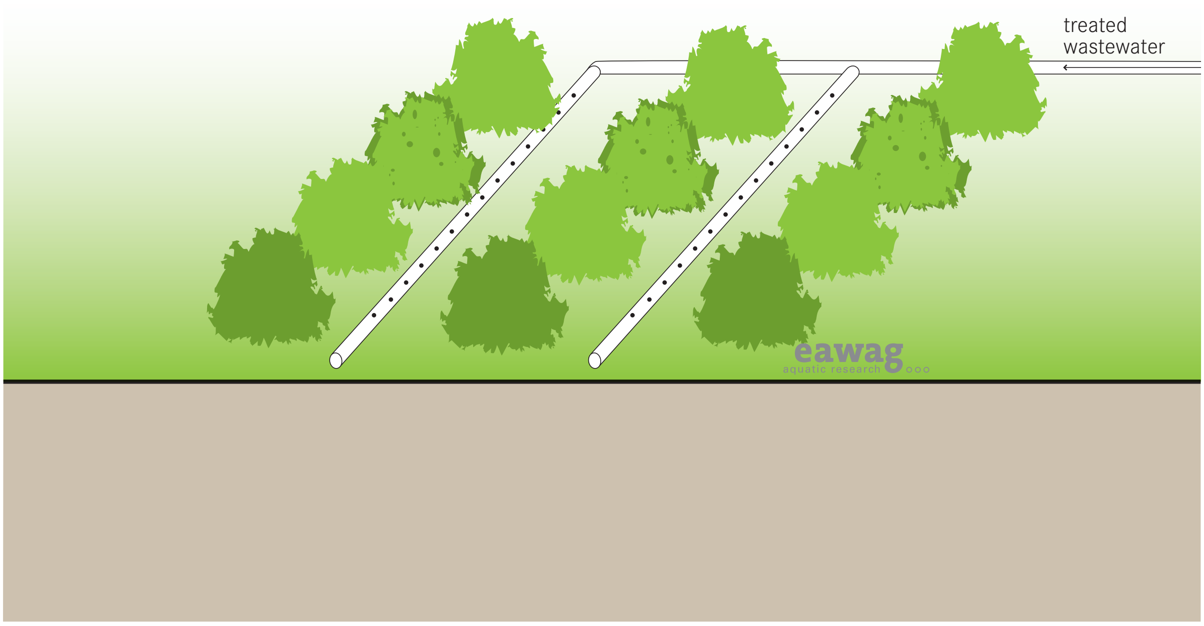
The WHO guidelines (WHO, 2006-4) exemplify the die-off efficiency with a temperature of 50°C for at least one week before it is considered safe. If it cannot be ensured that all parts of the material reach this temperature a prolonged period of composting is required. For systems that generate EcoHumus in-situ (i.e. Fossa Alterna), a minimum of 1 year of storage is recommended to eliminate bacterial pathogens and reduce viruses and parasitic protozoa.

Risk summary
Number of exposed: variable number of farmers and consumers of compost fertilized crops

Frequency of exposure: LOW for farmers, HIGH for consumers

Level of risk: LOW for the farmers and consumers if storage guidelines are followed. MEDIUM for the farmers and the consumers, if treatment is to short (HIGH for helminth infections).

Irrigation/Application of wastewater



Exposure pathways

Risk groups

F C

Technology description
Wastewater irrigation in agriculture is practised as a mean to reduce dependence on freshwater and maintain a constant source of irrigation water throughout the year. Generally, only secondary treated (i.e. physical and biological treatment) wastewater should be used, to reduce the crop contamination and the health risk to workers. Properly treated wastewater can significantly reduce dependence on freshwater, and/or improve crop yields by supplying increased water and nutrients to plants. Irrigation with treated wastewaters is mainly through:

- Manual application with i e watering cans.
- Surface water irrigation where water is routed overland in a series of dug channels or furrows.
- Drip irrigation through perforated pipes near the plant root area.
- Sprinkler irrigation.

Raw sewage or untreated blackwater should not be used from a health perspective due to elevated microbial risks. Similarly, wastewater with substantial industrial effluents (except for food processing plants) should not be used both from a health perspective and from an environmental perspective due to long-term degradation of soils. Soil quality can be degraded over time (e.g. accumulation of salts) if poorly treated wastewater is applied. The application rate must be appropriate for the soil, crop and climate. To minimize evaporation and aerosol transmission of pathogens, spray irrigation should be avoided.

Exposure pathways

Exposure of farmers and consumers to pathogens in wastewater may occur via different pathways depending on the irrigation and post-harvesting handling practices.

- pathogens may be ingested orally, as in the case of farmers using the wastewater for irrigation and consumers of the irrigated produce;
- through skin contact, mainly by farmers using the wastewater; or by inhalation of aerosols, as in the case of farmers.

Aerosols from spray irrigation as an exposure route is also relevant for nearby communities if these are living in the close proximity to the irrigated area. The extent of the health risk and disease burden resulting from these exposure routes depends on the characteristics of the exposed population, frequency/ intensity of wastewater use or consumption of irrigated produce, and the concentration (dose) of the pathogen at the time of exposure.

The main exposure risk is through the crops, where the irrigation practices play a fundamental role for the risk. (1) Sprinkler irrigation relates both to aerosols, deposition on the crops and deposition of droplets on other surfaces or directly on humans. (2) Manual application with water cans relate to a direct exposure to farmers upon contact and a contamination of the crop surfaces that is a function of the contamination level in the applied water. (3) Surface water irrigation will reduce the direct exposure of human during handling and also the contamination of crop surfaces as compared to manual application. Contamination of crop surfaces will occur but usually to a less extent than manual application and sprinkler irrigation. (4) Drip irrigation requires a functional operation and management system. It limit exposure both to farmers, communities and crops and is thereby less risky than the other alternatives. The 4 alternative technologies that broadly has been considered here thereby can be arranged from less risky to most risky, if we assume that the same inlet water quality is applied: Drip irrigation < surface water irrigation < manual application < sprinkler irrigation.

The direct use of untreated wastewater for irrigation can also affect the groundwater quality in porous soils (Matsuno *et al*., 2004).

Epidemiological and health risk evidence

Health risks associated with wastewater irrigation, relate to exposure of pathogens from the farm-to-fork (WHO, 2006). Significant health risks and higher disease burden of wastewater irrigation include the following major risk groups:

- Farmers and their families engaged in wastewater irrigation;
- Consumers of the wastewater irrigated produce; and
- Communities including populations living in close proximity to wastewater irrigation sites, but who are not directly involved in wastewater irrigation.

The health risk evidence for these groups is summarized in Table 5 and commented on further in the following sections.

Farmers engaged in wastewater irrigation and their family members, particularly children, are at higher risk of helminth, diarrhoeal and skin infections. The likelihood to be infected with *Ascaris* and hookworm, are due to the duration and intensity of their contact with wastewater and contaminated soils and children are at higher risk. The *Ascaris* infection risk can vary between relative risks of 1.5 - 18.0 in children and relative risks of 3.5 - 5.4 in adults (Blumenthal and Peasey, 2002). Even where the wastewater had ≤ 1 nematode egg per litre children were still at a high risk of *Ascaris* infection (WHO, 2006).

Additionally an increased risk of diarrhoeal disease from contact with wastewater occurs, particularly in young children (Blumenthal *et al*., 2001; Cifuentes, 1998; Trang, 2007). Wastewater irrigation is also associated with skin infections among farmers as documented from Viet Nam (Trang, 2007), Nepal (Rutkowski *et al*., 2007) and Ghana (Obuobie *et al*., 2006).

The level of contamination relates to the health risks. Communities close to wastewater irrigation sites and exposed to aerosols from untreated wastewater were at risk of bacterial and viral infection when the wastewater has more than 10^6 themotolerant coliforms/100mL. When the concentration was lower (10^4–10^5 thermotolerant coliform/100 mL or less) no risk was recorded (WHO, 2006; Shuval *et al*., 1989). This relates to the distance from the irrigation site and the metrological conditions. No excess risk was found in the study from Israel if the distance was in excess of 300 – 600 m. However, earlier exposure may play a significant role. Children, who are more vulnerable, living 600-1000 m from a sprinkler wastewater irrigated field had a two-fold excess risk of clinical 'enteric' infection. This was only evident in the summer months of the study (WHO, 2006).

Consumers of wastewater irrigated produce account for the greatest health risk and disease burden. Excess viral (norovirus and rotavirus), bacterial, protozoan and parasitic infection risk with the consumption of wastewater irrigated vegetables have been recorded (WHO, 2006). Wastewater irrigated vegetables eaten uncooked, include diarrhoeal outbreaks of cholera (Shuval *et al*., 1984); typhoid (Shuval, 1993) and shigellosis (Porter *et al*., 1984) as well as by Harris *et al*., (2003) and Beuchat, (1998).

Protozoan infections are sometimes neglected when accounting for risks from wastewater.

Risk mitigation measures

For vegetables consumed uncooked WHO (2006) estimates a 6 – 7 log reduction of pathogens from wastewater to fork to achieve a tolerable health based target. This relates to a wastewater quality used for irrigation of 1000 *E. coli* /100mL and < 1 helminth egg/100mL. Advanced biological or tertiary treatment may achieve this microbial quality but will not account for further contamination along the farm to fork chain. No single measure can independently achieve the health based target. Therefore, a multi-barrier approach of treatment and/or non-treatment measures is essential (Table 6). Depending on the wastewater quality, a combination of these measures is used where the sum of the individual log unit reductions equal the required overall reduction of 6 - 7 log units.

Crop selection is an integral part of the precautions. Surface irrigation is prone to large water losses from evaporation but requires little/ no infrastructure and may be appropriate in many situations. Crops such as corn, alfalfa (and other feed), fibers (cotton), trees, tobacco, fruit trees (where fruits are not picked from the ground) and foods requiring processing (sugar beet) can be grown safely with treated effluent. More care should be taken when growing fruits and vegetables that may be eaten raw. Energy crops like eucalyptus, poplar, willow, or ash trees can be grown in short-rotation and harvested for biofuel production. Since the trees are not

Table 5: Summary of microbial health risks associated with the use of wastewater for irrigation

(from WHO, 2006)

Group exposed	Bacterial/virus infections	Protozoan infections	Helminth infections
Farm workers and their families	Increased risk of diarrhoeal disease in children with wastewater contact, if water quality exceeds 10^4 fecal coliforms /100mL; elevated risk of *Salmonella* infection in children exposed to untreated wastewater; elevated sero-response to norovirus in adults exposed to partially treated wastewater	Risk of *Giardia* intestinalis infection significant for contact with both untreated and treated wastewater; One study in Pakistan has estimated a three-fold increase in risk of *Giardia* infection for farmers using raw wastewater as compared to fresh water; increased risk of amoebiasis observed with contact with untreated wastewater	Significant risk of helminth infection of adults and children for untreated wastewater; increased risk of hookworm infections for workers without shoes; risk remains, for children, but not for adults, even when wastewater is treated to < 1 helminth egg/L;
Populations living within or near wastewater irrigation sites	Poor water quality sprinkler irrigation with (10^6 – 10^8 total coliforms /100mL) and high aerosol exposure associated with increased infections; use of partially treated water (10^4 – 10^5 fecal coliforms /100mL or less) in sprinkler irrigation not associated with increased viral infection rates	No data on transmission of protozoan infections during sprinkler irrigation with wastewater	Transmission of helminth infection not studied for sprinkler irrigation, but same as above for flood or furrow irrigation with heavy contact
Consumers of wastewater irrigated produce	Cholera, typhoid and shigellosis outbreaks reported from the use of untreated wastewater, sero-positive responses for *Helicobacter pylori* (untreated); increase in non-specific diarrhoea when water quality exceeds 10^{-4} fecal coliform/100mL	Evidence of parasitic protozoa found on wastewater irrigated vegetable surfaces but no direct evidence of disease transmission	Significant risk of helminth infection for both adults and children with untreated wastewater

for consumption, this is a safe, efficient way of using lower quality effluent.

It should be stressed that these risk reduction practices may not be adopted by all farmers. Drip irrigation and cessation of irrigation are reported to reduce the risks but also reduce farmers' income due to loss of vegetables (Box 13). Therefore, further reduction in pathogens is only assured when these measures are complemented with appropriate post-harvest handling practices. Farmers have to use health protective measures and their children must not be involved in the wastewater irrigation activities. However, in most areas where wastewater irrigation is practiced, farmers rarely use protective clothes even if they have them (Box 13). A survey of farmers who used raw wastewater for irrigation in Dakar, Senegal, revealed that less than half were aware of the health risks posed by the use of raw wastewater for irrigation purposes and very few took precautions to reduce their exposure (eg. by wearing gloves or shoes). Thus, it is important that farmers are motivated or incentivized through effective social-marketing programmes to adopt improved practices.

Risk summary
Number of exposed: variable number of farmers, large number of consumers, variable number of community members

Frequency of exposure: HIGH for farmers (constant exposure), MEDIUM for community, depending on exposure routes. HIGH for consumers

Level of risk: HIGH for the farmer, MEDIUM for the community and consumers, depending on the quality of the irrigation water and the post-harvest practices.

Table 6: Pathogen reductions achievable by various health protection measures

Control measure	Pathogen reduction (log units)	Notes
Wastewater treatment	1-6	The required pathogen reduction to be achieved by wastewater depends on the combination of health protection measures selected
Localized drip irrigation (low growing crops	2	Root crops and crops such as lettuce that grow just above, but partially in contact with the soil
Localized drip irrigation (high growing crops	4	Crops, such as tomatoes, the harvested parts of which are not in contact with the soil
Spray rift control (spray irrigation)	1	Use of micro-sprinklers, anemometer-controlled direction switching sprinkler, inward-throwing sprinkler etc
Spray buffer zone(spray irrigation)	1	Protections of residents near spray or sprinkler irrigation. The buffer zone should be 50-100m
Pathogen die-off	0.5 -2 per day	Die-off on crop surfaces that occur between last irrigation and consumption. The log unit reduction achieved depends on climate (temperature, sunlight intensity, humidity), time, crop type, etc.
Produce washing with water	1	Washing salad crops, vegetables and fruit with clean water
Produce disinfection	2	Washing salad crops, vegetables and fruit with weak disinfectant solution and rinsing with clean water
Produce peeling	2	Fruits, root crops
Produce cooking	6-7	Immersion in boiling or close to boiling water until the food is cooked ensures pathogen reduction

Source: WHO, 2006

Box 13: Effective risk reduction practices may be economic disincentives (based on IWMI, 2009)

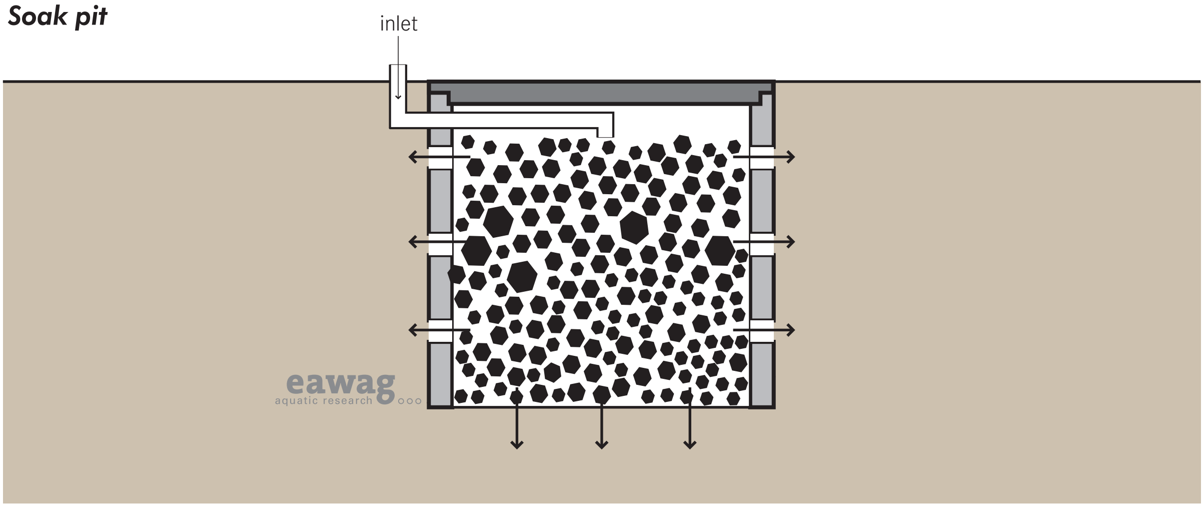
In urban Ghana, farmers predominantly use water from faecally contaminated drains and streams for irrigating vegetables that is eaten raw such as lettuce and cabbage, due to lack of fresh water and high demand for vegetables in the urban areas. Farmers mainly use watering cans to collect and spray the water directly on the vegetables. They do not wear any protective clothes even if they have them, because they think it slows down their work. Their understanding of the link between their activity and disease is weak and perceive that their practice does not cause any significant disease risk.

The International Water Management Institute (IWMI) in West Africa embarked on several studies that evaluated the efficacy of different on-farm and post-harvest interventions for reducing the health risk associated with the practice. At the farm level, i) irrigation cessation before harvest and ii) drip irrigation were assessed as well as different post-harvest washing methods. Significant reduction of health hazards (as measured by the quantities of faecal coliforms and helminth eggs) could be achieved if improved on-farm and post harvest practices were effectively combined. However, the willingness and ability of farmers to adopt and practice these remained a major challenge. Frequent clogging of the drip kits was experienced, which impacted negatively on farmers' yields. Cessation of irrigation also reduced the freshness of the vegetables thus reducing their market value. For instance, during the dry season, lettuce per square meter of farmland lost on average, 0.14 kg fresh weight following irrigation cessation.

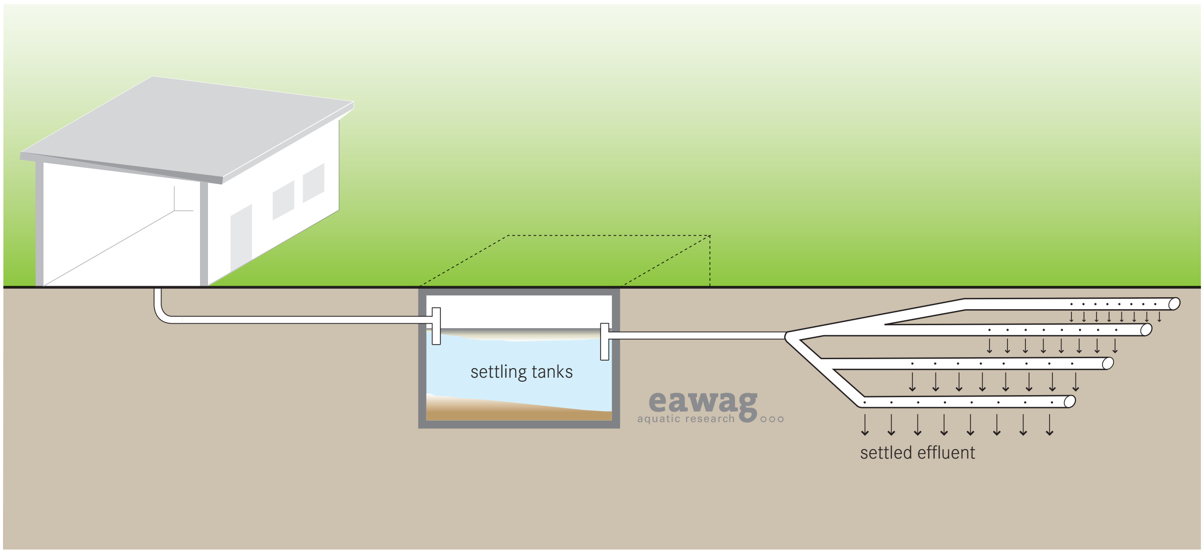
Take home message: Interventions should be felt needed by users, although "the experts" know that a positive impact will occur. In the example above, technologies like here, the drip irrigation" that give trouble and cessation that create a feeling of "loss of benefits" will not be adopted. A sensitization is needed with a clear realization of long-term benefits.

Infiltration- Soak Pits and Leach Fields

Soak pit



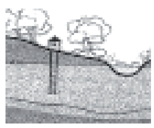
Leach field



Technology description
Infiltration is a general term used to describe a variety of technologies designed to disperse a liquid effluent into a porous soil.

A Leach Field, or drainage field, is a network of perforated pipes that are laid in underground gravel-filled trenches to distribute the effluent from a water-based collection and storage/treatment or (semi-) centralized treatment technology. Effluent is fed into a distribution box which for leach-fields directs the flow into several parallel channels. A small dosing system releases the effluent into the Leach Field. If pressurized

Exposure pathways



Risk groups

and distributed based on a timer it ensures that the whole length of the Leach Field is utilized and that aerobic conditions are allowed to recover between doses. The dimension of the trenches is based on the amount of liquid that needs to be distributed. The bottom of each trench is filled with about 15 cm of clean pebbles and a perforated distribution pipe is laid on top. More pebbles cover the pipe so that it is completely surrounded. This is again covered with a layer of geo-textile fabric to prevent small particles from plugging the pipe. A final layer of sand and/or topsoil covers the fabric and fills the trench to the ground level.

Since the technology is underground it requires little operation and maintenance and users will rarely come in contact with the effluent, whereby direct contact is eliminated. The Leach Field must be kept as far away as possible from any potential potable water sources to avoid contamination and should not be built, where the groundwater level is high. An unsaturated zone of 2 meters is recommended beneath the perforated pipes.

A Soak Pit, also known as a soak- away, is a covered, porous-walled chamber that allows water to slowly soak into the ground. Pre-settled effluent from a collection and storage/treatment or (semi-) centralized treatment technology is discharged to the underground chamber from where it infiltrates into the surrounding soil. The Soak Pit can be left empty and lined with a porous material (to provide support and prevent collapse), or left unlined and filled with coarse rocks and gravel. The rocks and gravel will prevent the walls from collapsing, but will still provide adequate space for the wastewater. In both cases, a layer of sand and fine gravel should be spread across the bottom to help disperse the flow. The soak pit should be between 1.5 and 4 m deep, but it is recommended that the bottom of the soak pit should never be less than 2 m above the ground water table.

As wastewater (pre-treated greywater or blackwater) percolates through the soil from the Soak Pit, small particles are filtered out by the soil matrix and organics are digested by micro-organisms. Thus, Soak Pits are best suited to soils with good absorptive properties; clay, hard packed or rocky soils are not appropriate.

Exposure pathways
The greatest risk of exposure comes from groundwater contamination and overflowing, or malfunctioning. If the leach field or soak pit is working well, a very low risk of exposure pertain. Improper pre-treatment or saturation of the surrounding soil may cause the infiltration to malfunction. In this case, the effluent may back up and pool on the surface, thus possibly exposing the user or community to the wastewater.

If a leach field or soak pit is built in an area with a high water table, the effluent will not be sufficiently degraded as it passes through the soil matrix and will contaminate the groundwater and be transported with the groundwater flow. Careful consideration of the hydrology should be considered before building an infiltration technology.

Epidemiological and health risk evidence
Epidemiological study has assessed the health risk associated with infiltration technologies. Several outbreaks have occurred where the siting of these technologies have been inappropriate.

Risk mitigation measures
To prevent backups and overflows, effective pre-treatment (screening and grease traps) are essential to prevent exposure. With time, the porous material surrounding the leach field pipes, or within the soak pit, will accumulate a biofilm in the solid matrix, and particles. Clogging may occur and the frequency with which the solid material must be replaced will be a function of the pretreatment, treatment and site conditions. When excavating and changing the material, workers must take proper hygiene precautions.

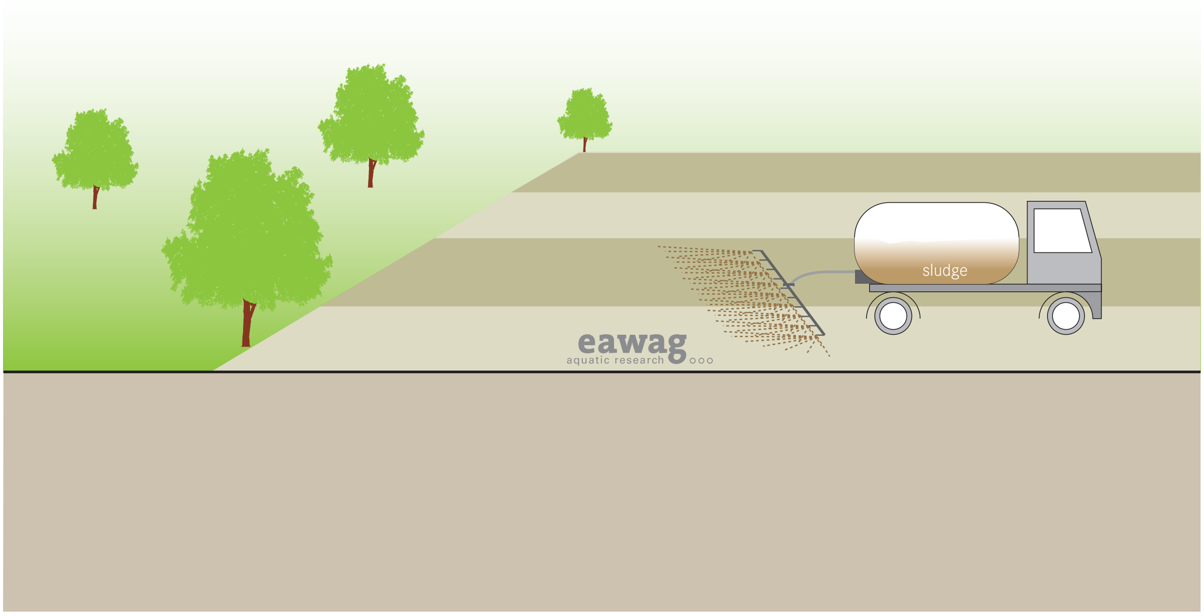
The effluent from an infiltration technology must percolate through the unsaturated soil media. If the soil media is inadequate (e.g too much clay) or if the groundwater table is too high, then the risk of groundwater contamination is increased.

Risk summary
Number of exposed: variable depending on the housing density and the groundwater conditions

Frequency of exposure: LOW, depending on the functioning (maintenance is infrequent); HIGH if groundwater conditions is adverse or surface pooling occurs

Level of risk: MEDIUM for the user (owner of the infiltration technology) LOW-HIGH for the community, depending on the location and functioning of the technology

Application of Faecal Sludge and Biosolids



Technology description
Digested or stabilized Faecal Sludge is sometimes referred to as 'Biosolids'. Depending on the quality, it can be applied to public or private lands, for landscaping or for agriculture. The United States Environmental Protection Agency (USEPA) has a classification based on the treatment and quality (health risk) into "Class A" (i.e. biosolids that can be sold for public use) and "Class B" for restricted use (USEPA, 2007). Biosolids can, depending on quality and classification, be used in agriculture, home gardening, forestry, sod and turf growing, landscaping, parks, golf courses, mine reclamation, dump cover, or erosion control. Biosolids add nutrients although in lower amounts than commercial fertilizers and have bulking and water retention properties with a slow, steady release of nutrients. Spreading can be done with different means, but care should be taken to reduce human exposure. Faecal sludge from domestic septage have less chemical contamination than municipal sludge with industrial inputs. Sludge from large-scale wastewater treatment plants is therefore more likely to have negative environmental effects. Applied amounts and usages of biosolids should account for both pathogens, chemical contaminants and its nutrient contents in relation to the crop uptake. Biosolids can be treated so that they are generally safe and without significant odour or vector problems.

Exposure pathways

Risk groups

F C

In agricultural land application, the main groups of methods used are:

- incorporation: biosolids are applied to the surface of the soil and physically worked into the soil;

- injection: vehicles inject liquid biosoilds into the soil. The injectors may simultaneously disc the field and include fine injection tubes to minimize soil breakup;
- surface application: liquid or cake biosolids are applied to the soil surface but are not incorporated. Surface applied fields can attract vectors and also be an odour nuisance.

Exposure pathways

The land application of biosolid or faecal sludge may affect a) farmers b) consumers and c) communities living close to the application site. Farmers may ingest small amounts of sludge or biosolids during land application through its deposition on surfaces following touching, through direct contact with soil, the sludge or equipment and subsequent oral transfer. They may also ingest aerosols and particles generated from the sludge or biosolids during application. Consumers may ingest pathogens through the consumption of products fertilized with faecal sludge or biosolids. Three factors govern the ingestion of pathogens by consumers: pathogens must be present in the biosolids; the application of the biosolids to the food crop must transfer the pathogen to the harvested crop and the crop must be ingested. Community members may ingest faecal sludge or biosolids upon contact (for example due to spillage, children playing, at site, or similar) or be exposed to pathogens through aerosols generated from the application site. Depending on the land application methods, runoffs from the application site can occur and may lead to the contamination of secondary sites or surface water used by community members (for recreation, drinking, washing dishes and clothes etc). Biosolids or faecal sludge may if it is not fully composted or stabilized also attract flies or vermins that may serve as mechanical vectors for the transmission of infectious materials.

Epidemiological and health risk evidence

Box 14 describes a quantitative microbial risk assessment of faecal sludge application in the Northern Ghana.

A three-year prospective epidemiologic survey was carried out in Ohio, US to compare disease incidence in farm residents and domestic animals at treated sludge application farm (receiving 2 – 10 dry metric tons/ha/year) and compared to control farms (Dorn *et al*., 1985). No significant increase in respiratory illness, gastrointestinal illness, or general symptoms was found among residents or domestic animals of the biosolids application farms. The sludge application rates were in accordance with Ohio and U.S. EPA guidelines. In contrast, Lewis *et al*., (2002) reported elevated disease incidence and mortality among residents of sewage sludge applied fields in Canada and the US. The affected residents lived within 1 km of the applications sites. These residents complained about irritation (i.e. skin rashes and burning eyes, throat, and lungs). In addition 1 in 4 of the 54 individuals surveyed had *Staphylococcus aureus* infections of the skin and respiratory tract. Two mortalities of septicemia and pneumonia were recorded.

In a national study, Brooks *et al*., (2005) evaluated the community health risk associated with the bioaerosols

Box 14: Traditional faecal sludge application in northern Ghana may be safe

(Based on Seidu *et al*., 2008)

In Tamale, Ghana untreated faecal sludge from public VIP latrines and septic tanks is applied on peri-urban farms as fertilizers and soil conditioners for food crops. Before incorporation into the soil, it is spread on random spots or contained in shallow pits to dewater it into 'cake' for easy handling by farmers. Sludge dewatering is done during a few weeks to months, and usually in the dry season when temperature averages 25°C to 33°C and exposed to sunlight.

The dewatered sludge 'cake' is carried and incorporated into the soil by farmers using simple implements such as buckets, shovels, hoes, etc. without any protective clothes (e.g. boots, masks etc). Children living near the faecal sludge farms also play in the farms and sometimes assist with the application.

The rotavirus and *Ascaris* single exposure infection risks were evaluated as: a) accidental ingestion of cake sludge by farmers and children d; b) accidental ingestion of soil-sludge (cake sludge to soil ratio of 1: 100 assumed) mixture by farmers and children after sludge incorporation in the field. Health risks were estimated using quantitative microbial risk assessment.

It can be concluded that a resulting risk for *Ascaris* infection occurs for both exposure scenarios; but without an excess risk for rotavirus if the 'cake' sludge had been dewatered for more than 3 weeks. Children accidentally ingesting 3 months dewatered cake sludge were 2 times more likely to be infected with *Ascaris* than adults.

from Class B biosolids land application sites throughout the United States. Downwind aerosol samples from biosolids loading, unloading, land application and background operations were assessed. All samples were analysed for indicator bacteria, coliphage, enteroviruses, hepatitis A virus and norovirus. Biosolids loading operations resulted in the largest concentrations of these aerosolized microbial indicators. Microbial risk analyses were conducted on loading and land application operations and their subsequent residential exposures determined. The annual risks of infection was below the WHO target values, but the highest risk level occurred during loading operations, and resulted in a 4 x 10^{-4} chance of infection from inhalation of coxsackievirus A21. Land application of biosolids resulted in risks that were <2 x 10^{-4} from inhalation of coxsackievirus A21. The study concluded that bioaerosol exposure from biosolids operations poses little community risk. A similar finding was made in Ghana, where Seidu (2010) found low rotavirus infection risk from exposure to aerosolized rotavirus during the field application of faecal sludge.

It can further be concluded in general that the level of contamination of the sludge is the determinant of the risk.

Risk mitigation measures

The pathogen, heavy metal, nutrient, and organic content of sludge is extremely variable; the quality of the sludge (or excreta) dictates where and how much of it, can be used.

Low quality sludges can be used in mine reclamation, forestry or slope stabilization projects. Higher quality sludges can be used in agriculture, though usually only after strict monitoring and analysis. The origin and content of the sludge will dictate where it can be used so that risk is minimized. To minimize the health risk and environmental impact associated with biosolids application, the USEPA categorizes biosolids into two main classes - A and B - based on pathogen removal (Table 7) and on the type of treatment prior to application. These are grouped in processes to further reduce pathogens (PFRP) versus processes to significantly reduce pathogens (PSRP). Class A biosolids must meet specific criteria to ensure they are safe in areas used by the general public such as golf courses while Class B biosolids can be applied to agricultural land (with some limitations) or disposed of in a landfill. The corresponding treatment requirements in respect of microbial density for the two categories are summarized in Table 7.

The World Health Organisation specifies limits for the application of biosolids similar to the provisions made by USEPA for Class A biosolids; but more stringent on helminth ova; < 1000 *E. coli*/ g TS and < 1 helminth ova /g TS (WHO, 2006-4).

The USEPA specifies guidelines regarding the minimum duration between the application of class B biosolids and the harvesting of certain crops, the grazing of animals, and public access (Table 8). These minimum durations are primarily based on the inactivation of helminth ova, considered to be the most persistent in the environment. These minimum durations, significantly reduce health hazards to levels equivalent to those achievable with the unregulated application of Class A biosolids.

Stockpiling of Class B biosolids in the open field should be avoided, and if practiced, should be done in a manner that will prevent runoff to surface water or any adjacent land where community members may be exposed. Further protection of surface water bodies can be achieved with minimum set-back distances from the applied site to surface water sources. Factors such as the specific uses of the surface water, topography, buffer strips and the method of biosolids application may be considered in establishing set-back distances. Runoffs-can be reduced if liquid sludge or biosolid is injected into the soil rather than spreading on the surface.

Furthermore, irrespective of the sludge quality, farmers (workers) have to wear protective clothes (e.g. boots, gloves, masks etc) during sludge/biosolids application.

Table 7: USEPA classification of biosolids

Class	Indicator or pathogen	Density limits (dry wt basis)
A	*Salmonella* Fecal coliforms Enteric viruses Viable helminth ova	<3 MPN/4 g or <1000 MPN/g and <1 PFU/4 g and <1 ova/4 g
B	Fecal coliforms	<2,000,000 MPN/g

MPN: Most Probable Number

Source: USEPA (1992)

Table 8: Minimum duration between application and harvest/grazing/access

	Period between application and harvest/Grazing/Access		
Criteria	**Surface**	**Incorporation**	**Injection**
Food crops whose harvested may touch the soil /biosolids mixture (beans, melons, squash etc)	14 months	14 months	14 months
Food crops whose harvested parts grow in the soil (potatoes, carrots etc)	20/38 months[a]	38 months	38 months
Food, feed, and fiber crops (field corn, hay, sweet corn, etc)	30 days	30 days	30 days
Grazing Animals	30 days	30 days	30 days
Public access restriction			
High potential[b]	1 yr	1yr	1yr
Low potential	30 days	30 days	30 days

Class B Biosolids Applied to the Land

a: The 20 month duration between application and harvesting applies when the biosolids that are surface applied stays on the surface for 4 months or longer prior to incorporation into the soil. The 38 month duration is in effect when the biosolids remain on the surface for less than 4 months prior to incorporation;
b: This includes application to turf farms which place turf on land with a high potential for public exposure.

Source: Adapted from 40 CFR Part 503 (USEPA, 1992)

Populations, especially children, should be prevented from accessing fields where sludge or biosolids is applied.

To reduce consumers' health risk, some of the post harvest washing practices, can also be employed for further health hazard reduction if biosolids is applied to vegetables eaten uncooked. As noted in Table 6, washing of salad crops, vegetables and fruit with clean water can lead to a 1 log unit reduction in pathogens; washing with a weak disinfectant solution and rinsing with clean water can lead to 2 log unit reduction; peeling of fruit vegetables and root crops can lead to a 2 log unit reduction and immersion of salad in boiling or close-to-boiling until it is cooked can result in 6 – 7 log pathogen reduction (WHO 2006).

Risk summary
Number of exposed: variable number of farmers, community members and consumers

Frequency of exposure: MEDIUM for farmers (depending on how much they apply), LOW - MEDIUM for community depending on site and secondary contamination and for consumers depending on habits

Level of risk: LOW – MEDIUM for the farmer, LOW for the community, depending on the quality of the sludge; and LOW – HIGH for consumers depending on the quality of the sludge and amounts deposited of eatable parts that are consumed raw.

Technology	Barrier efficiency and robustness			Exposure pathways	Likelihood of occurrence	Diarrhoea Risk				Helminths Risk				Risk Management
	Input pathogens	Treat-ment	Typical malfunction			User	Worker	Farmer	Community	User	Worker	Farmer	Community	*assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Fill and cover/ abor-loo	Viruses Bacteria Protozoa Helminths	NA NA NA NA	-pit is not filled in or covered properly	Ingestion of excreta (E1)										-a tree or plant should be put on top and/or the area should be clearly marked (the contents will reduce in volume over time)
				Contaminated groundwater/ surface water (E5)										
Appli-cation of urine	Viruses Bacteria Protozoa Helminths	NA NA NA NA	-urine is splashed onto skin or inhaled due to improper spread-ing technique - urine is sprayed onto vegetable leaves, fruit	Ingestion of urine (E1)										-drip irrigation and/or application from a low level should be used -application should be stopped 1 week before harvesting
				Inhalation of urine aerosol (E4)										
				Consumption of contami-nated produce (E9)										
Appli-cation of dehy-drated faeces	Viruses Bacteria Protozoa Helminths	NA NA NA NA	-dried faeces pow-der blows onto skin and clothing -faeces are not sufficiently dried or hygienized	Ingestion of dehydrated fae-ces (E1)										-a face mask (bandana, handkerchief) should be worn -the application should not be done on a windy day -the dried faeces can simply be put in a small hole and buried to pre-vent further transmission
				Inhalation of aerosols / particles (E4)										
				Consumption of contami-nated produce (E9)										
Appli-cation of com-post/ eco-humus	Viruses Bacteria Protozoa Helminths	NA NA NA NA	-garbage is mixed into the contents of the pit and is there-fore present in the compost- must be sorted -insufficient degra-dation	Ingestion of compost/Eco-humus (E1)										pit must be properly designed for adequate storage time -compost should be well-mixed into soil before planting and/or transferred to another compost pile for further maturation
				Inhalation of aerosols/parti-cles (E4)										
				Consumption of contami-nated produce (E9)										

Figure 13: Disposal and/or reuse: exposure scenarios and health risk levels

Technology	Barrier efficiency and robustness			Exposure pathways	Likelihood of occurrence	Diarrhoea Risk				Helminths Risk				Risk Management
	Input pathogens	Treat-ment	Typical malfunction			User	Worker	Farmer	Community	User	Worker	Farmer	Community	*assuming that standard hygiene behaviour and practices are followed (including hand-washing, toilet cleaning, etc.)
Irriga-tion	Viruses	NA	-water is sprayed onto skin and crop	Ingestion of irrigation water (E1)										-drip or furrow irrigation should be employed -wastewater should be applied to crops that are not eaten raw, preferably foods or materials that are processed further (e.g. fruit trees, tobacco, cotton) -crops grown in wastewa-ter should be washed and/ or disinfected before con-sumption
	Bacteria			Dermal contact (E2)										
	Protozoa	NA		Inhalation of aerosols (E4)										
	Helminths	NA		Ingestion of contami-nated groundwater/sur-face water (E5)										
				Consumption of contami-nated produce (E9)										
Aquac-ulture	Viruses	NA	-workers immerse parts or all of their bodies into the ponds -ponds are improperly designed and attract vectors	Ingestion of wastewater (E1)										contact with the water should be minimized -fish that is grown in wastewater should be transferred to freshwa-ter ponds for some days before they are harvested -fish must be well-cooked before consumption
	Bacteria			Falling into pond (E2)										
	Protozoa	NA		Consumption of fish (E9)										
	Helminths	NA												
Infil-tration –soak pit and leach fields	Viruses	NA		Ingestion of contami-nated groundwater/sur-face water (E5)										
	Bacteria													
	Protozoa	NA												
	Helminths	NA												
Applica-tion of faecal sludge and bio-solids	Viruses	NA		Ingestion of sludge or biosolid (E1)										-sludge and biosolid should be well treated before application to crops eaten raw,. Preferably should be applied to crops that are processed further (e.g. fruit trees, tobacco, cotton) -crops grown in sludge/ biosolid should be washed and/or disinfected before consumption
	Bacteria			Dermal contact (E2)										
	Protozoa	NA		Inhalation of aerosols (E4)										
				Ingestion of contami-nated groundwater/sur-face water (E5)										
	Helminths	NA		Consumption of contam-inated produce (E9)										

Figure 13 (cont): Disposal and/or Reuse: Exposure Scenarios and Health Risk Levels

PART 3 - SANITATION SYSTEMS AND HEALTH

This chapter explores exposure in a system framework. For each technology, critical control points for exposure and disease transmission are identified in a system context. Furthermore, health risk protection/mitigating measures are exemplified for some of the control points as cases.

Structure of the chapter

Seven different 'typical' system configurations are presented. A visualization of each system configuration is presented as a combination of technologies and the products which are put into and generated by the system.

Each system description includes an overview of the typical components and a description of where this system is currently employed. The successes and failures of each system are discussed as well as the key exposure points in the systems context.

Bucket Latrine System

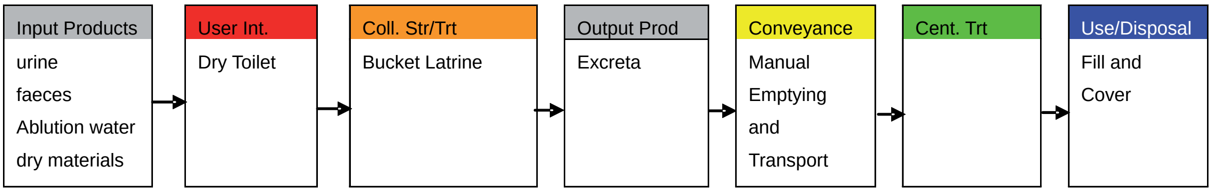


Figure 14

Typical system description

A Bucket latrine system is the most basic, and most risky of all the systems presented here. The bucket latrine system may be appropriate in the first phase of an emergency situation but because of the need for a required frequent emptying and transport it should not be considered as a long term solution.

Case study

One of the most well documented cases of Bucket Latrine use in an urban setting was undertaken by the WSP program during the early 90s. As part of a strategic sanitation planning project in Kumasi, Ghana, a comprehensive assessment of the sanitation situation was made. Approximately 25 per cent of the public latrines were bucket latrines (serving 40 per cent of the population) and another 25 per cent of the population had bucket latrines at home. The buckets were generally emptied by workers/companies who typically came two times per week. Some buckets were emptied by desludging trucks (15 per cent of the buckets). The collected sludge was most often dumped locally, either into waterways or on open dumps due to the lack of centralized depot or treatment facilities (Saidi-Sharouze, 1994).

About 150,000 people were using privately owned bucket latrines. Emptying of these generated about $16,000 per month in emptying fees, or the equivalent of about $0.11 per month for emptying. Compared to $0.25 for using public latrines, the bucket latrine was both cheaper and more convenient. As a percentage of income, families with bucket latrines were spending slightly more than 1 percent of their income on emptying.

Potential for exposure

The groups with the greatest risk for exposure in this case (and in most bucket latrine systems) are the workers, or the person who is responsible for emptying the buckets. Though protective equipment and practice can minimize exposure, the need to constantly handle excreta results in an elevated oral transmission risk and consequently a high risk for infection.

There is also an elevated exposure risk for the community at large depending on spills and how and where they live in relation to the dumping site of the excreta. Direct contact, water contamination and/or the inhalation of aerosols from the discharged sludge are all potential exposure routes, which could disproportionatly, affect those living in the vicinity and especially children living or playing in the neighbourhood.

System gaps

In relation to this case the following can be stated. “Because the owners had little contact with the excreta, and there was a reliable emptying service available, they did not perceive serious problems with the bucket latrine system. In fact, from the point of the user, the ‘system’ worked very well”. From a systems perspective however, the system was seriously flawed. The first part of the system, i.e. the User Interface and Collection and Storage technologies were adequate for the user, and the Conveyance technology was satisfactory. Though, because there was no Treatment or Reuse/Disposal Technologies linked, the system was effectively open. A transfer station would provide the manual emptiers with a safe, reliable option for disposing of the collected excreta. In Berekum, a different city in Ghana, one study reported that the public toilets were being used as informal transfer stations: an average of 8 people per minute emptied their full buckets into a public VIP (Tipple, *et al.*, 1999). A vacuum truck would be required to empty the transfer station periodically, and therefore the cost of operation would have to be borne by an organized group or department. A drying bed would be appropriate for dewatering the sludge collected, and the dried sludge could be further treated in a co-composting facility, and resold for agricultural use if properly dired or co-composted. In fact, a drying bed and co-composting facility was established outside of Kumasi, located about 15 km from the centre. Due to the distance it could only be served by motorized vacuum trucks, and not by manual emptiers who were still emptying bucket latrines often indiscriminately.

Single Pit System

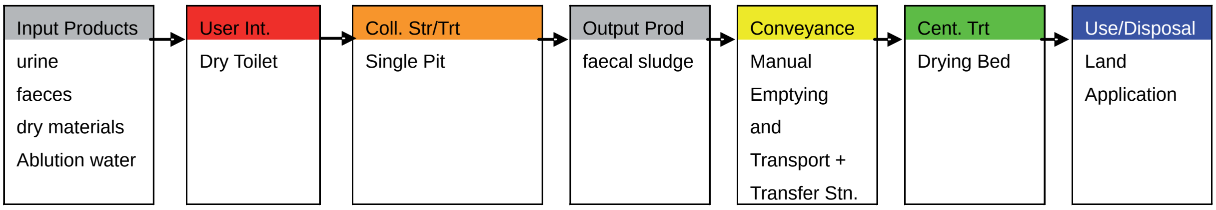


Figure 15

Typical system description

A typical Single Pit System would consist of a toilet placed on top of a single pit, with or without ventilation (VIP). The pit would be used to collect urine, faeces, greywater and anal cleansing water (if anal cleansing with water is practiced). When the pit is full, it could be manually emptied by the use of a manual emptying technology, by hand or with added technologies like the Gulper or Vacutug. The emptied excreta would then be disposed of in a transfer station and later be transported to a centralized treatment facility like a sludge drying bed.

Case study

Variations of this system are common in dense, urban African slums. The most common operating and maintenance problem is the emptying and transportation of the pit content. In dense urban settlements, the housing density and lack of roads prevent vacuum trucks from accessing and emptying the pits. Manual emptying technologies like the 'Vacutug' developed by UN-HABITAT was designed specifically for these contexts to meet a severe need. The benefit of this technology is that it allows the user to maintain a convenient sanitation technology onsite, while the downside is that there is rarely an adequate way of disposing of the excreta that is pumped out. Because of the urban context there is no place for urban agriculture and therefore, no need for the sanitation products to be re-used. When this system is installed, care must be taken to ensure that there is a suitable technology available to treat and discharge the excreta collected.

The Vacutug consists of a 500L steel tank (appropriate for 1 emptying load), connected to a check valve and two ports for sludge input and discharge. The tank is mounted on a steel frame with wheels. The vacuum pump can suck at a rate of 1,700L (airflow) per minute. It can move at a speed of up to 5 km/h. The vacutug can also discharge the sludge under pressure.

Kibera in Nairobi has an unknown number of permanent and temporary residents, but estimates reach up to 2 million inhabitants. It is an extremely dense settlement and covers a small area of 225 ha that is strategically placed to provide labour to Nairobi's industrial area and city centre. The high density, unplanned and crowded houses together with a lack of infrastructure has led to severe drainage, sanitation and solid waste problems.

Within Kibera, there are 11 villages in which the Vacutug project has been or is operating. In one pilot study, the NGO in charge gained permission from the Nairobi City Council to dump the sludge into the sewers. Kibera is relatively small and several sewer lines are crossing. People use these open sewers as toilets and have to walk for less than half an hour to reach them.

For the literally thousands of people who own pits which have never been emptied, this technology represents the missing link in the system which had not been envisaged when the pits were designed, i.e. they were isolated, hard to access, away from roads, and/or on difficult slopes.

Potential for exposure

The men who operate the Vacutugs have high risks of exposure, both because of the close contact with the excreta and because of the frequency of the contact.

The family, as well as neighbouring community members, may infrequently be exposed during emptying from accidental spills. The community at large may be exposed to additional potential transmission, depending on where and how the sludge is stored or disposed of, and the way in which it is transported. Technologies like the Vacutug and Transfer stations significantly reduce the exposure risk for the community as compared to manual emptying.

System gaps

Though the sludge from this project was dumped into a sewer, the majority of sludge is still emptied into rivers and alleys. There are no known transfer stations that are accessible to private operators at this point. Furthermore, the dumping into sewers may affect the treatment plant through increased loading.

Transfer stations, though common for septage in North America, are a relatively new concept for use in Africa. The successful use of a transfer station implies that either;

- there is sufficient flow in the sewer to dilute and transport heavy sludge to a centralized facility with adequate treatment, OR
- that the transfer station operates more as a centralized holding tank which can then be emptied by a mechanical emptying truck and transported to a dedicated faecal sludge treatment facility.

The reality in most large cities in developing countries is that neither of these conditions exists. Transfer stations are simple interventions that could, in many cases, complete still-open sanitation systems and significantly reduce the exposure of pathogens to large populations.

Waterless System with Alternating Pits

Input Products	User Int.	Coll. Str/Trt	Output Prod	Conveyance	Cent. Trt	Use/Disposal
urine faeces ACW	Dry Toilet	Fossa Alterna	Eco-humus	Manual Emptying and Transport		Application of Compost/Eco- humus

Figure 16

Typical system description

A typical Waterless System with Alternating Pits could consist of a dry toilet placed above one of two shallow, unlined pits, which are used in alternation. Soil and/or bulking material would be added to reduce wetness, help balance the carbon to nitrogen ratio and facilitate in-situ composting. When one pit is full, the toilet slab (and super structure, if it does not cover both pits) would be moved to cover the second pit. After 1 year of filling of the second pit, while the first one is not in use, the contents of the first pit would be excavated using a shovel and would be mixed into the soil.

Case study

This system is common in rural communities that need nutrients for agriculture. In Zimbabwe numerous Fossa Alternas have been constructed mostly in the rural and peri-urban areas surrounding Harare for this purpose. The fossa alterna was created to meet the needs of rural communities with no sanitation, poor soil, few resources, little water, and a desire for improved agricultural production.

A Dry Toilet (or in some cases a Urine-Diverting Dry Toilet) is connected to one of two shallow, unlined pits. It is important that moisture is free to move out. Similarly important is the continued addition of bulking material which will facilitate the decomposition of organic material and prevent compaction of the excreta.

The removed material can be stored for longer periods in containers or bags after excavation. In Zimbabwe most people will however simply mix the material into topsoil before crops are planted. Approximately 0.5-0-6 cubic metres of material will be produced by a family in a year sufficient for a garden of about 15 square metres. Green peppers, beans, onions, tomatoes, spinach and other leafy greens have been cultivated successfully in eco-humus enriched gardens.

Zimbabwe shows that the non-odourous material that is removed from the Fossa Alterna is easily adopted in small-scale agriculture.

Potential for exposure

The potential exposure risks relate to the possibility of emptying the pits before the contents have been stored and decomposed for a sufficient time of 1.5 - 2 year degradation period.

There is a minimal risk of exposure to those who are consuming the products of low-growing vegetables, which are consumed fresh.

System gaps

The success of this system is due to the fact that the emptying is simplified, can be used locally and that the need for (semi-) centralized treatment is less.

Waterless System with Urine Diversion

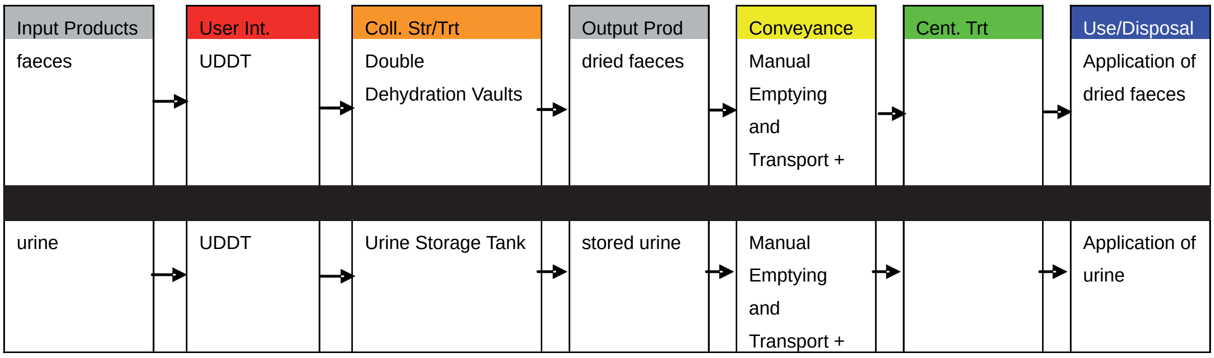


Figure 17

Typical system description
A typical Waterless System with Urine Diversion would consist of a Urine-Diverting Dry Toilet placed over Double Dehydration Vaults, with a connection to a urine storage tank for the urine. The faeces chambers are used in an alternating fashion- with a cycle of 6 months to one year or longer- so that when one side is full, the faeces in the other chamber have been dehydrated and hygienized (depending on time and location). The urine would be applied onto local gardens or fields and the dried faeces would be buried or mixed into the soil before planting.

Case study
This system is common in water-scarce, rocky, or difficult to access areas where typical pit-based systems can not be easily introduced.

In the eThekwini Municipality in South Africa, a large-scale project was implemented starting in 2002 in an attempt to mitigate the recent outbreaks of cholera and to reduce the backlog of over 140,000 households without access to adequate sanitation. More than 70 people died in a cholera outbreak in KwaZulu-Natal and tens of thousands more were affected during 2000-2001.

When the project began to improve the sanitation in the rural peri-urban area, a system based on dehydration chambers with urine diversion was selected as an easy and cheap technology to empty. The urine is not used in agriculture but allowed to soak into the ground via a soak pit. Previous programs had installed thousands of Ventilated Improved Pits (VIPs) which all required costly and sometimes difficult emptying. In 2006 over 100,000 VIPs were in urgent need of emptying.

The emptying is the major barrier against acceptance. More than half of the families felt 'very bad' about emptying the chambers. Therefore the municipality has established a network of contractors who empty the vaults for a small fee. The family is also given a rake and gloves for cleaning.

By 2010 more than 80,000 urine-diverting units were in place. In an epidemiological study performed in the intervention area (Knight *et al*., 2011, submitted) on multiple interventions of urine diverting toilets without reuse, safe water and hygiene education, a risk reduction of 41 per cent of diarrhoea episodes (adjusted Incidence Risk Ratio: 0.59 (95 per cent Confidence Interval 0.34 - 0.96; $p = 0.033$) was obtained in the areas of the multiple intervention.

Potential for exposure
There may be some risk associated with infiltrating urine directly into the ground, as it may contaminate the groundwater but these risks are small compared to the benefits of the hygiene provided with a reduced occurrence of open defecation.

There may be a small risk associated with the emptying of the dehydrated faeces. If the vaults have not been used properly, if the material is wet, or if to short time is applied to dehydrate the contents, the faeces may not be thoroughly hygienized and may therefore be more risky to handle especially during times when the users have diarrhoea. Reuse of the excreta in agriculture will not involve any main risks if the material is properly stored for long enough periods in alternating waterless pits. In case of a single pit the risks related to emptying is higher and the material needs to be stored in a secondary pit or treated at a treatment station.

System gaps
The dehydrated faecal material is usually buried in a second shallow pit after excavation. The municipality is not advocating the use of it as a soil conditioner.

Since the urine is not used, the full potential of the nutrients is not realized; however the system still provides a high degree of safety and risk reduction. By containing the faeces and allowing it to dehydrate in the absence of moisture, the risk of further pathogen transmission from the material is low.

Pour Flush System with Twin Pits

Input Products	User Int.	Coll. Str/Trt	Output Prod	Conveyance	Cent. Trt	Use/Disposal
urine faeces ACW	Pour-Flush Toilet	Twin Pits for Pour Flush	Compost/Eco-humus	Manual Emptying and Transport +		Application of compost/eco-humus

Figure 18

Typical system description

A typical Pour Flush System with Twin pits would consist of a toilet placed over (or adjacent to) Twin Pits for Pour flush. Urine, faeces, flushwater, anal cleansing water (if practiced) and in some cases greywater, would enter into the pits, which are used in an alternating fashion. The walls of the pits are porous and allow the liquid to infiltrate into the soil so that with time, the contents reduces in moisture and volume, and eventually degrades into a compact, soil-like material which can be excavated with a shovel. The material can then be used directly in agriculture or treated further in a composting process to further reduce the pathogen load.

Case study

This system is common in India, where the Sulabh system has become commonplace with more than 1.2 million individual house units and public facilities at 7500 locations which together serve more than 10 million people.

The pour-flush toilet that is the User Interface, is designed with a steep slope and a 20 mm waterseal to minimize the amount of water required (only 1.5-2 L) and odours which would otherwise escape. The twin pits are designed to contain material for about 2 years before it needs to be emptied. The material that is produced after 2 years of degradation is solid, easy to shovel and rich in nutrients. The popularity of this system is in part due to the fact that it eliminates the need for manual scavenging of fresh human waste. Though technically illegal, the practice of manually scavenging by the lowest caste continues - putting the waste collector in constant risk of exposure to pathogens, flies, and gases. The emptying of the Sulabh system is easier, more hygienic and requires in theory emptying only once every 2 years.

Potential for exposure

Though the need to empty the pits is infrequent, the emptying, will pose an exposure risk, which varies due to the storage time without adding fresh material. The person emptying the pit may be exposed to a significant amount of pathogens, though in most cases, the risk should be low due to extended storage time.

Because the pits and the connection to the toilet is covered, there is rarely an opportunity for the user of the system to be exposed to the excreta, except during routine cleaning and maintenance. As in other system alternatives the secondary use is important to consider in an exposure assessment.

System gaps

The provisions for emptying are by Sulabh or a private enterprise. The handlling and/or disposal of the compost/sludge that is generated is crucial and linked the potential risks. The material that is produced after 2 years of maturation in the pits is safe and useful for agriculture. If the material can not be used in peri-urban and urban centres, due to land limitations communal discharge points (e.g. community gardens) or transfer stations can function as intermediate storage points before further transport.

Blackwater Treatment System with Infiltration

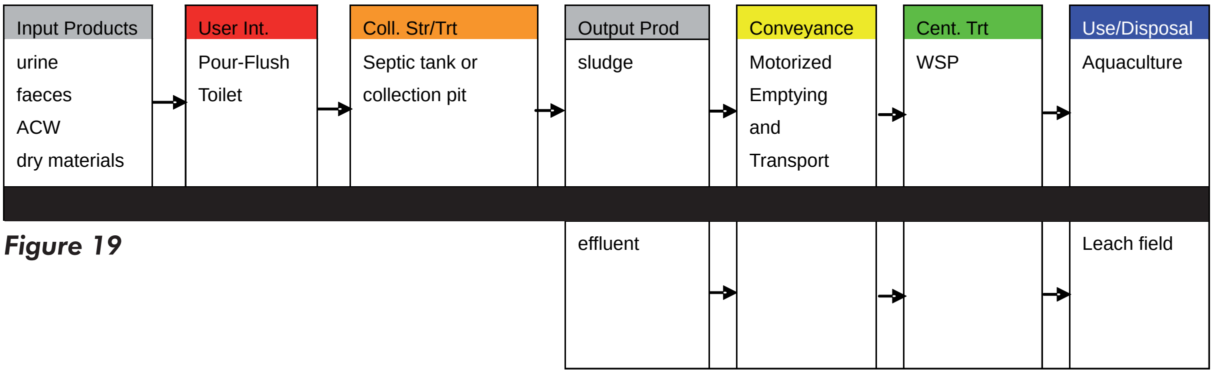


Figure 19

Typical system description
A typical Blackwater Treatment System with infiltration would consist of a Pour-Flush or Cistern Flush toilet connected to a septic tank or to a pre-treatment system followed by a leach field. This system requires water and a significant space for the leach field for adequate infiltration. The septic tank requires regular desludging with a vacuum truck to accommodate for the sludge that is generated. The sludge is then transported to a (semi-) centralized treatment facility, commonly a waste stabilization pond or to a conventional wastewater treatment plant for further treatment before it is used or disposed of. (Often this system is designed with little consideration for the emptying and collection of the sludge generated in the septic tank, even though the pathogenic content here may be high).

Case study
This system is common in Costa Rica, since septic tanks are the only type of decentralized sanitation technology that is allowed. In one peri-urban area of San José - La Europa - every family has a septic tank, but the sanitation system is incomplete. The plots that the families live on are too small for a leach field, and in many cases the septic tank is directly below the house (the access port to the septic tank is often inside the house). With no place for a leach field, and with a high density of septic tanks in a small area, the ground beneath La Europa is completely saturated with wastewater. This is thus not septic tanks but instead leach pits. These have been under-designed and do not provide the residence time necessary to provide any degree of protection. Furthermore, the town is built on the side of a valley, with poor, inaccessible roads. Therefore, most of the septic tanks (leach pits) in La Europa have never been emptied. The raw wastewater that enters the units essentially exits without a substantial treatment.

Potential for exposure
In this system, the whole community is continually at risk of exposure, since the effluent has nearly saturated the soil below the town. Further some people may have connected their septic tanks directly to the storm water drains and are discharging raw sewage into the community drains.

If this system operated correctly with closed septic tanks and is maintained consistently, it provides a high degree of safety and risk reduction. Systems based on septic tanks that are emptied by professional vacuum trucks that discharge into government controlled sludge facilities are the most common sanitation system in rural North America, where safety and environmental standards are rigorous.

System gaps
The major gaps in this system are the poor construction of the collection units and lack of collection and transportation. The lack of a semi-centralized facility for the wastewater and/or effluent treatment further aggrevates the situation.

Considering the social, geographic and environmental conditions of La Europa, the so called septic tanks could be connected to simplified sewers for collectionto prevent infiltration in the soil (posing a high risk to those using the groundwater). A semi-centralized treatment facility, for example a constructed wetland, could treat the collected wastewater.

Though there is no recovery of beneficial products (e.g. nutrients) the water discharged from the constructed wetland will contribute an environmental benefit to the nearby river.

Blackwater Treatment System with Sewerage

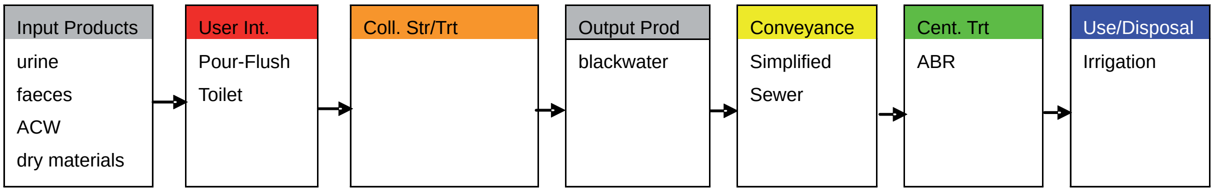


Figure 20

Typical system description
A typical Blackwater Treatment System with Sewerage would consist of Pour-Flush or Cistern Flush toilets connected to an interceptor tank (for settling out solids and larger particles), then to a simplified sewer network that is shared between the community members. The effluent collected in this 'condominial sewer' would then be transported to a semi-centralized treatment technology.

Case study
Condominial sewers were developed and made popular in Brazil in the 1980s. Because of the simplicity and robustness the technology has been replicated extensively in Brazil.

The design of the sewer network in Santa Maria in Brazil was determined by the watershed that ran through the town, and divided the network into two natural catchment areas. It included twenty-one micro-networks that took advantage of the topography to minimize excavation and length of sewer pipe. The small-diameter pipes (starting at 100 mm for networks and branches) meant that significant material and excavation savings was done.

The sewer network was then connected to anaerobic reactors (an Upflow Anaerobic Sludge Blanket reactors) constructed of pre-molded tanks. As a further polishing step, the effluent was sent to High Rate Oxidation Ponds (similar to Waste stabilization Ponds but with increased oxygen, and therefore increased treatment capacity with a decreased footprint). The ponds were used to further remove organic matter and pathogenic organisms.

The effluent that was produced was then dispersed in an infiltration field into the soil for further removal of the solids (mostly algae) that had accumulated.

A connection to this system ranged between $95-175 USD and was divided into 24 monthly payments. The construction was done mostly by private contractors, though the work was managed and monitored by the municipal authority.

This project is an example of how a high level of service and hygiene can be brought to a community which could otherwise not afford a water-based, semi-centralized system. The key factors to success are that the community and the municipality were able to co-operate, that the municipality was open to innovative ideas, and that the community was willing to pay for the services, and were offered different payment and connection options in order to do so.

Potential for exposure
This system offers a high degree of protection and minimal risk of exposure. The most likely point of exposure would come from the routine maintenance of pipes and the occasional emptying of the interceptor tanks as well as at the oxidation ponds. However if proper personal protection equipment is worn, the risk of infection is minimal. Additionally the downstream exposure of the effluent from the system needs to be considered. This also relates to its potential use in agriculture.

System gaps
Care must be taken in the regular desludging of both the interceptor tanks and the semi-centralized treatment technology. The solids must be emptied, transported and either treated further or disposed of. A transfer station (Waste Stabilization Pond or dedicated sludge treatment facility) must be available and willing to accept the emptied sludge (these facilities in turn will in turn generate both effluent and treated sludge which must then be disposed of). Disposing and/or using the emptied sludge directly are not recommended.

(Semi-) Centralized Treatment System

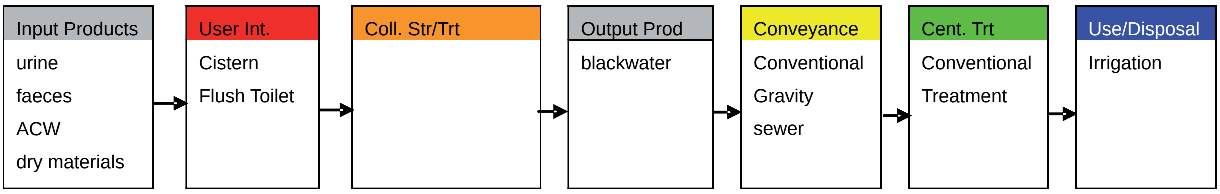


Figure 21

Typical system description

A typical (Semi-) Centralized Treatment System would consist of Pour-Flush or Cistern Flush toilets connected to a Conventional Gravity Sewer which would convey the wastewater to a semi-centralized or centralized treatment facility. This system is common in North America, Europe and the commercial centres of most African and Asian Cities, regardless of whether there is sufficient water and operational capacity to allow it to function properly. When there is inadequate electricity or skilled workers to operate the treatment plant, the raw wastewater is often discharged directly into the local water body where it poses a high risk.

Case study

This system was commonly built in many cities, despite the fact that there was insufficient water to sustain the functioning sewer system. This system has now become 'state of the art' despite its intensive water, energy and labour demands. It depends on water which many poor people can barely afford.

As part of the US-led reconstruction effort following the invasion of Iraq in 2003, the US Army Corps of Engineers (USACE) in collaboration with the Iraqi government, planned to build a massive wastewater treatment plant for the 400,000 residents of Fallujah, about 60 kms west of Baghdad.

The project was estimated to cost around 30 million USD and be finished in 18 months, though by the time it opened in April 2009, it cost nearly 100 million USD and had lasted almost 5 years. Though it was designed to serve the whole city, it will only serve about 38 per cent of the city's residents.

Most of the residents in Fallujah were originally using septic tanks, which were prone to leaking and flooding, and there was a problem with the raw sewage contaminated the Euphrates river which served as a drinking water source for downstream communities. Therefore a centralized sewage treatment plant was seen as a priority to improve the health and hygiene of both the city and the river.

The initial proposal was to incorporate waste stabilization ponds, but this idea was dismissed as being 'stinking' and something appropriate for the 'third world'. The system was redesigned to include a more 'traditional' wastewater treatment plant, despite the fact that generators- requiring 6,000 gallons of fuel a day- are needed since the electrical supply is so unreliable. Pump stations, capable of moving 150,000 cubic metres of sewage daily to the inlet tanks, aeration chambers, settling tanks and finally chlorination contact chambers which will produce an effluent that is suitable for release into the Euphrates.

Potential for exposure

Given the deficiencies in the current system it is hard to differentiate between the groups that will be more or less exposed. The current 'system' exposes the users of the river water, virtually all members of the communities with unattended septic tanks, and all those living in the vicinities where sludge is dumped, at risk.

System gaps

Thirty thousand metres of sewer lines have been built, but only 3000 families have connections to the sewer mains. Unfinished digging has left potholes, small bombs have setback construction and there is no money set aside to connect individual homes to the sewer mains or to continually purchase the fuel needed to ensure that the plant continues to operate.

This is a classic example of inappropriate technology that is inconsistent with the resources (water, energy, and money), environment and long-term sustainability. Furthermore, it is not clear how the existing leaking septic tanks are being handled and how the sludge generated at the treatment plant will be treated and disposed of.

Investment in improving and upgrading septic tanks and providing adequate emptying services, along with well-operated sludge management facilities would likely cost less, be more sustainable, and still provide the same level of comfort to the users. Though the 'sewer system' is often described as the epitome of sanitation, it requires a special set of conditions, a high level of operational and financial commitment and sustained resource inputs to ensure that it is not actually a high-risk system.

(http://www.cleveland.com/world/index.ssf/2008/10/fallujah_sewer_project_a_lesso.html)

PART 4 - REFERENCES AND ANNEXES

REFERENCES

Acosta, C.J *et al*., (2001) Cholera Outbreak in Southern Tanzania: Risk Factors and Pattern of Transmission. *Emerging Infectious Diseases*. 7(3): 583- 587.

Almedom, A. (1996) Recent Developments in Hygiene Behaviour Research: An Emphasis on Methods and Meaning. *Tropical Medicine and International Health*. Volume 1, Part 2: pp 171-182.

Amerashinghe, F.P. and Ariyasena,T.G. (1990) Larval survey of surface water breeding mosquitoes during irrigation development in the Mahaweli project. Sri Lanka. *J. Med. Entomol*. 27: 789-802.

Ansari, S.A., Sattar, S.A., Springthropem V.S., Wells, G.A. and Tostowaryk, W. (1988) Rotavirus survival on human hands and transfer of infectious virus to animate and nonporours inanimate surfaces. *J Clin Microbiol* 26(8):1513-1518.

Ashley, M. J., Gryfe, C. I. *et al*., (1977) A longitudinal study of falls in an elderly population II. Some circumstances of falling. *Age Ageing* 6(4): 211-20.

Asoalu, S.O., Ofoezie, I.E., Odumuyiwa, P.A., Sowemimo, O.A. and Ogunniyi, T.A.B. (2002) Effect of water supply and sanitation on the prevalence and intensity of Ascaris lumbricoides among pre-school-age children in Ajebandele and Ifewara, Osun State, Nigeria. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 96: 600 – 604.

Azurin, J.C. and Alvero, M. (1974) Field evaluation of environmental sanitation measures against cholera. *Bull World Health Organ*; 51: 19–26.

Banda, K., Sarkar, R., Gopal, S., Govindarajan, J., Bahadur Harijan, B., Jeyakumar, M., Mitta, P., Sadanala, E., Sewyn, T., Suresh, R., Anjilivelil Thomas, V., Devadason, P., Kumar, R., Selvapandian, D., Kang, G. and Balraj, V. (2007) Water Handling, Sanitation and Defecation Practices in Rural Southern India: A Knowledge, Attitudes and Practices Study. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 101, pp1124-1130.

Barker, J. and Bloomfield, S. F. (2000) Survival of Salmonella in bathrooms and toilets in domestic homes following salmonellosis. *J Appl Microbiol* 89(1): 137-44.

Barreto, M.L., Genser, B., Strina, A., Teixeira, M.G., Assis, A. M.O., Rego, R.F., Teles, C. A., Prado, M.S., Matos, S.M.A., Santos, D.N., dos Santos, L.A. and Cairncross, S. (2007) Eff ect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil: assessment by two cohort studies. *Lancet* 2007; 370: 1622–28.

Barrett, E. C., Sobsey, M. D. *et al*., (2001). Microbial indicator removal in onsite constructed wetlands for wastewater treatment in the southeastern U.S. *Water Sci Technol* 44(11-12): 177-82.

Beuchat, L. R. (1998) *Surface Decontamination of Fruits and Vegetables Eaten Raw: A Review*, Food Safety Unit, World Health Organization, WHO/FSF/98.2, available at www.who.int/foodsafety/publications/fs_management/en/surface_decon.pdf

Blake, J. (1999) Overcoming the Value-Action Gap in Environmental Policy. *Local Environment* 4, 257-278.

Blumenthal U.J., Cifuentes, E., Bennet, S., Quigley, M. and Ruiz-Palacios G. (2001) The risk of enteric infections associated with wastewater reuse: the effect of season and degree of storage of wastewater. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 95: 131-137.

Blumenthal, U.J. and Peasey, A. (2002) *Critical Review of Epidemiological Evidence of the Health Effects of Wastewater and Excreta Use in Agriculture*. London: London School of Hygiene and Tropical Medicine.

Borchardt, M. A., Chyou, P. H. *et al*., (2003) Septic system density and infectious diarrhoea in a defined population of children. *Environ Health Perspect* 111(5): 742-8.

Bouhoum K., Amahmid O., and Asmama S. (2000) Occurrence and removal of protozoan cysts and helminth eggs in waste stabilization ponds in Marrakech. *Water Science and Technology*, 42(10-11):159-164.

Breslin, E. D. and Dos Santos, F. (2001) *Introducing Ecological Sanitation in Rural and Periurban Areas of Northern Mozambique*. Paper Presented at: First International Conference on Ecological Sanitation: 5-11 November 2001. Nanning, Guangxi Zhuang Autonomous Region, China.

Brooks, J.P., Tanner, B.D., Josephson, K.L., Gerba, C.P., Haas, C.N. and Pepper, I.L. (2005) A National study on the residential impact of biological aerosols from the land application of biosolids. *Journal of Applied Microbiology* 99 (2): 310-322.

Bunger, J., Antlauf-Lammers, M., Schulz ,T.G., Westphal, G.A., Muller, M.M., Ruhnau, P., Hallier, E. (2000) Health complaints and immunological markers of exposure to bioaerosols among biowaste collectors and compost workers. *Occup Environ Med* 57:458–464.

Burney, M. I. and Munir., A. H. (1966) Role of arthropod viruses in human diseases in Rawalpindi and Peshawar areas. II - Isolation of West Nile virus from human blood and Culicine mosquitoes in Rawalpindi areas. *Pak. J. Med. Res*. 5: 271–285.

Burubai, W., Akor, A.J., Lilly, M.T and Ayawari, D.T. (2007) An Evaluation of Septic Tank Performance in Bayelsa State, Nigeria". *Agricultural Engineering International: The CIGR Ejournal*. Manuscript BC 06 009. Vol. IX.

Campos, C., Guerrero, A and Cárdenas, M. (2002) Removal of bacterial and viral indicator organisms in a waste stabilization pond system in Chocontá. Cundinamarca (Colombia). *Water Science and Technology* 45, 61–66.

Carlander, A. and Westrell, T. (1999) *A microbiological and sociological evaluation of urine-diverting, double-vault latrines in Cam Duc, Vietnam*. Report no. 91, International Office, Swedish University of Agricultural Sciences,Uppsala, Sweden.

Carr, R. (2001) Excreta-related infections and the role of sanitation in the control of transmission. In Fewtrell, L. and Bartram J. (eds) *Water Quality: Guidelines, Standards and Health*. London: IWA Publishing.

CDC (1999) Outbreak of Escherichia coli O157:H7 and Camplyobacter among attendees of the Washington County Fair – New York 1999. *Morbidity and Mortality Weekly Report* 48(36): 803-804.

Cetin, H., Yanikoglu, A. *et al*., (2006) Efficacy of diflubenzuron, a chitin synthesis inhibitor, against Culex pipiens larvae in septic tank water. *J Am Mosq Control Assoc* 22(2): 343-5.

Chang, M. S., Lian, S. *et al*., (1995) A small scale field trial with expanded polystyrene beads for mosquito control in septic tanks. *Trans R Soc Trop Med Hyg* 89(2): 140-1.

Charles, K.J., Ashbolt, N.J., Roser, D.J., McGuinness, R. and Deere, D.A. (2005) Effluent quality from 200 on-site sewage systems: design values for guidelines, *Water Science & Technology*, vol. 51, no. 10, pp. 163-169.

Charlwood, J. D. (1994) The control of Culex quinquefasciatus breeding in septic tanks using expanded polystyrene beads in southern Tanzania. *Trans R Soc Trop Med Hyg* 88(4): 380.

Chien, B.T., Phi, D.T., Chung, B.C., Stenström, T.A., Carlander, A., Westrell, T. and Winblad, U. (2001) *Biological study on retention time of microorganisms in faecal material in urine-diverting eco-san latrines in Vietnam.* Abstract Volume, First International Conference on Ecological Sanitation. 5th-8th November, Nanning, China: 120-124.

Cifuentes, E. (1998) The Epidemiology of enteric infections in agricultural communities exposed to wastewater irrigation: Perspectives for Risk Control. *International Journal of Environmental Health Research* 8 (3): 203-213.

Cadilhac P., Roudot-Thoraval, F. (1996) Seroprevalence of hepatitis A virus infection among sewage workers in the Parisian area, *France. Eur. J. Epidemiol*. 12, 237-240.

Carlson, D. B. and Knight, R. L. (1987) Mosquito production and hydrological capacity of southeast Florida impoundments used for wastewater retention. *J. Am. Mosq. Control Assoc*. 3: 74-83.

Carlson, D. B., Vigliano, R. R. and Wolfe, G. I. (1986) Distribution of mosquitoes in different wastewater stages of secondarily treated domestic efßuent and untreated citrus washwater. J. *Am. Mosq. Control Assoc*. 2: 516-521.

Clark, C.S., Rylander, R. and Larsson. L. (1983) Levels of Gram-negative Bacteria, Aspergillus Fumigatus and Endotoxin at Compost Plants. *Appl. Env. Microbiol*. 45:1501-1505

Clark, C.S., Bjornson, H. S., Schwartz-Fulton, J., Holland, J. W. and Gartside, P. S. (1984)

Biological Health Risks Associated with the Composting of Wastewater Treatment Plant Sludge *Water Pollution Control Federation,* Vol. 56, No. 12.

Clarke, R. and King, J. (2004) *The Atlas of Water*. Earthscan, London.

Chang, M.S., (1993) *Aedes Larval Survey in Septic tanks in Taiwan Jaya and Foochow Road*, Medical Department, Sarawak report .

Chavasse, D. C., Shier, R. P., Murphy, O. A., Huttly, S. R. A., Cousens, S. N. and Akhtar, T. (1999) Impact of fly control on childhood diarrhoea in Pakistan: community-randomised trial. *Lancet* 1999; 353: 2 2 – 2 5.

Cofie, O.O., Kranjac-Berisavljevic, G. and Drechsel, P. (2005) The Use of Human Waste for Peri-urban Agriculture in Northern Ghana. *Renewable Agriculture and Food Systems*. 20 (2): 73-80.

Cohen, D., Green, M., Block, C., *et al*., (1991) Reduction of transmission of shigellosis by control of houseflies (Musca domestica). *Lancet* 1991; 337: 9 9 3 – 9 7.

Corrales, L.F., Izurieta, R. and Moe, C.L. (2006) Association between intestinal parasitic infections and type of sanitation system in rural El Salvador. *Tropical Medicine and International Health*. 11 (2): 1821-1831.

Craun, G.F. (1984) Health aspects of groundwater pollution. In *Groundwater Pollution*, (eds. G. Bitton and C. Gerba), pp. 135-179, John Wiley & Sons, New York.

Craun, G.F. (1985) A summary of waterborne illness transmitted through contaminated groundwater. *J. Environ. Health*, 48, 122-127.

Curtis, C.F. and Hawkins, P.M. (1982) Entomological studies of on-site sanitation systems in Botswana and Tanzania. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 76(1): 99-108.

Curtis, V., Kanki, B., Mertens, T., Traore, E., Diallo, I., Tall, F. and Cousens, S. (1995) Potties, pits and pipes: Explaining hygiene behaviour in Burkina Faso. *Social Science and Medicine*, 41 (3): 383-393.

Curtis, V. and Cairncross, S. (2003) Effect of washing hands with soap on diarrhoea risk in the community: a systematic review. *Lancet Infect Dis* 3(5):275-81.

Danso, G., Drechsel, P., and Gyiele, L. (2004) Urban Household Perceptions of Urine-Excreta and solid waste source Separation in Urban Areas of Ghana, In: C. Werner et al., (eds): *Closing the Loop* - Proceedings of the 2nd International Symposuim on Ecological Sanitation. Ecosan, 7-11 April 2003, Lübeck, Germany –GTZ Publication, ISBN 3-00-012791-7, 2004 Eschborn, Germany.

Daniels, D.L., Cousens, S.N., Makoae, L.N. and Feachem, R.G. (1990) A case control study of the impact of improved sanitation on diarrhoea morbidity in Lesotho. *Bull World Health Organ* 68: 455–63.

Dorn, R.C., Reddy, C.S., Lamphere, D.N., Gaeuman, J.V. and Lanese, R. (1985) Municipal sewage sludge application on Ohio farms: health effects. *Environ Res* 1985 , 38:332-359

Drake, L.J. and Bundy, D.A. (2001) Multiple helminth infections in children: impact and control. *Parasitology* 122: (Suppl) S73–81.

Drangert, J-O., Duncker, L., Matsebe, G. and Abu Atukunda, V. (2002) *Ecological Sanitation, Urban Agriculture, and Gender in Periurban Settlements: A Comparative Multidisciplinary Study of Three Sites in Kimberley in South Africa and Kampala, Kabale and Kisoro in Uganda*. Report to Sarec on project. SWE-2002-136 (13).

Duncker, L., Matsebe, G. and Moilwa, N. (2007) *The Social/cultural Acceptability of Using Human Excreta (faeces and urine) for Food Production in Rural Settlements in South Africa*. WRC Report No TT 310/07. Pretoria, South Africa.

Eales, K. (2005) Sanitation partnership series: *Bringing pit emptying out of the darkness: A comparison of approaches in Durban, South Africa, and Kibera, Kenya*. Building Partnerships for Development. Available from: http://www.bpdws.org/bpd/web/d/doc_131.pdf?statsHandlerDone=1

Emerson, P. M., Lindsay, S. W., Walraven, G. E., *et al*., (1999) Effect of fly control on trachoma and diarrhoea. *Lancet* 1999; 353: 1401–03.

Ensink, J.H.J., Mukhtar, M., van der Hoek, W. and Konradsen, F. (2007) Simple intervention to reduce mosquito breeding in waste stabilisation ponds. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 101, 1143-1146.

Epstein, E. (1997) *The Science of Composting*. CRC Press LLC Boca Raton, Florida.

Esrey, S., Gough, J., Rapaport, D., Sawyer, R., Simpson-Hérbert, M., Vargas, J. *et al*., (Eds.). (1998) *Ecological Sanitation*. Stockholm: Swedish International Cooperation Agency.

Falkenmark, M. (1998) *Willful neglect of water: Pollution - A major barrier to overcome*. Stockholm International Water Institute Waterfront, Stockholm, Sweden.

Falkland, A. (ed.) (1991) Hydrology and water resources of small islands: a practical guide. *Studies and reports in hydrology* no. 49, 435p. UNESCO, Paris.

Farrah, S.R. and Bitton, G. (1983) Bacterial survival and association with sludge flocs during aerobic and anaerobic wastewater sludge under laboratory conditions. *Applied and Environmental Microbiology*, 45(1): 174-181.

Faruqui, N., Biswas, A.K. and Bino, M.J. (2001) *Water Management in Islam*. United Nations University Press and International Development Research Centre.

Fattal, B., Bercovier, H., Derai-Cochin, M. and Shuval, H.I. (1985) Wastewater reuse and exposure to Legionella organisms. *Water Resources* 19 (6), 693-696.

Fattal, B., Yekutiel, P., Wax. Y, and Shuval, H.I. (1986) Prospective epidemiological study of health risks associated with wastewater utilization in agriculture. *Water Science and Technology* 18 (10): 199-209.

Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. (1983) *Sanitation and disease: health aspects of excreta and wastewater management*. World Bank Studies in Water Supply and Sanitation 3, Wiley, Chichester, UK.

Ferrer, S.R., Strina, A., Jesus, S.R., *et al*., (2008) A hierarchical model for studying risk factors for childhood diarrhoea: a case-control study in a middle-income country. *Int J Epidemiol* 37: 805–15.

Fewtrell, L. and Kay, D. (2007) Quantitative Microbial Risk Assessment with respect to Campylobacter spp. in toilets flushed with harvested rainwater. *Water & Environment Journal,* 21 : 275-280.

Fong, T. T., Mansfield, L. S. *et al.*, (2007) Massive microbiological groundwater contamination associated with a waterborne outbreak in Lake Erie, South Bass Island, Ohio. *Environ Health Perspect* 115(6): 856-64.

Foster, S. S. D., Adam B, Morales, M. and Tenjo, S. (1993) *Groundwater protection strategies: a guide to implementation*, PAHO-CEPIS, Lima, Peru.

Fracchia, L., Pietronave, S., Rinaldi, M. and Martinotti, M.G. (2006) Site-related airborne biological hazard and seasonal variations in two wastewater treatment plants. *Water Research*, 40 (10): 1985-1994.

Franceys, R., Pickford, J. and Reed, R. (1992) *A guide to the development of on-site sanitation*. WHO, Geneva.

Frerichs, R.R, Sloss, E.M, and Satin, K.P. (1982) Epidemiologic Impact of Water Reuse in Los Angeles County. *Environ Res*. 29:109-22.

Frerichs (1984) Epidemiologic monitoring of possible health reactions of wastewater reuse. *Sci Total Environ* 32 (3):353-63

Friis, L., Norback, D. and Edling, C. (1999) Self-reported asthma and respiratory symptoms in sewage workers. *J Occup Health* 41:87–90.

Geake, A. K., Foster, S. S. D., Nakamatsu, M., Valenzuela, C. F. and Valverde. M. L. (1987) *Groundwater recharge and pollution mechanisms in urban aquifers of arid regions*, BGS Hydrology Research Report 86/11, British Geological Survey, Wallingford, UK.

Gerba, C. P., Wallis, C. *et al*., (1975) Microbiological hazards of household toilets: droplet production and the fate of residual organisms. *Appl Microbiol* 30(2): 229-37.

Grimason, A.M., Smith, H.V., Young, G. and Thitai, W.N. (1996) Occurrence and removal of Ascaris sp. ova by waste stabilisation ponds in Kenya. *Water Science Technology* 33:75–82

Gross, R., Schell, B., Molina, M.C.B., Leao, M.A.C. and Strack, U. (1989) The Impact of Improvement of Water Supply and Sanitation Facilities on Diarrhoea and Intestinal Parasites: A Brazilian Experience with Children in Two Low-Income Urban Communities. *Rev. Saude publ. S. Paulo*, 23 (3): 214 -20.

Guzman, C., J. Jofre, J., Montemayor, M. and Lucena, F. (2007) Occurrence and levels of indicators and selected pathogens in different sludges and biosolids, *Journal of Applied Microbiology* 103 : 2420–2429.

Heistad, A., Seidu, R., Flø, A., Paruch, A.M., Hanssen, J.F. and Stenström, T.A. (2009) Long-term hygienic barrier efficiency of a compact on-site wastewater treatment system. *Journal of Environmental Quality* 38 (6): 2182-2188.

Hansen, E.S., Hilden, J., Klausen, H. and Rosdahl, N. (2003) Wastewater exposure and health- a comparative study of two occupational groups. *Occup Environ Med*, 60:595-598.

Harris, L.J., Farber, J.M., Beuchat, L.R., Parish, M.E., Suslow, T.V., Garrett, E.H. and Busta, F.F. (2003) Outbreaks associated with fresh produce: incidence, growth, and survival of pathogens in fresh and fresh-cut produce. *Comprehensive Reviews in Food Science and Food Safety* 2 (1):78-141.

Hench, K.R., Bissonnette, G.K., Sexstone, A. J., Coleman, J.G., Garbuttb, K. and Skousen, J. G. (2003) Fate of physical, chemical, and microbial contaminants in domestic wastewater following treatment by small constructed wetlands. *Water Research*. 37: 921–927.

Heinss, U., Larmie, S. A. and Strauss, M. (1998). *Solid Separation and Pond Systems for the Treatment of Faecal Sludges in the Tropics: Lessons Learnt and Recommendations for Preliminary Design*, SANDEC Report no 05/98, EAWAG/SANDEC, Dübendorf, Switzerland.

Heistad, A., Paruch, A.M., Vråle, L., Adam, K. and Jenssen, P.D. (2006) A high-performance compact biofilter system treating domestic wastewater. *Ecol. Eng* 28(4): 374-379.

Heng , B.T., Goh, K.T., Doraisingham, S. *et al*., (1994) Prevalence of hepatitis A virus infection among sewage workers in Singapore. *Epidemiol. Infect.* 17, 162-166.

Hoglund, C., Stenstrom, T.A., Jonsson, H. and Sundin, A. (1998) Evalauation of faecal contamination and microbial die-off in urine separating sewage systems. *Wat. Sci. Tech*. 38 (6), 17 – 25

Hoglund, C. (2001) *Evaluation of microbial health risks associated with the reuse of source-separated human urine*. Phd Thesis. Royal Institute of Technology, Department of Biotechnology, Applied Microbiology, Sweden.

Horan, N. J. (1990) *Biological wastewater treatment systems*, Wiley, Chichester, UK.

Hutchinson, R.I. (1956) Some observations on the spread of Sonne dysentery. *Monthly Bulletin of Ministry of Health Laboratory Service* 15, 110–118.

Isaacson, M. and Sayed, A.R. (1988) Health Aspects of the use of recycled water in Windhoek, SWA/ Namibia, 1974 – 1983. *Sr Afr Med J.* 73(10): 596-9.

IWMI (2009) *Wastewater Irrigation and Public Health From Research to Impact - A roadmap for Ghana*. Report prepared for Google.org.

Jenssen, P.D. and Vråle, L. (2003) Greywater Treatment in Combined Biofilter/ Constructed Wetlands in Cold Climate. In: C. Werner et al., (eds.). *Ecosan – closing the loop*. Proc. 2nd int. symp. ecological sanitation, Lübeck Apr. 7-11. 2003, GTZ, Germany, pp:875-881.

Jimenez, B., Austin, A., Cloete, E., Phasha, C. and Beltran, N. (2007) Biological risks to food crops fertilized with Ecosan sludge. *Water Science and Tech*. 55 (7): 21-29.

Kalia, A.K. and Kanwar, S.S. (1989) Temperature profiles of biogas plants operating under hilly conditions. *Biological Wastes* 30, 217-224.

Kato, S., Fogarty, E. and Bowman, D. D. (2003) Effect of aerobic and anaerobic digestion on the viability of Cryptosporidium parvum oocysts and Ascaris suum eggs. *Int. J. Environ. Health Res*. 13, 169–179.

Katzenelson, E., Buium, I. and Shuval, H.I. (1976) Risk of communicable disease infection associated with wastewater irrigation in agricultural settlements. *Science* 194, 944-946.

Kearney, T. E., Larkin, M. J. Frost, J. P. and Levett, P. N. (1993a) Survival of pathogenic bacteria during mesophilic anaerobic digestion of animal waste. *J. Appl. Bacteriol*. 75:215–219.

Kearney, T. E., Larkin, M. J. and Levett, P. N. (1993b) The effect of slurry storage and anaerobic digestion on survival of pathogenic bacteria. *J. Appl. Bacteriol.* 74:86–93.

Kengne, I. M., Akoa, A. and Koné, D. (2009) Recovery of biosolids from constructed wetlands used for faecal sludge dewatering in tropical regions, *Environmental Science and Technology*, 43: 6816–21.

Khuder S.A., Arthur, T., Bisesi, M.S. and Schaub, E.A. (1998) Prevalence of infectious diseases and associated symptoms in wastewater treatment workers. *Am J Ind Med* 33:571–577.

Kolahi, A-A., Rastegarpour, A. and Sohrabi, M-R. (2008) The impact of an urban sewerage system on childhood diarrhoea in Tehran, Iran: a concurrent control field trial. *Trans R Soc Trop Med Hyg*, (in press).

Koné, D., Cofie, O., Zurbrugg, C., Gallizzi, K., Moser, D., Drescher, S. and Strauss, M. (2007) Helminth eggs inactivation efficiency by faecal sludge dewatering and cocomposting in tropical climates. *Water Research*, 41(19): 4397–402.

Kollmus, A. and Agyeman, J. (2002) Mind the Gap: Why Do People Act Environmentally and What Are the Barriers to Pro-Environmental Behavior? *Environmental Education Research* 8 (3): 239-60.

Koottatep, T., Surinkul, N., Polprasert, C., Kamal, A. S. M., Koné, D., Montangero, A., Heinss, U. and Strauss, M. (2005) Treatment of septage in constructed wetlands in tropical climate: Lessons learnt from seven years of operation, *Water Science and Technology*, 51(9):119–26.

Kudlinski, D.N, (1995) *Measurement of airborne Gram-negative bacteria in selected areas of a sludge dewatering building.* Unpublished thesis research. Department of Occupational Health, Medical College of Ohio.

Kumar, R., Gupta, M.K. and Kanwar, S.S. (1999) Fate of bacterial pathogens in Cattle dung slurry subjected to anaerobic digestion. *World Journal of Microbiology & Biotechnology* 15: 335-338.

Kunte, D.P., Yeole, T.Y. and Ranade, D.R. (2000) Inactivation of Vibrio cholera during anaerobic digestion of human night soil. *Bioresource Technology,* 75: 149-151.

Lafleur, J. and Vena, J.E. (1991) Retrospective cohort mortality study of cancer among sewage plant workers. *Am J Ind Med*, 19:75–86.

Lam, W.K., (1989) A field trial to control Aedes albopictus breeding in septic tanks with expanded polystyrene beads in Taman Gulf, Ipoh, Malaysia. *Mosquito-Borne Diseases Bulletin* (Thailand) 6, pp. 101–104.

Lan, Y., Xueming, L., Qinhua, W., Hongbo, X., Caiyun, N. and Lianghong, N. (2001) *Observation of the inactivation effect on eggs of Ascaris ssum in urine diverting toilets*. Abstract Volume, First International Conference on Ecological Sanitation. 5th-8th November, Nanning, China:125.

Lawty, R., Ashworth, J. de B. and Mara, D. D. (1996) Waste Stabilization Pond Decommissioning: A painful but necessary decision', *Water Science and Technology*, 33(7): 107–115.

Levine, O. S. and Levine, M. M. (1991) Houseflies (Musca domestica) as mechanical vectors of shigellosis. *Rev Infect Dis* 1991; 13:688 – 96.

Lewis, D. L., Gattie, D. K., Novak, M. E., Sanchez, S. and Pumphrey, C. (2002) Interactions of Pathogens and Irritant Chemicals in Land-Applied Sewage Sludges (biosolids). *BMC Public Health.* 2:11.

Mahassen M. Ghazy, E-D., Morsy El-Senousy, W., Abdel-Aatty, A. M. and Kamel, M. (2008) Performance Evaluation of a Waste Stabilization Pond in a Rural Area in Egypt. *American Journal of Environmental Sciences* 4 (4): 316-325.

Lundholm, M. and Rylander, R. 1980. Work related symptoms among sewage workers. *British Journal of Industrial Medicine*. 40: 325-329.

Margalith, M., Morag, A. and Fattal, B. (1990). Antibodies to polioviruses in an Israeli population and overseas volunteers. *J. Med. Virol*. 30: 68-72

Malmros, P. (1990) *Problems with the working environment in solid waste treatments*. Report No. 10/1990. The National Labour Inspection of Denmark.

Majumber, N. *et al*., (1969) A critical study of septic tank performance in rural areas. *Journal of the Institute of Engineers* (India), 40 (21): 743-761.

Mara, D. (1985) T*he Design of Pour-Flush Latrines.* UNDP/World Bank. TAG Technical Note No. 15. Interregional Project INT/81/047.

Mara D, (1997) *Design manual for waste stabilisation ponds in India,* Lagoon Technology International, Leeds, UK.

Mara, D.D. and Cairncross, S. (1989) *Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture*. Geneva: World Health Organisation.

Mashauri, D.A., Mulungu, D.M.M and Abdulhussein, B.S. (2003) Constructed wetland at the University of Dar es Salaam. *Water Research*. 34 (4): 1135 – 1144.

Matsby, I. and Rylander, R. (1978) Clinical and Immunological Findings in Workers Exposed to Sewage Dust. *J. Occup. Med.* 20, 690.

Maxwell, C. A., Curtis, C. F., Haji, H., Kisumku, S., Thalib, A. I. and Yahya, S. A. (1990) Control of Bancroftian filariasis by integrating therapy with vector control using polystyrene beads in wet pit latrines. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 84: 709-714.

Mbambisa, G.P. and Selkirk, W.T. (1990) Sanitation in Transkei: Problems and Perspectives. International Water Supply Association (IWSA). In: *Seminar on Water and Sanitation*, Wild Coast Sun, Transkei, 26-27 June. Volume of Papers ISBN 0 7988 4938 X.

Meddings, D.R., Ronald, L.A., Marion, S., Pinera, J.F. and Oppliger, A. (2003) Cost Effectiveness of a Latrine revision programme in Kabul, Afghanistan. *Bulletin of the World Health Organization*. 82 (4).

Menon, S., Santosham, M. *et al.*, (1990) Rotavirus diarrhoea in Apache children: a case-control study. *Int J Epidemiol* 19(3): 715-21.

Misstear, B.. White, M.. Bishop, P. and Anderson G, (1996) *Reliability of sewers in environmentally vulnerable areas*, CIRIA Project Report 44, CIRIA, London, UK.

Millner, P.D., Marsh, P.B., Snowden, R.B., Parr, J.F., (1977) Occurrence of *A. fumigatus* during composting of sewage sludge. *Applied and Environmental Microbiology*, 34 (6), 765-772.

Moe, C. and Izurieta, R. (2003) *Longitudinal study of double vault urine diverting toilets and solar toilets in El Salvador*. Proceedings from the 2nd International Symposium on Ecological Sanitation. Lübeck, Germany, 7th-11th April 2003.

Molin, S.A., Cvetkovic, V., Stenstrom, T.A. and Harikumar, P.S. *Quantitative Microbial Risk Assessment of Shallow Well Water Supplies from On-site Sanitation in Heterogeneous Aquifers.* (In preparation).

Moraes, L.R.S., Cancio, J.A. and Cairncross, S. (2004) Impact of Drainage and Sewerage on Intestinal Nematode Infections in poor urban areas in Salvador, Brazil. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 98: 197 – 204.

Moraes, L.R.S., Cancio, J.A., Cairncross, S. and Huttly, S. (2003) Impact of drainage and sewerage on diarrhoea in poor urban areas in Salvador, Brazil. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 97: 153 – 158.

Morgan, P.R. (1977) The pit latrine-revived. *Central African Journal of Medicine*, 23: 1-4.

Morgan, P. (2007) *Toilets that make compost: Low-cost, sanitary toilets that produce valuable compost for crops in an African context*. EcoSanRes Programme, Stockholm Environment Institute

Mukhtar, M., Herrel, N., Amerasinghe, F. P., Ensink, J., van der Hoek, W. and Konradsen, F. (2003) Role of wastewater irrigation in mosquito breeding in south Punjab, Pakistan. *Southeast Asian J. Trop. Med. Public Health* 34: 72-80.

Matsuno, Y., Ensink, J.H.J., Van der Hoek, W. and Simmons. R.W. (2004) *Assessment of the use of wastewater for irrigation: a case in Punjab, Pakistan*, Proceedings of the Symposium on Wastewater Reuse and Groundwater Quality July 2003, Sapporo, IAHS Publication 285 (2004), pp. 28–33.

Nadkarni, M. (2002) *Drowning in Human Excreta*. Down to Earth, Centre for Science and Environment, New Delhi. http://www.downtoearth.org.in/cover.asp?foldername=200202&filename=Anal&sid=3&page=4&sec_id=7&p=1.

Nawab, B., Nyborg, I., Esser, K. and Jenssen, P. (2006) Cultural Preferences in Designing Ecological Sanitation Systems in Nortyh West Fronteir Province, Pakistan. *Journal of Environ. Psycho*. 26: 236-246.

Nielsen, S. (2007) Helsinge sludge reed beds systems: reduction of pathogenic microorganisms, *Water Science and Technology* 56 (3) : 175–182.

Obuobie, E., Keraita, B., Danso, G., Amoah P., Cofie, O., Raschid-Sally, L. and Dreschel, P., (2006) *Irrigated Urban Vegetable Production in Ghana: Characteristics, Benefits and Risks*, IWMI-RUAF-CPWF. CSIR-INSTL, Accra, Ghana.

Olsen, J. E. and Larsen. H. E. (1987) Bacterial decimation times in anaerobic digestions of animal slurries. *Biol. Wastes* 21:153–168.

Oppliger, A., Hilfiker, S. and Vu Duc, T. (2005) Influence of seasons and sampling strategy on assessment of bioaerosols in sewage treatment plants in Switzerland, *Ann. Occup. Hyg*. 49 (5): 393–400

Ottoson. J., (2003) *Hygiene aspects of greywater and greywater reuse*. Licenciate thesis. Royal Institute of Technology/Swedish Institute for Infectious Disease Control. Stockholm.

Pearson, H.W., Silva Athayde, S.T., Athayde, S.T., Jr and Silva, S.A. (2005) Implications for physical design: the effect of depth on the performance of waste stabilisation ponds. *Wat. Sci. Tech* 51(12): 69–74.

Peiris, J.S.M. and Amerasinghe, F.P. (1994) West Nile fever. In: Beran GW, Steele JH, eds. *Handbook of zoonoses*, Section B: Viral. 2nd ed. Boca Raton: CRC Press, 139-48.

Plym-Forshell, L. (1995) Survival of Salmonella spp. and Ascaris suum eggs in a thermophilic biogas plant. *Acta Vet. Scand.* 36:79–85.

Porter, B., Schinder, E., Nagar, H., Gilad, Y. and Torek, V. (1984) An outbreak of shigellosis in an ultra-orthodox Jewish community. *Social Science and Medicine* 18 (12): 1061-1062.

Pourcher, A.M., Morand, P., Picard-Bonnaud, F., Billaudel, S., Monpoeho, S., Federighi, M., Ferré, V. and Moguedet, G. (2005) Decrease of enteric micro-organisms from rural sewage sludge during their composting in straw mixture, *J. Appl. Microbiol*. 99 : 528–539.

Redlinger, T., Graham, J. *et al*., (2001) Survival of fecal coliforms in dry-composting toilets. *Appl Environ Microbiol* 67(9): 4036-40.

Richert, A., Gensch, R., Joensson, H., Stenstroem, T., Dagerskog, L. (2010). *Practical guidance on the use of urine in crop production.* Stockholm Environment Institute (SEI), Sweden.

Rulin, J. (1997) Collection and Disposal of Excreta from Public Dry Latrines, Household Dry Pit Latrines and Bucket Latrines in Yichang City China in Muller, M.S (ed) *Household Excreta: The Operation of Services in Urban Low-income Neighbourhoods*. Pathumthani : ENSIC/AIT, Urban Waste Series 6.

Rutkowski, T., Raschid-Sally, L. and Buechler, S. (2007) Wastewater irrigation in the developing world- Two case studies from Katmandu Valley in Nepal. *Agricultural Water Management* 88 (1-3): 83-91.

Rosemarin, A., Ekane, N., Caldwell, I., Kvarnstrom, E., McConvite, J., Ruben, C. and Fodge, M. (2008) *Pathways for Sustainable Sanitation- Achieving the Millennium Development Goals.* SEI/IWA.

Rylander, R. and Lundholm, M. (1979) Responses to wastewater exposure with reference to endotoxin. In: Pahren H, Jakubowski W, eds. *Wastewater aerosols and disease*. Proceedings of a symposium 19-21 September 1979. Cincinnati, Ohio: US Environmental Protection Agency, 1980: 90-8. (EPA-600/9-80-028.)

Saidi-Sharouze, M. (1994) *Ouagadougou and Kumasi Sanitation Projects: A Comparative Case Study.* UNDP-World Bank Water and Sanitation Program; West Africa Regional Water and Sanitation Group, Cote D'Ivoire: Abidjan.

Schad, G. (1978) Effects of leaky sanitation on hookworms. In: Pacey A (ed). *Sanitation in Developing Countries*. John Wiley and Sons, Chichester and New York.

Schonning, C., Westrell, T., Stenstrom, T.A., Arnbjerg-Nielsen, K., Hasling, A.B., Hoibye, L., and Carlsen, A. (2007) Microbial risk assessment of local handling and use of human faeces. *J Water Health*; 5(1):117-28

Schulz, S. and Kroeger. A. (1995) Soil contamination with Ascaris lumbricoides eggs as an indicator of environmental hygiene in urban areas of north-east Brazil. *J. trop. Med. Hyg*. 95: 95-103.

Seidu, R., Drechsel, P., Amoah, P., Lofman, O., Heistad, A., Fodge, M. Jenssen, P. D. and Stenstrom, T-A. (2008) Quantitative Microbial Risk Assessment of Wastewater and Faecal Sludge reuse in Ghana. In: *Access to Sanitation and Safe Water: Global Partnerships and Local Actions.* Proceedings of the 33rd WEDC International Conference, April 7-11, 2008. Accra, Ghana.

Seidu, R., Heistad, A., Amoah, P., Drechsel, P., Jenssen, P.D. and Stenström, T-A. (2008) Quantification of the Health Risk Associated with Wastewater Reuse in Accra, Ghana: A contribution toward Local Guidelines *Journal of Water and Health* 06 (4): 461-471.

Seidu, R. (2010) *Disentangling the Risk Factors and Health Risks Associated with Faecal Sludge and Wastewater Reuse in Ghana*. Phd Thesis. Norwegian University of Life Sciences, Ås, Norway.

Shaban, A.M. (1999) Bacteriological evaluation of composting systems in sludge treatment. *Water Science and Technology* 40, 165–170.

Shuval H.I., Adin A., Fattal B., Rawitz E. and Yekutiel P. (1986) *Wastewater irrigation in developing countries: health effects and technical solutions.* Technical Paper No. 51. World Bank, Washington DC.

Shuval, H., Guttman-Bass, N., Applebaum, J. and Fattal, B. (1989). Aerosolized enteric bacteria and viruses generated by spray irrigation of wastewater. *Water Science and Technology* 21(3): 131 – 135.

Shuval, H.I. (1993). Investigation of typhoid fever and cholera transmission by raw wastewater irrigation in Santiago, Chile. *Water Science and Technology* 27 (3-4): 167-174.

Simpson-Hebert, M. (2006) *Ecological Sanitation: A CRS Ethiopia Success Story*. Report posted to the EcoSanRes discussion forum on Yahoo Groups 11 Dec. 2006.

Sloss, E.M., Geschwind, S.A., McCaffrey, D.F., Ritz, B.R. (1996) *Groundwater recharge with reclaimed water: An epidemiologic assessment in Los Angeles County,* 1987-1991.: RAND Corporation.

Smith, C. (1993) *The effect of the introduction of piped sewerage on Ascaris infection and environmental contamination in a Gaza Strip refugee camp*. Thesis. Department of Epidemiology and Population Sciences. London, London School of Hygiene and Tropical Medicine (University of London).

Stott, R., May, E. and Mara, D.D. (2003) Parasite removal by natural wastewater treatment systems: performance of waste stabilisation ponds and constructed wetlands. *Water Science and Technology*, 48: 97-104.

Strauss, M., Larmie, S. A., Heinss, U. and Montangero. A. (2000) Treating faecal sludges in ponds. *Water Science and Technology*; 42 (10-11): 283-290.

Strauss, M. and Blumenthal, U. J. (1990) *Human waste use in agriculture and aquaculture: utilization practices and health perspectives*. International reference Centre for Waste Disposal, Duebendorf,Switzerland.

Thompson, J., Porras, I.T., Tumwine, J.K., *et al*., (2001) *Drawer of water II: 30 years of change in domestic water use and environmental health in East Africa*. London: IIED.

Thurston, J.A., Gerba, C.P., Foster, K.E. and Karpiscak M.M. (2001) Fate of indicator microorganisms, Giardia and Cryptosporidium in subsurface flow constructed wetlands. *Water Res*. 35:1547–51.

Tilley, E. *et al*., 2008. *Compendium of Sanitation Systems and Technologies*. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dubendorf, Switzerland.

Tipple, G., Korboe, D., Garrod, G., Willis, K., (1999) Housing Supply in Ghana: a Study of Accra, Kumasi and Berekum. *Progress in Planning* 51 (4), 253-324.

Tortora, G.J., Funke, B.R. and Case, C.L. (1992) *Microbiology: an introduction*. The Benjamin/ Cummings Publishing Company, Inc., Redwood City, California, USA.

Trang, D.T. (2007) *Health risks associated with wastewater use in agriculture and aquaculture in Vietnam*. PhD Thesis. University of Copenhagen, Denmark.

Trout, D., Mueller, C., Venczel, L. *et al*., (2000) Evaluation of occupational trasmission of hepatitis A virus among wastewater workers. *J. Occup. Environ. Med*. 42, 83-87.

Tsiagbey, M., Danso, G., Anang, L. and Sarpong, E. (2005) *Perception and Acceptability of Urine Diverting Toilets in a Low-income Urban Community in Ghana*. Third International Conference on Ecological Sanitation.

Ulrich, H., Klaus, D., Irmgard, F., Annette, H., Juan, L-P. and Regine, S. (2005) Microbial Investigations for sanitary assessment of wastewater treated in constructed wetlands. *Water Research*, 39 (20): 4849 – 4858.

USEPA (1999) Water efficiency technology fact sheet – Composting Toilets. Publication No. EPA832-F-99-066.Watt, J. L. D. R. 1948. Effect of fly control in a high morbidity area. *Public Health Rep* 1948; 6 3 : 1319 – 34.

USEPA (2007) *Technical support document for land application of sewage sludge*. Vol. I and II (PB93-110575). Office of Water, Washington DC.

Vinnerås, B., Schönning, C. and Nordin, A. (2006) Identification of the microbiological community in biogas systems and evaluation of microbial risks from gas usage. *Science of the Total Environment*, 367: 606-615.

Wang, J.Q. (1999) *Reduction of microorganisms in dry sanitation due to different adsorbents under low temperature conditions*. Abstracts from the 9th Stockholm Water Symposium, 9th-12th August. Stockholm, Sweden: 396-398.

Watanabe, T., San, D. and Omura, D. (2002) Risk evaluation for pathogenic bacteria and viruses in sewage sludge compost. *Water Science and Technology*, 46 (11-12): 325-330.

Westrell, T. (2004) *Microbial Risk Assessment and its Implications for Risk Management in Urban Water Systems.* Phd Thesis. Department of Water and Environmental Studies, Linköping University.

Westrell, T., Schonning, C., Stenstrom, T-A. and Ashbolt, N. J. (2004) QMRA (quantitative microbial risk assessment) and HACCP (hazard analysis critical control points) for management of pathogens in wastewater and sewage sludge treatment and reuse. *Water Science and Technology*. 50(2): 23 – 30.

WHO-EMRO (1987) *Wastewater Stabilization Ponds: Principles of planning and practice*, WHO-EMRO Technical Publication No. 10, WHO-EMRO, Alexandria, Egypt.

WHO (2006-2) Guidelines for the Safe Use of Wastewater, Excreta and Greywate: Wastewater Use in *Agriculture,* World Health Organization, Volume II, Pg. 101, 102.

WHO (2006-4) Guidelines for the Safe Use of Wastewater, Excreta and Greywate: Excreta and Greywater Use in *Agriculture*, World Health Organization, Volume IV.

WHO (2007) *A safe Future.* Global Public Health Security in the 21st Century. World Health Report, WHO, Geneva.

WHO (2008) *Almost a quarter of all disease caused by environmental exposure*. http://www.who.int/mediacentre/news/releases/2006/pr32/en/index.html.

WHO/UNICEF (2010) *Progress on Sanitation and Drinking Water*. WHO/UNICEF.

De Serres, G., Levesque, B., Higgins, R., *et al*., (1995) Need for vaccination for sewer workers against leptospirosis and hepatitis A. *Occup. Environ. Med.* 52, 505-507.

Yates, M.V. and Yates, S.R. (1988) Modeling microbial fate in the subsurface environment. CRC *Critical Reviews in Environmental Control*, 17 (4) 307-344.

Yajima, A., Jouquet, P., Trung, D. D., Cam, T. D.T., Cong, D.T., Orange, D. and Montressor, A. (2008) *High Latrine Coverage is not reducing the prevalence of soil-transmitted helminthiasis in Hoa Binh province*, Vietnam. Transaction of the Royal Society of Tropical Medicine and Hygiene

Yu, I.T., Li, Y., Wai Wong, T., Tam, W., Chan, A.T., Lee, J.H.W., Leung, D.Y.C. and Ho, T. (2004) Evidence of Airborne Transmission of the Severe Acute Respiratory Syndrome Virus, *The New England Journal of Medicine*, 350 (17): 1731-1739.

ANNEXES

ANNEX 1 : PATHOGEN REDUCTION IN ANAEROBIC DIGESTORS

<table>
<tr><th>Country</th><th>Feed</th><th>Pathogens</th><th>Pathogen reduction (time)</th><th colspan="2">Digester operational condition(s)</th><th>Reference</th></tr>
<tr><td>India</td><td>Manure from 200 diary cows and 400 calves and young stock</td><td>Salmonella
Ascaris eggs</td><td>No viable Salmonella or Ascaris eggs found after 24 hr in the digester</td><td colspan="2">Continuous biogas digester (24h at 55°C)</td><td>Plym-Forshell, 2005</td></tr>
<tr><td>Na</td><td>Biosolids</td><td>Cryptosporidium parvum
Ascaris suum</td><td>>3 log in 24 hrs
>3log in 1 hr</td><td colspan="2">Anaerobic digester (55 °C)</td><td>Kato et al., (2003)</td></tr>
<tr><td></td><td>Biosolids</td><td>Ascaris suum</td><td>95% eggs inactivated in 2 days</td><td colspan="2">Anaerobic digester (47°C)</td><td>Kato et al., (2003)</td></tr>
<tr><td>India</td><td>Cattle dung slurry</td><td>Escherichia coli
Salmonella typhi
Shigella dysenteriae
Streptococcus faecalis</td><td>Survived for 20 days
Survived for 20 days
Survived for 10 days
Survived for 35 days</td><td>Anaerobic batch digester at room temperature (35°C)</td><td rowspan="2">2.5 litre capacity bottles with a facility for withdrawing and injecting samples were used as anaerobic batch digestors. Digestors were fed with 300g of cattle dung and seeded with 10% inoculum obtained from</td><td rowspan="2">Kumar et al., 1999</td></tr>
<tr><td>India</td><td>Cattle dung slurry</td><td>Escherichia coli
Salmonella typhi
Shigella dysenteriae
Streptococcus faecalis</td><td>Survived for 10 days
Survived for 10 days
Survived for 5 days
Survived for 15 days</td><td>Anaerobic batch digester at room temperature (18-25°C)</td></tr>
<tr><td>UK</td><td>Cattle slurry (TS content of 5-10%)</td><td>Escherichia coli
Salmonella typhi
Yersinia enterocolitica
Listeria monocytogenes
Campylobacter jejuni</td><td>1 log (76.9days)
1log (34.5 days)
1log (18.2 days)
1log (28.5 days)
1log (438.6 days)</td><td colspan="2">Continuously stirred anaerobic digester operating at 28°C with a mean hydraulic retention time of 25 days. Working volume: 210m³</td><td>Kearney et al., (1993)</td></tr>
<tr><td>India</td><td>Human excreta</td><td>Vibrio cholera</td><td>1 log (2.63 days)</td><td colspan="2">The anaerobic digesters used in the study were 9.5 L capacity, KVIC design, non-stirred, floating-dome digesters (23-27°C)
(VFA = 500 mg/l and pH 7.6),</td><td>Kunte et al., 2000</td></tr>
<tr><td>India</td><td>Human excreta</td><td>Vibrio cholera</td><td>1 log (1.63 days)</td><td colspan="2">The anaerobic digesters used in the study were 9.5 L capacity, KVIC design, non-stirred, floating-dome digesters (23-27°C)
(VFA = 8000 mg/l and pH= 6.4),</td><td>Kunte et al., 2000</td></tr>
<tr><td>Denmark</td><td>Pig slurry</td><td>Salmonella typhimurium</td><td>1 log (2 days)</td><td colspan="2">Pilot anaerobic digester</td><td>Olsen and Larsen (1987)</td></tr>
<tr><td>Denmark</td><td>Cattle slurry</td><td>Salmonella typhimurium</td><td>1 log (2.9 days)</td><td colspan="2">Pilot anaerobic digester</td><td>Olsen and Larsen (1987)</td></tr>
</table>

VFA= Volatile Fatty Acid

ANNEX 1 CONT: PATHOGEN REDUCTION IN ANAEROBIC DIGESTORS

County	Treatment process	Feed	Pathogens	Pathogen reduction (log_{10})	Technology description	Reference
France	Mesophilic stabilisation	Sludge from a treatment plant (PH: 5.9; Dry matter: 3.8%)	*E. coli* *Enterococci* SRB Nematode eggs	0.9 0.5 0.03 1.8	Capacity: 20,000pe Retention or storage time: 10 days Temperature: 35^{0}C	Gantzer *et al*.2001
	Anaerobic mesophilic digestion	Sludge from a treatment plant (PH: 5.4; Dry matter: 5.1%)	*E. coli* *Enterococci* SRB Nematode eggs	1.5 1.1 0.3 3.8	Capacity: 250,000pe Retention or storage time: 20 days Temperature: 35-37^{0}C	Gantzer *et al*.2001
	Aerobic mesophilic digestion	Sludge from a treatment plant (PH: 6.1; Dry matter: 3%)	*E. coli* *Enterococci* SRB Nematode eggs	3.5 2.1 1.3 0.5 - 1	Capacity: 17,000pe Retention or storage time: 30 days Temperature: 25-48^{0}C)*	Gantzer *et al*.2001
Spain	Anaerobic mesophilic digestion + mechanical dewatering	Composite mixture of primary sludge (2/3) and secondary sludge (1/3) from an activated sewage sludge treatment plant serving 400000 inhabitants. (Dry matter: 3.6%)	*Faecal Coli*forms SRB Somatic *Coliphages* F-specific RNA phages Phage infect *Bact. Fragilis* Enteroviruses *Cryptosporidium* spp(viable	0.78 0.03 0.9 2.21 1.28 1.53 1.14	After thickening sludge was subjected to anaerobic mesophilic (35^{0}C) digestion for 20 – 25 days. It was then mixed with a solution of synthetic organic polyelectrolyte flocculatnt prior to mechanical dewatering by means of centrifugation. The final disgested-dewatered sludge contained about 25% dm.	Guzman *et al*.2007

* winter temperature SRB: Sulphite-reducing bacteria;

ANNEX 2: PATHOGEN REMOVAL IN WASTE STABILISATION PONDS

Country, Site	Pathogen	Pathogen concentration per litre: Raw wastewater	Anaerobic pond	Facultative pond	Maturation pond	Pathogen reduction	Technology description	Reference
Kenya, Dandora	*Ascaris*	61.5		0.7	0	100%	Pond series comprises 2 lines : one facultative pond +3 maturation pond in parallell. Retention time: 26.2 days	Grimason *et al.*, 1996
Kenya, Karatina	*Ascaris*	17.5		0	0	100%	Series comprises one line consisting 1 facultative pond and 3 maturation ponds	Grimason *et al.*, 1996
Kenya, Eldoret	*Ascaris*	24.3	3.6	0	0	100%	Four anaerobic ponds in parallel, + 2 facultative, 2 primary maturation and 2 final maturation ponds in parallel. Retention time: 12.4 days	Grimason *et al.*, 1996
Kenya, Kitale	*Ascaris*	18.8	0	0	0	100%	Series comprising 4 anaerobic ponds in parallel, + one line consisting of 1 facultative and 3 maturation ponds	Grimason *et al.*, 1996
Kenya, Nakuru	*Ascaris*	133.3	88.9	2	0	100%	2 anaerobic ponds in parallel +3lines in parallel consisting of 1 facultative and 3 maturation ponds. Retention time: 17.8 days	Grimason *et al.*, 1996
Morroco, Marakech	Ent. Histolytica *Giardia sp.* *Entamoeba* coli	2×10^3 3×10^3 10^4				97% 99% 98%	Stabilisation ponds consist of 2 circular basins arranged in series each with a surface area of 2500m^2 and depth 2.3m in the first basin and 1.5m in the second.	Bouhoum *et al.*, 2000
	Ascaris *Trichuris* Hymen-olepsis *Enterobius* *Taenia*	3 2.2 2.1 0.2 0.1				100% 100% 100% 100% 100%	Stabilisation ponds consist of 2 circular basins arranged in series each with a surface area of 2500m^2 and depth 2.3m in the first basin and 1.5m in the second.	Bouhoum *et al.*, 2000
Brazil	Parasite eggs	992.6 *Ascaris*, *Trichuris*, Hookworm Hymen-olepis spp	54.0 *Ascaris*, *Trichuris*, Hook-worm	0.2 (*Ascaris*)	0	100%	Each of the ponds received an average inflow of 14.7 m^3/d and had the following dimensions: 10 m × 3.35 m × 2.20 m deep. Themean hydraulic retention time for each pond was 5 days	Stott *et al.*, 2003
Brazil	Helminth eggs	477	278	3	0	100%	Anaerobic pond followed by a secondary facultative pond and eight maturation pond. The dimension (length, width, depth) of the anaerobic pond was 1.80m x 1.20m x1.50m and the rest were 3.60m x 1.20m x 1.50m. Receives a flow of 30,000m3/d. Mean hydraulic retention time: 19 and 28.5days.	Oliviera *et al.*, 1996

ANNEX 2 CONT: PATHOGEN REMOVAL IN WASTE STABILISATION PONDS

Coun-try	Pathogen	Pathogen concentration per 100mL §				Pathogen reduction (Log or %)	Technology description	Reference
		Raw Waste-water	Anaerobic	Facultative	Maturation			
Brazil	*Faecal Coli*	2 x 10^7	4 x 10^6	8 x 10^5	7 x 10^3	3.5	The pond comprises two systems of ponds: 10 series and 17 pond system comprising different combinations of pond types in seriesThe 2 anaerobic ponds had volumentric loadings of 187g BOD5/m^3/d and the secondary facultative ponds each had a surface organic loading rate of 217kgBOD5/ha/d	Pearson *et al.*, 2005
	Campylo spp	70	20	0.2	0	6		
	Salmonella spp	20	8	0.1	0	6		
	Enteroviruses	1 x 10^4	6 x 10^3	1 x 10^3	9	3		
	Rotaviruses (10L-1)	800	200	70	3	2.4		
Kenya	*Faecal Coli*forms	8.5 x 10^6	1.49 x 10^6	-	16 (0-30)	> 6 log	Have a design capacity of 80,000m3/d Comprising six parallel series of pond with each series comprising a primary facultative pond, followed by a sequence of three maturation ponds	Pearson *et al.*, 1996
Brazil	*Faecal Coli*form	2.72 x 10^7 - 4.12 x 10^7	9.2 x 10^6 - 1.07 x 10^7	2.37 x 10^6 - 3.88 x 10^6	2.84 x 10^2 - 1.07 x 10^2	5 log	Anaerobic pond followed by a secondary facultative pond and eight maturation pond. The dimension (length, width, depth) of the anaerobic pond was 1.80m x 1.20m x1.50m and the rest were 3.60m x 1.20m x 1.50m. Receives a flow of 30,000m3/d. Mean hydraulic retention time: 19 and 28.5days.	Oliviera *et al.*, 1996
Colum-bia Choc-onta.	*Faecal Coli**	5.5 -6.5	-	-	2.0 -3.4	48% –64%	The WSP consist of two facultative ponds in series treating a flow of 1555 m^3 /day.	Campos *et al.*, 2002
	*E. coli**	6.9	-	-	2.5 – 3.9	43% –64%		
	*Strep. Faecalis**	6.4 – 6.9	-	-	2.5 – 3.9	43% –61%		
	*Clostridium p**	5.8	-	-	2.5	57%		
	F+ phages**	4.8 – 5.0	-	-	1.3 – 2.9	42% –73%		
	Somatic phages**	4.8 – 5.6	-	-	1.0- 3.6	25% –79%		
	RYC phages**	1.8 – 3.2	-	-	0.9 – 2.3	28% –50%		

* log. CFU/100 mL ** log. PFP/100 mL § pathogen concentration is expressed per 100mL unless stated otherwise

ANNEX 3: PATHOGEN REMOVAL IN CONSTRUCTED WETLANDS

Technology	Country	Wastewater type	Pathogen	Influent (Log_{10}) CFU/ PFU/ 100mL§	Effluent (Log_{10}) CFU/PFU/ 100mL§	Log Reduction	Technology description	Sampling protocol	Reference
Constructed Wetland	Alabama, USA	NA	TC & FC *Enterococci* *C. Perfringes* *Somatic. C* F+ C	NA	NA	0.5- 2.6 0.1-1.5 1.2-2.7 -0.3 – 1.2. -0.2 – 2.2	NA	NA	Barrett *et al.*, (2001)
Constructed Wetland	North Carolina, USA	NA	TC & FC *Enterococci* *C. Perfringes* *Somatic. C* F+ C	NA	NA	0.8- 4.2 0.3 - 2.9 1.6-2.9 -0.2 – 2.8 -0.1 – 1.5	NA	NA	Barrett *et al.*, (2001
Sub-surface flow horizontal Constructed Wetland	Ås, Norway	Greywater from a student hostel	TCB	6	0 – 3	3-6	Aerobic Biofilter + subsurface horizontal flow wetland. Boifilter and horizontal flow wetland have 2 -4 mm LWA (Filtralite™). Retention time: 6-7 days	2 years of sampling (11 samples)	Jenssen and Vråle (2003)
Sub-surface flow horizontal Constructed Wetland	Ås, Norway	Blackwater + greywater from a single household (5 years of operation)					Pre-treatment biofilter (LWA (2-4 mm grain size) with spray nozzle and effective surface area of $3.4m^2$ with a loading rate of 132 and 254 m^{-2} day^{-1}. Upflow filter (Filtralite P™ with a grain size of 0-4 mm) with total filter volume of 6 m^3 and a depth of 1.2m		Heistad *et al.*, 2006
Constructed Wetland	Morgantown, U.S.A	Primary-clarified sewage influent from a wastewater treatment plant from Morgantown, WV	FC *Enterococci* *Salmonella* *Shigella* *Yersinia* *Coliphage*	8.0 5.8 5.3 5.8 6.2 5.2	5.7 3.9 3.8 4.1 4.7 4.0	2.3 1.9 1.5 4.7 1.5 1.2	Vegetated. (19L per day) Eight 400L black plastic troughs (1.5m x 1m) filled with pea gravel up to a depth of 45 or 65 cm (combination of plants (cattails (typha latifolia, rush (Juncus effusus) and bulrush (Scirpus validus) retention time : 6 -8 days	2 years of sampling (9 samples per month)	Hench *et al.*, (2003)
Sub-surface flow Constructed Wetland	Tucson, USA	Unchlorinated secondary wastewater after treatment by a duckweed pond	TC FC *Coliphage* *Giardia* *Cryptosporidium*	4.23 3.8 2.39 1.15 per 100L 1.10 per 100L	2.04 1.6 0.69 - 0.43 per 100L	2.19 2.2 1.7 1.30 0.67	The cells of the wetland have a maximum depth of 1.4m and are 61m long and 8.2m wide. Each of these SSF wetlands were planted with cattail (Typha domingenisis), bulrush (Scirpus olneyi), black willow (Salix nigra), and cottonwood (Populus fremontii). Retention time: 4 days. Average flow rate: 58 and 55 L	1- 2 samples per month for 18 months Colip and protozoa samp 1yr No bact in June 1996	Thurston *et al.*, (2001)

§ Unless indicated otherwise TC- total coliforms FC-Faecal coliforms TCB- Thermotolerant coliform bacteria

ANNEX 3 CONT: PATHOGEN REMOVAL IN CONSTRUCTED WETLANDS

Technology	Country	Wastewater type	Pathogen	Influent (Log10) CFU/ PFU/MPN/ No,/ 100mL	Effluent (Log10) CFU/PFU/ 100mL	Log Reduction	Technology description	Sampling protocol	Reference
Horizonal Subsurface flow Constructed Wetland	DareSalaam, Tanzania	Secondary treated wastewater (WSP)	TC FC	4.7 4.6	3.7 3.6	1 1	Horizontal subsurface flow. Constructed wetland planted with Typha latifolia. Low filtration (0.27 m/h). Retention time (hours). Reed bed (5 x 1x1 m); rock material (d10 = 21.24 mm. Uc 1.49 mm)	1 month sampling (4 – 7 samples)	Mashauri *et al.*, (2000)
Horizontal Subsurface Constructed Wetland	Dare-Salaam, Tanzania	Secondary treated wastewater (WSP)	TC FC	4.8 4.7	4.7 4.6	0.1 0.1	Horizontal subsurface flow. Constructed wetland planted with Typha latifolia. High Filtration (2.3 m/h). Retention time (hours). Reed bed (5 x 1x1 m); rock material (d10 = 21.24 mm. Uc 1.49 mm)	1 month sampling (4 -7 samples)	Mashauri *et al.*, (2000)
Vetical Filter + horizontal subsurface flow Constructed Wetland	Wiedersberg, Germany	Domestic sewage (effluent of multi-chamber septic tank)	*E. coli* Enteroccoci Campylo/acrobacter Clostrid. perf Crypto oocysts *Giardia*	6-7 5 6.6 4 1.7 per 100L 3.5 per 100L	2 – 3 2 – 3 2.5 1 0 -0.30	2 – 2.5 0.5 – 1 4.1 3 1.7 3.80	Multi-chamber septic tank to 1 vertical and 1 horizontal filter (Filter area: 7m^2/PE; Coarse sand)- 1 yr of operation	76 samples Every fortnight 3 years of sampling	Ulrich *et al.*, (2005)
Surface flow + vertical Constructed Wetland	Ettenbuettel , Germany	Municipal water (effluent of lagoon 2)	*E. coli* Enteroccoci Campylo/acrobacter Clostrid. perf Crypto oocysts *Giardia*	6-7 4.93 5.6 3.9 1.8 per 100L 3.4 per 100L	3 - 4 3 3 2.1 0.69 per 100L 0.69 per 100L	2 1.5 2.6 1.8 1.1 2.7	2 successive sewage lagoons to 2 vertical filter (Filter area: 2.3m^2/PE; sand/gravel)- 1 yr of operation	38 samples Every month 3 years of sampling	Ulrich *et al.*, (2005)
Horizontal subsurface flow Constructed Wetland	See, Germany	Domestic sewage	*E. coli*	6.7 -7	4.6	2.1 – 2.4	Multi-chamber septic tank to 2 successive horizontal filters (Filter area: 7 -10 m^2/PE; medium sand)-11 yrs of operation	41 samples Intensive day to day	Ulrich *et al.*, (2005)

ANNEX 4 A: PATHOGEN REMOVAL IN SLUDGE SETTLING PONDS

County	Treatment process	Sludge type	Pathogen	Inlet (gTS-1)	Outlet (gTS-1)	Pathogen reduction (log)	Technology description	Refrence
Alcorta, Argentina	Primary dewatering septage pond	Septage	*Ascaris*	0.1 – 16	0.1 - 1.4	0.8*	Alternatively operated septage sedimentation/digestion ponds. Sludge stored between 346 and 633 days. Humidity 85% during 535 days of storage but decreased to 53% in the subsequent 70 days	Sanguinetti *et al.*, 2005
Alcorta, Argentina	Storage in a plastic tank	Septage	*Ascaris* suum	20	1.8 **	1.13	70 L plastic tank was filled with sludge and inoculated with *Ascaris* suum. The tank was set into sludge accumulated in primary dewatering septage pond for 8 months.	Sanguinetti *et al.*, 2005
Alcorta, Argentina	Storage in a plastic tank	Septage	*Salmonella*	7.0 x 10^6	3.0 x 10^4	2.37***	*Salmonella* enteritidis was seeded into a container with sludge. Ambient and sludge temperatures ranged from 13°C -28°C and 14.5°C - 29.5°C respectively. PH=6.5 -7.5	Sanguinetti *et al.*, 2005
		Septage	Helmith eggs			3	4 months retention in settling pond	Fernandez *et al.*, 2004

* log reduction based on maximum value of the range **Concentration after 7 months of storage *** Concentration after 3.8 months of storage

ANNEX 4 B: PATHOGEN REMOVAL BY CO-COMPOSTING

County	Treatment process	Sludge type/ characteristics	Pathogen	Input	Output	Pathogen reduction (log or %)	Technology description	Reference
France	(Aerated Pile 1/3 sludge, 1/3 saw dust,)	(PH: 7.8; Dry matter: 20.4%)	*E. coli*	-	3.1	1.8	Retention time: 21 days. Temperature: 50-55°C)	Gantzer *et al.*, 2001
			Enterococci		5.1	1.0		
			SSRB		4.6	1.7		
			Nematode eggs (10g-1DM)	1.5	<1			
Spain	Windrow + aerated composting	Dewatered sludge (15%DM) from different municipal sewage plants	*Faecal Coli*forms (10g-1DM)	6.6 x 10^7	2.0 x 10^2	5.51	Dewatered sludge is mixed with waste and inert vegetable materials and subjected to a thermophilic (55°C) composting process by longitudinal windrows (covered with a Gore cover) with a residence time of 4 weeks. The product passes to a second series of piles (aerated) for maturation (a mesophilic process) for a minimum of 2 weeks and a maximum of 6 weeks.	Guzman *et al.*,
			SSRC* (10g-1DM)	5.2 x 10^7	1.3 x 10^5	2.59		
			Somatic Coliphages	3.3 x 10^7	4.6 x 10^1	5.85		
			F-specific RNA phages	1.7 x 10^6	-			
			Phage infect *Bact. Fragilis*	3.4 x 10^4	-			
			Enteroviruses	2.7 x 10^1	-			
			Cryptosporidium spp(viable	7.6 x 10^2	2.3	2.518		
			Helminth ova (viable)	1.5	<1.0			
Egypt	Static pile with forced aeration	Faecal Sludge	*Faecal Coli*form (LogMPN/g)	6.04 - 6.96	0	6.04 - 6.96	Retention time: 28 days	Shaban, 1999
			Faecal streptococci(logMPN/g)	6.18 – 6.66	2.36 – 4.04	3.82 – 2.62		
			Salmonellae	2.0 -2.79	0	2.0 -2.79		
			Coliphage (LogCFU/g)	4.86	2.0 - 2.86	2 – 2.86		

SSRB: Spores of sulphite-reducing bacteria; SSRC: Spores of sulphite-reducing coliform * CFU: colony forming units

ANNEX 4 B: PATHOGEN REMOVAL BY CO-COMPOSTING

County	Treatment process	Sludge type	Organism	Input concentration. (Log MPN or CFU/gTS)	Output concentration (Log MPN or CFU/gTS)	Pathogen reduction (log10)	Technology description	Reference
Egypt	Static pile with forced aeration	Faecal Sludge	*Faecal Coliform*	6.04 - 6.96	0	6.04 - 6.96	Retention time: 105 days	Shaban, 1999
			Faecal streptococci	6.18 – 6.66	0	6.18 – 6.66		
			Salmonellae	2.0 -2.79	0	2.0 -2.79		
			Coliphage	4.86	0	4.86		
Egypt	Windrow composting	Faecal sludge	*Faecal Coliform*	6.34	0	6.34	Retention time (3 weeks to 4 weeks)	Shaban, 1999
			Faecal streptococci	7.36	0	7.36		
			Salmonellae	2.48	0	2.48		
			Coliphage	5.80	2.38 – 2.70	3.42 – 3.10		
Egypt	Windrow composting	Faecal Sludge	*Faecal Coliform*	6.34	4.34	2	Retention time (5 weeks)	Shaban, 1999
			Faecal streptococci	7.36	4.59	2.77		
			Salmonellae	2.48	1.56	0.92		
			Coliphage	5.80	4.59	1.21		
Egypt	Natural draft system	Faecal sludge	*Faecal Coliform*	6.30	2.08 (0)§	4.22	Retention of 23 days (73 days)	Shaban, 1999
			Faecal streptococci	6.04	3.60 (0)§	3.56		
			Salmonellae	2.08	0 (0)§	2.08		
			Coliphage	4.79 – 4.86	2.38 – 2.56 (0)§	2.41 – 2.30		

* CFU: colony forming units; § : 73 days retention time

ANNEX 4 B: PATHOGEN REMOVAL BY CO-COMPOSTING

County	Treatment process	Sludge type	Organism	Input (gTS-1)	Output concentration. (gTS-1)	Pathogen reduction (log or %)	Technology description	Reference
Ghana	Thermophilic Co-composting	Septage sludge	Helminth egg	25 – 83	< 1 egg	1.40 – 1.9	Biosolids were mixed with solid waste as bulking material for co-composting at a 1:2 volume ratio. Two replicate sets of compost heaps were mounted in parallel and turned at different frequencies during the active composting period: (i) once every 3 days and (ii) once every 10 days. The composting process lasted about 60 days	Kone *et al.*, 2007
France	Thermophilic co-composting	Sewage sludge	*E. coli*	$2.1 \times 10^5 – 9.2 \times 10^6$	$65 – 3.4 \times 10^3$	3.4 - 3.5	The composting facility was an open greenhouse with a concrete floor on which boxes are installed 6 m long and 4 m wide, which are able to be filled up to 2 m in height, separated by concrete walls heightened by planks. A total of 8.1 tonnes of pressed sludge was mixed with 1.4 tonnes of straw in a 1 : 0.17 ratio based on the weight. The C : N ratio of the starting compost material was 9.3 : 1, the moisture content, 74.9%. The mixture was composed in a trapezoidal shaped pile (1.2m high with bases of 4.85 and 3.85m and 3.90m wide). Composting lasted 4 months with turning every month, considered as the fermentation phase and the following 3 month period without turning, as the maturation phase (Temperature; < 50°C – 66°C)	Pourcher *et al.*, 2005
			Enterococci	$2.1 \times 10^5 – 9.6 \times 10^6$	$3.4 \times 10^2 – 1.0 \times 10^3$	2.8 - 3.9		
			C. perfringens	$(4.4 \times 10^4 – 8.4 \times 10^4)$*	nd	-		
			Listeria sp.	44 – >44	nd -2.6	-		
			L. monocytogenes	0.8 – 44	0.15	2.5		
			Salmonella sp.	1.7 – 9.6	nd	-		
			Enteroviruses	$(2.3 \times 10^3 – 4.8 \times 10^3)$**	nd	-		

* CFU: colony forming units;
** Genome copies ; nd: below detection limit; i.e. $< 5.6 \times 10^2$ for *C. perfringes.*, < 0.5 for *Salmonella sp.*, < 50 for genome copies of Enteroviruses.

ANNEX 4 C: PATHOGEN REMOVAL IN SLUDGE DRYING BEDS

County	Treatment process	Sludge type	Organism	Input concentration.	Output concentration.	Pathogen Reduction (log10)	Technology description	Reference
Cameroun, Yaounde	Planted Vertical Flow Drying bed	Mixture of FS from traditional pit latrines, septic tanks and public toilets	Total Helminth eggs	10409 per litre	1 month storage (count/gTS) 78.9 total eggs 38.5 *Ascaris* eggs 19.5*Trichuris Trichuris* 0.5Ancyclostoma duodenale. 0.6 Strongyloides stercoralis. 0.5 *Enterobius* vermicularis 0.9 Tenia sp. 6 months storage (count/gTS) 7.5 total eggs 4.03 *Ascaris* eggs - *Trichuris Trichuris* 0 Ancyclostoma duodenale. 0 Strongyloides stercoralis. 0 *Enterobius* vermicularis 0 Tenia sp.	Total eggs (3.14 log)	The system comprises two storage tanks of 1 m^3 mounted at 1.5 m above ground to allow a gravitational supply of six VFCW bed units (1 × 1 × 1 m) vegetated with two indigenous macrophytes (Echinochloa pyramidalis and Cyperus papyrus) The beds were fed at nominal solid loading rates (SLR) of 100 (SLR1), 200 (SLR2), and 300 kg TS (total solids)/m^2/yr (SLR3) for six months at one application per week, except for the E. pyramidalis beds. Temperature was between 18 and 30°C.	Kengne *et al.*, (2009)
Helsinge, Denmark	Planted Vertical flow drying bed	Activated sludge direct from the activated sludge plant and activated sludge from final settling tanks	*Salmonella* *Enterococci* *E. coli*	9 / g(ww) 11,000 g(ww) 3100-79000/g(ww)	<0.02/ g <10/g < 2 /g	2.64 5 6 -7	The reed bed system has a capacity of 630 TDS per year and consists of 10 basins, each having an area of 1,050m^2 at the filter surface and a maximum area loading rate of 60 kg DS/m^2 /yearThe loading regime of the system consists of applications of approximately 130–150m^3 of sludge being applied once or twice daily, The feed concentration being approximately 0.5–0.8% DS.. 4 Months of storage	Nielsen, 2007

ANNEX 4 C: PATHOGEN REMOVAL IN SLUDGE DRYING BEDS

County	Treatment process	Sludge type	Organism	Input concentration (eggs/g TS)	Output concentration (counts/gTS)	Pathogen reduction (log)	Technology description	Reference
Bangkok, Thailand	Planted / dewatering Constructed wetland	Septage	Helminth eggs	0 – 14	< 6 eggs	0.37	The constructed wetland was planted with cattails (Typha augustifolia), The substrata depth in these experiments was designed to be 65-cm, consisting of a 10 cm layer of 1-mm Ø fine sand, a 15 cm layer of 25-cm Ø small gravel, and a 40 cm layer of 50-cm Ø large gravel. A free board of 1m was allowed for accumulation of the dewatered septage (biosolids). Retention time : 12 months	Koottatep *et al.*, 2005.
Alcorta, Argentina	Unplanted drying bed	Septage	*Ascaris* suum	13	0.2 – 0.4	1.49 - 2	A plastic box of 40 x 50 x 20 cm size with bottom drainage was used to simulate a drying bed. 8 months dewatered sludge was subjected drying for 12 months.	Sanguinetti *et al.*, 2005

ANNEX 5 : OPEN DEFAECATION

System	Country	Use and mainte-nance	Health Outcome and outcome measure	Prevalence of outcome meas-ure (%)	Relative risk or odds ratio (95% CI)	Study design, sample size and age group	Reference
Open Air	Brazil (low income urban c'ties)		Diarrhoea	Period Preva-lence (days/child/year) 42.5 vs 28.7	1.48	Period Prevalence Age. < 6 years Open air vs Septi Pit Lat	Gross *et al*., (1989)
Open Air	Brazil (low income urban c'ties)	-	Diarrhoea	Period Preva-lence (days/child/year) 42.5 vs 39.7	1.07	Period Prevalence Age. < 6 years Open air vs Pit latrine	Gross *et al*., (1989)
Bush	Nigeria		*Ascaris*	22.05 vs. 16.25	1.35	Bush vs pit latrine	Asoalu *et al*., 2002
Bush	Nigeria	Na	*Ascaris*	22.05 vs 7.70	2.86	Case-control study (0 – 108 months) Data taken at clinic Bush vs flush toilet	Asoalu *et al*., 2002

ANNEX 6: EPIDEMIOLOGICAL AND HEALTH RISK EVIDENCE OF PIT AND VIP LATRINES

System	Country	Use and mainte-nance	Health Out-come and outcome measure	Prevalence of outcome meas-ure (%)	Relative risk or odds ratio (95% CI)	Study design, sample size and age group	Reference
Communal latrines (also including improved water supply)	Philippines (urban)	-	Cholera		RR 0.32 (0.24 - 0.42)	Age group: all	Azurin and Alvero (1974) described in Fewtrel *et al.*, (2005)
Communal latrines (also including improved water supply	Philippines (urban)	-	Cholera		RR 0.59 (0.43 - 0.81)	Age group: 0 – 48 months	Azurin and Alvero (1974) described in Fewtrel *et al.*, (2005)
VIP Latrine installation (including hygiene educa-tion)	Lesotho (rural)	-	Diarrhoea		OR 0.76 (0.58 – 1.01)	Age group: 0 – 60 months	Daniels *et al.*, (1990)
Septic pit latrine (VIP)	Brazil (low income urban c'ties)		Diarrhoea	Period Prevalence (days/child/year) 28.7 vs 42.5	0.67	Longitudinal Study Period Prevalence Age. < 6 years Septi Pit Lat vs Open air	Gross *et al.*, (1989)
Pit latrine	Brazil (low income urban c'ties)	-	Diarrhoea	Period Prevalence (days/child/year) 39.7 vs 42.5	0.93	Longitudinal study Period Prevalence Age. < 6 years Pit latrine vs Open air	Gross *et al.*, (1989)
VIP latrine (2.1m³ volume for faecal matter)	Afghanistan (Kabul)	Quarterly Faecal matter evacua-tion	Diarrhoea		OR 0.57 (0.42 – 0.77)	Case-Control verbal autopsy methodology	Meddings *et al.*, (2004)
Pit Latrine	El-Salvador	-	Helminthes	Na	OR *Ascaris* : 0.9 (0.1- 6.0) *Trichuris*: 0.6 (0.1 - 1.5) Hookworm: 1.4 (0.5 – 3.5) *Giardia* : 0.5 (0.2 – 1.3) *Entamoeba*: 0.8 (0.4 – 1.8)	Cross sectional Survey Pit latrine vs No latrine Age group: 4 - > 40 yrs	Corrales *et al.*, 2006
Pit Latrine	Nigeria		Helminths	16.25 vs 22.05	*Ascaris* (0.73)	Case- control study pit latrine vs Bush	Asoalu *et al.*, 2002
Pit Latrine	Nigeria		Helminths	16.25 vs 7.70	*Ascaris* (2.1)	Case- control study Pit latrine vs Flush toilet	Asoalu *et al.*, 2002

ANNEX 7: EPIDEMIOLOGICAL AND HEALTH RISK EVIDENCE OF URINE DIVERTING AND COMPOSTING TOILETS

System	Country	Use and maintenance	Health outcome and outcome measure	Prevalence of outcome measure	Relative risk or odds ratio (95% CI)	Significance	Study design, sample size and age group	Reference
Single Pit latrine / Double vault pit latrine (with urine diversion into a local drain)	Vietnam	4-6 month storage time Straw addition & reuse	Helminthes	*Ascaris* : 13.5 vs 0 *Trichuris*: 44.5 vs 33 Hookworm: 56.7 vs 66	13.5A 1.36 (0.27 – 6. 81) 0.87 (0.39 - 1.96)		Cross sectional design Age group : all included Sample size: 155 RR: latrine vs no latrine	Yajima *et al.*, 2008
Latrina Abonera Seca Familiar (LASF) Double Vault latrine	El-Salvador	Storage	Helminthes	NA	Odd Ratios *Ascaris* : 15.5 (3.3-74.8)* *Trichuris*: 7.1 (3-17.1)* Hookworm: 0.5 (0.2 – 1.3) *Giardia* : 0.4 (0.2 – 1.1)* *Entamoeba*: 0.5 (0.2 – 1.4)	 P<0.05 P<0.05 P>0.05 P<0.05 P<0.05	Cross-sectional survey (sero-prevalence?) survey 127 individuals LASF vs No latrine	Corrales *et al.*, 2006
Solar Latrine (composting)	El-Salvador	-	Helminthes	NA	Odd Ratios *Ascaris* : 0.7 (0.1- 8.2) *Trichuris*: 0.7 (0.2-1.9) Hookworm: 0.4 (0.1 – 1.3)* *Giardia* : 0.3 (0.1 – 1.1) *Entamoeba*: 1.4 (0.5 – 4.2)*	 P>0.05 P0.05	Cross sectional survey (sero-prevalence) 79 individuals LASF vs No Latrine	Corrales *et al.*, 2006
Pit Latrine	El-Salvador	-	Helminthes	NA	Odd Ratios *Ascaris* : 0.9 (0.1- 6.0) *Trichuris*: 0.6 (0.1 - 1.5) Hookworm: 1.4 (0.5 – 3.5)* *Giardia* : 0.5 (0.2 – 1.3) *Entamoeba*: 0.8 (0.4 – 1.8)	 P>0.05 P>0.05 P<0.05 P>0.05 P>0.05	Cross-sectional survey Pit latrine vs No latrine	Corrales *et al.*, 2006
LASF and Solar Latrine	El-Salvador		Helminthes	*Ascaris* (13.3 vs 15.3) *Trichuris* (41.7 vs 23.7) Hookworm (33.3 vs 10.2) *Giardia* (11.7 vs 1.7) *Entamoeba* (23.3 vs 6.8)	*Ascaris* : 0.8 (0.3- 2.4) *Trichuris*: 2.3 (1.1 – 5.1) Hookworm: 4.4 (1.6 – 12.0)* *Giardia* : 7.7 (0.9 – 64.3) *Entamoeba*: 4.2 (1.3 – 13.6)*		Cross-sectional survey Application of biosolids in field vs burial in yard.	Corrales *et al.*, 2006
LASF and Solar Latrine	El-Salvador		Helminthes	*Ascaris* (16.1 vs 15.3) *Trichuris* (38.7 vs 23.7) Hookworm (8.1 vs 10.2) *Giardia* (9.7 vs 1.7) *Entamoeba* (16.1 vs 6.8)	*Ascaris* : 1.1 (0.4- 2.8) *Trichuris*: 2.0 (0.9 – 4.5) Hookworm: 0.8 (0.2 – 2.7) *Giardia* : 6.2 (0.7 – 53.3) *Entamoeba*: 2.6 (0.8 – 9.0)		Cross-sectional survey Application of biosolids in household gardens or trees vs burial in yard	Corrales *et al.*, 2006

- B : INFECTION RISK ASSOCIATED WITH URINE INGESTION

Facility	Country	Pathogen	Treatment condition	Risk group	Exposure event	Mean ann risk of infection	Reference
Urine Diverting Dry Toilet	Sweden	*Campylobacter* jejuni	Unstored	All	Accidental ingestion under an epidemic situation	4.8×10^{-4}	Hoglund, 2001
			1 month storage 4°C	All	Accidental ingestion under an epidemic situation	Nr	
			6 months storage 4°C	All	Accidental ingestion under an epidemic situation	Nr	
			1 month storage 20°C	All	Accidental ingestion under an epidemic situation	Nr	
			6 months storage 20°C	All	Accidental ingestion under an epidemic situation	nr	
		Cryptosporidium	Unstored	All	Accidental ingestion under an epidemic situation	8.7×10^{-5}	
			1 month storage 4°C	All	Accidental ingestion under an epidemic situation	1.6×10^{-5}	
			6 months storage 4°C	All	Accidental ingestion under an epidemic situation	2.6×10^{-8}	
			1 month storage 20°C	All	Accidental ingestion under an epidemic situation	6.9×10^{-11}	
			6 months storage 20°C	All	Accidental ingestion under an epidemic situation	Nr	
		Rotavirus	Unstored	All	Accidental ingestion under an epidemic situation	5.6×10^{-1}	
			1 month storage 4°C	All	Accidental ingestion under an epidemic situation	5.6×10^{-1}	
			6 months storage 4°C	All	Accidental ingestion under an epidemic situation	5.6×10^{-1}	
			1 month storage 20°C	All	Accidental ingestion under an epidemic situation	3.3×10^{-1}	
			6 months storage 20°C	All	Accidental ingestion under an epidemic situation	5.4×10^{-4}	

nr = negligible risk ($< 10^{-15}$)

- C: INFECTION RISK ASSOCIATED WITH THE INHALATION OF URINE AEROSOL

Facility	Country	Pathogen	Treatment condition	Risk Group	Exposure pathway	Risk of Infection	Reference
Urine Diverting Dry Toilet	Sweden	*Campylobacter* jejuni	Unstored	All	Aerosol inhalation	1.2×10^{-4}	Hoglund, 2001
			1 month storage 4°C	All	Aerosol inhalation	Nr	
			6 months storage 4°C	All	Aerosol inhalation	Nr	
			1 month storage 20°C	All	Aerosol inhalation	Nr	
			6 months storage 20°C	All	Aerosol inhalation	Nr	
		Cryptosporidium	Unstored	All	Aerosol inhalation	2.0×10^{-5}	
			1 month storage 4°C	All	Aerosol inhalation	3.6×10^{-6}	
			6 months storage 4°C	All	Aerosol inhalation	6.0×10^{-9}	
			1 month storage 20°C	All	Aerosol inhalation	1.6×10^{-11}	
			6 months storage 20°C	All	Aerosol inhalation	Nr	
		Rotavirus	Unstored	All	Aerosol inhalation	4.2×10^{-1}	
			1 month storage 4°C	All	Aerosol inhalation	4.2×10^{-1}	
			6 months storage 4°C	All	Aerosol inhalation	4.2×10^{-1}	
			1 month storage 20°C	All	Aerosol inhalation	2.0×10^{-1}	
			6 months storage 20°C	All	Aerosol inhalation	1.4×10^{-4}	

nr = negligible risk ($< 10^{-15}$)

- D: INFECTION RISK ASSOCIATED WITH CONSUMPTION OF CROPS FERTILIZED WITH URINE

Facility	Country	Pathogen	Treatment duration	Risk group	Exposure pathway	Risk of Infection	Reference
UDT	Sweden	*Campylobacter* jejuni	Unstored	All	Consumption of urine fertilized crops	4.2×10^{-6}	Hoglund, 2001
			1 month storage 4°C	All	Consumption of urine fertilized crops	Nr	
			6 months storage 4°C	All	Consumption of urine fertilized crops	Nr	
			1 month storage 20°C	All	Consumption of urine fertilized crops	Nr	
			6 months storage 20°C	All	Consumption of urine fertilized crops	Nr	
		Cryptosporidium parvum	Unstored	All	Consumption of urine fertilized crops	7.8×10^{-7}	
			1 month storage 4°C	All	Consumption of urine fertilized crops	1.3×10^{-7}	
			6 months storage 4°C	All	Consumption of urine fertilized crops	1.8×10^{-10}	
			1 month storage 20°C	All	Consumption of urine fertilized crops	6.2×10^{-13}	
			6 months storage 20°C	All	Consumption of urine fertilized crops	Nr	
		Rotavirus	Unstored	All	Consumption of urine fertilized crops	1.2×10^{-1}	
			1 month storage 4°C	All	Consumption of urine fertilized crops	1.2×10^{-1}	
			6 months storage 4°C	All	Consumption of urine fertilized crops	1.2×10^{-1}	
			1 month storage 20°C	All	Consumption of urine fertilized crops	3.5×10^{-2}	
			6 months storage 20°C	All	Consumption of urine fertilized crops	6.7×10^{-6}	

nr = negligible risk ($< 10^{-15}$)

- E : INFECTION RISK ASSOCIATED WITH ACCIDENTAL INGESTION OF FAECES FROM A UDT VAULT

Facility	Country	Treatment Condition	Pathogen	Treatment duration	Risk Group	Exposure pathway	Risk of infection	Reference
Urine Diverting Dry toilets	Denmark	Denmark Storage pH: 6.7 – 8.4 dry matter content : 22 – 39% Temp: 20^{0}C	*Ascaris*	0 months	Children and adults	Emptying of container	1	Schonning *et al.*
				12 months	Children and adults	Emptying of container	1	
			Cryptosporidium	0 months	Children and adults	Emptying of container	1	
				12 months	Children and adults	Emptying of container	2×10^{-3}	
			Salmonella	0 months	Children and adults	Emptying of container	2×10^{-1}	
				12 months	Children and adults	Emptying of container	4×10^{-5}	
			E.coli (EHEC)	0 months	Children and adults	Emptying of container	9×10^{-5}	
				12 months	Children and adults	Emptying of container	$< 10^{-14}$	
			Giardia	0 months	Children and adults	Emptying of container	1	
				12 months	Children and adults	Emptying of container	8×10^{-5}	
			Rotavirus	0 months	Children and adults	Emptying of container	1	
				12 months	Children and adults	Emptying of container	7×10^{-1}	
			Hepatitis A	0 months	Children and adults	Emptying of container	6×10^{-1}	
				12 months	Children and adults	Emptying of container	2×10^{-4}	

ANNEX 8: EPIDEMIOLOGICAL AND HEALTH RISK EVIDENCE ASSOCIATED WITH CISTERN FLUSH TOILET

A:

System	Country	Use and maintenance	Health outcome and outcome measure	Prevalence of outcome measure	Relative risk or odds ratio (95% CI)	Study design, sample size and age group	Reference
Flush Toilet	Nigeria	Na	*Ascaris*	7.70 vs 22.05	0.34	Case-control study (0 – 108 months) Bush vs flush toilet	Asoalu *et al.*, 2002
Flush Toilet	Nigeria	Na	*Ascaris*	7.70 vs 16.25	0.47	Case-control study (0 – 108 months) pit latrine vs. flush toilet	Asoalu *et al.*, 2002
Flush Toilet	Nigeria	Na	*Ascaris*	7.70 vs 54.5	0.14	Case-control study (0 – 108 months) Pit +bush vs flush toilet	Asoalu *et al.*, 2002
Flush Toilet	Brazil, Salvador (urban)	Na	Diarrhoea	Prevalence 47.0 vs 55.4	OR 1.47 (1.26 – 1.70) 0.84	Case-Control Clinical Study (1688 cases and 1676 controls) Age group: 0 – 120 months Functional Flush toilet vs. None/others	Ferrer *et al.*, (2008)

B:

Facility	Country	Treatment Condition	Pathogen	Risk Group	Exposure pathway	Annual Risk of Infection	Risk of Illness	Reference
Flush toilet	England	Toilet flushed with harvested rain water containing 0 – 0.56 /100mL *Campylobacter*	*Campylobacter*	All except children under 1 yr old	- Inhalation of ejected aerosol during flushing - 3 to 6 times flushes per day	1.8×10^{-5}	5.4×10^{-6}	Fewtrell and Kay (2007)

ANNEX 9: EPIDEMIOLOGICAL AND HEALTH RISK EVIDENCE ASSOCIATED WITH SEPTIC TANKS

Outbreak Studies Associated with Septic tank breakdown

System	Country	Scenario	Health outcome	Cases	Study design, sample size and age group	Reference
Septic Tank	U.S.A	Septic tank 45m from city well	Gastroenteritis	1200	Outbreak Study	Yates and Yates, 1988
	U.S.A	Septic tank 15m above spring	Gastroenteritis	400	Outbreak Study	Yates and Yates, 1988
	U.S.A	Septic tank near water supply for commercial ice pellet operation	Hepatitis A	98	Outbreak Study	Yates and Yates, 1988
	U.S.A	Septic tank 2m from 30 m deep well	Hepatitis A	17	Outbreak Study	Yates and Yates, 1988
	U.S.A	Septic tank 65m from well	Typhoid	5	Outbreak Study	Yates and Yates, 1988

ANNEX 10: EPIDEMIOLOGICAL AND HEALTH RISK EVIDENCE ASSOCIATED WITH CONSTRUCTED WETLANDS

Facility	Country	Treatment condition	Risk group	Pathogen	Exposure pathway	Annual Risk of Infection	Reference
Constructed Wetland	Hassleholm, Sweden	Final polishing step for effluent of a combined wastewater treatment plant	Children and adults	EHEC	(Un)intentional immersion at wetland inlet (30mL for 1 time per yr)	3×10^{-5}	Westrell *et al.*, 2004
					Children playing at wetland inlet (1mL for 2 times per yr)	1×10^{-6}	
				Salmonella	(Un)intentional immersion at wetland inlet (30mL for 1 time per yr)	2×10^{-6}	
					Children playing at wetland inlet (1mL for 2 times per yr)	6×10^{-8}	
				Giardia	(Un)intentional immersion at wetland inlet (30mL for 1 time per yr)	3×10^{-4}	
					Children playing at wetland inlet (1mL for 2 times per yr)	1×10^{-5}	
				Cryptosporidium	(Un)intentional immersion at wetland inlet (30mL for 1 time per yr)	3×10^{-5}	
					Children playing at wetland inlet (1mL for 2 times per yr)	1×10^{-6}	
				Rotavirus	(Un)intentional immersion at wetland inlet (30mL for 1 time per yr)	5×10^{-2}	
					Children playing at wetland inlet (1mL for 2 times per yr)	2×10^{-3}	
				Adenovirus	(Un)intentional immersion at wetland inlet (30mL for 1 time per yr)	1×10^{-1}	
					Children playing at wetland inlet (1mL for 2 times per yr)	4×10^{-3}	

System	Country	Treatment efficacy	Health outcome and outcome measure	Age group	Prevalence of outcome measure	Relative risk or odds ratio (95% CI)	Study design, sample size and age group	Reference
Waste stabilisation pond	Israel	Treated (3-7) days retention	i. Salmonellosis ii. Shigellosis iii. Typhoid fever iv. Infectious hepatitis	All ages	i. 23.4 vs 6.3 ii. 100.2 vs 45.5 iii. 1.16 vs 0.27 iv. 8.8 vs 4.4	i. 3.7 ii. 2.2 iii.4.3 iv. 2.0	Population in kibbutzim using wastewater from stabilisation pond for irrigation vs not using wastewater (All ages)	Katzenelson, Buiu & Shuval (1976)
Waste stabilisation pond	Israel	5 -10 days retention 10^6-10^8 total coliforms/100mL	Enteric disease	i. 0 -4 ii. 5 – 18 iii. ≥ 19	i. 51.8 vs 27.4 ii. 11.2 vs 6.6 iii. 4.7 vs 1.8	i. 1.91 (1.30 – 2.80) ii. 1.23 (0.46 – 3.25) iii. 2.06 (0.69 – 6.16)	Comparison of enteric disease rates in kibbutzim when using wastewater for sprinkler irrigation vs when not using wastewater for irrigation, with allowance made for rate of control diseases and other factors; results from irrigation season	Fattal *et al.*, (1986)
Waste stabilisation pond	Israel	5 -10 days retention 10^4-10^5 total coliforms/100mL	Enteric disease	All ages 0 - 5	L 11.0 M 9.4 H 11.6 L 26.4 M 20.0 H 26.0	L 1.0 M 0.85 H 1.05 L 1.00 M 0.76 H 0.98	Comparison of rates in kibbutzim population with wastewater sprinkler irrigation within 300 – 600 m (High=high) or kibbutzim with wastewater use but no aerosols (Medium= M) vs kibbutzim with no use of wastewater (L)	Shuval *et al.*, (1989)
Waste stabilisation pond	Israel	5 -10 days retention 10^4-10^5 total coliforms/100mL	Echovirus type 4 infection (% seroprevalence and % seroconversion	i. 0 -4 ii. 6 – 17 iii. 25+	Seroprevalence i. 83 vs 33 ii. 73 vs 37 Seroconversion iii. 63 vs 20	i. 2.5 ii. 2.0 iii.3.2	Comparison of rates in kibbutzim population exposed to aerosolized wastewater from kibbutz itself and nearby towns vs kibbutzim not exposed to wastewater (other comparisons given in paper)	Fattal *et al.*, (1987)

ANNEX 11: EPIDEMIOLOGICAL AND HEALTH RISK EVIDENCE ASSOCIATED WITH STABILIZATION PONDS

System	Country	Treatment efficacy	Health outcome and outcome measure	Age group	Prevalence of outcome measure	Relative risk or odds ratio (95% CI)	Study design, sample size and age group	Reference
Waste stabilisation ponds	Israel	5 – 10 days retention	*Poliovirus* infection i. Polio 1 ii. Polio 2 iii. Polio 3 (% seroprevalence)	< 1 – 60+	i. 82 vs 86 ii.88 vs 91 iii. 80 vs 82	i. 0.95 ii. 0.97 iii.0.98	Comparison of rates in kibbutzim population exposed to aerosolized wastewater from kibbutz itself and nearby towns vs kibbutzim not exposed to wastewater	Margalith, Morag & Fattal (1990)
Wastewater stabilisation pond	Israel	5 -7 days retention 10^6-10^7 total coliforms/100mL	*Legionellosis* (% seroprevalence)	18 +	4.3 vs 1.4	3.14 (0.89 – 11.85)	Sewage contact workers vs non-irrigation workers	Fattal *et al.*, (1985)

ANNEX 12: EPIDEMIOLOGICAL AND HEALTH RISK EVIDENCE ASSOCIATED WITH WASTEWATER TREATMENT PLANTS

A- Diarrhoeal Diseases and Helminths Infections associated with the Use of Sewerage Treatment Systems

System	Country	Use and maintenance	Health outcome	Prevalence of outcome measure	Relative risk or Odd ratio (95% CI)	Study design, sample size and age group	Reference
Sewerage (also including drainage)	Brazil , Salvador	-	*Ascaris*	33 vs. 68.9	0.47	Age : 5 – 14 years Case- control study Sero-prevalence survey No Intervention vs WWTP	Moraes *et al.*, 2004
	Brazil , Salvador		*Trichuris*	64.4 vs. 93.4	0.68	No Intervention vs WWTP	Moraes *et al.*, 2004
	Brazil , Salvador		Hookworm	8.2 vs. 27.5	0.29	No Intervention vs WWTP	Moraes *et al.*, 2004
Sewerage	Salvador, Brazil		Diarrhoea		0.31 (0.28 – 0.34)*	Longitudinal study Age group (<5 yrs) Sewerage vs No Intervention	Moraes *et al.*, 2003
Sewerage Treatment system	Iran (urban)	-	Diarrhoea	Incidence 10.1vs. 10.5	0.96	Field trial with external concurrent control before and after intervention Age group : 6 – 60 months SWTP vs Other	Kolahi, A-A *et al.*(2008)
Sewerage network/ drainage/septic tank + soak away	Brazil Salvador (urban)	-	Diarrhoea	49.7 vs. 54.8	OR 1.31 (1.04 – 1.58)	Case-Control Clinical Study (1688 cases and 1676 controls) Age group: 0 – 120 months WWTP vs None/ others	Ferrer *et al.*, (2008)
Sewerage network connected to WWTP	Salvador , Brazil	-	Diarrhoea	Prevalence reduced by 22%	0.78	Longitudinal study Age : 0 - 36 months WWTP vs Open air	Barreto *et al.*, (2007)

* significant ($p < 0.0001$)

B-Epidemiological Evidence of Wastewater Treatment Plant Effluent Reuse

(Adapted from DHAC, 2001)

System	Country	Use and maintenance	Health outcome	Significant	Study design, sample size and age group	Reference
Wastewater Treatment Plant (Sedimentation, solids separation, biodegradation. Mono-or-dual media filtration, chlorination.)	Los Angeles County , U.S.A	Groundwater Recharge	*Giardia*	Significant+	Ecological (1987 – 1991) Exposed: 908, 221 Controls: 674, 071	Sloss *et al.*, 1996.
			Hepatitis A	Significant+		
			Salmonella	Not Significant		
			Shigella	Significant+		
Wastewater Treatment Plant (Sedimentation, solids, separation, biodegradation. Mono or dual media filtration chlorination	Los Angeles, U.S.A	Indirect reuse	hepatitis A Shigellosis	Not significant Not Significant	Ecological Exposed: 486000 Controls: 576000	Frerichs (1984)
Wastewater Treatment Plant Plant 1- Primary settling, activated sludge, secondary settling, maturation ponds Part 2- Chlorine, alum lime, settling, breakpoint chlorination, sand filtration, carbon filtration, blending	Windhoek, Namibia	Indirect reuse	Diarrhoeal disease 1977 1978 1979 1980 1981 1982	 Significant (p=0.03) NS NS NS NS Significant (p=<0.01)	Ecological (1977-1982) 75000 – 100,000	Isaacson and Sayed (1988)
Wastewater Treatment Plant (Sedimentation, solids separation, biodegradation, mono or dual media filtration, chlorination)	Los Angeles, USA	Indirect use	Hepatitis A Shigellosis	Significant (p=<0.05) Significant (p=<0.05)	Ecological (1969 -1971) Exposed 478182 Controls: 676924	Frerichs *et al.*, 1982

+ significantly greater number of cases in the area/s with low to medium % of reuse

C- Infection Risk Associated with the Operation of a Wastewater Treatment Plant

Facility	Country	Treatment condition	Risk group	Pathogen	Exposure pathway	Annual infection risk	Reference
WWTP	Hassleholm, Sweden	- 28 600 connected with mean daily input of 12, 500 m^3 – 32, 300 m^3 per day Primary-secondary-tertiary treatment	Children and adults	EHEC	Child playing at sludge storage (5 g for 1 time per yr)	1×10^{-2}	Westrell *et al.*, 2004
					Spreading sludge (2 g for 30 times per yr)	5×10^{-3}	
				Salmonella	Child playing at sludge storage (5 g for 1 time per yr)	6×10^{-4}	
					Adult spreading sludge (2 g for 30 times per yr)	3×10^{-4}	
				Giardia	Child playing at sludge storage (5 g for 1 time per yr)	2×10^{-2}	
					Adult spreading sludge (2 g for 30 times per yr)	1×10^{-2}	
				Cryptosporidium	Child playing at sludge storage (5 g for 1 time per yr)	6×10^{-3}	
					Adult spreading sludge (2 g for 30 times per yr)	2×10^{-3}	
				Rotavirus	Child playing at sludge storage (5 g for 1 time per yr)	4×10^{-1}	
					Adult spreading sludge (2 g for 30 times per yr)	3×10^{-1}	
				Adenovirus	Child playing at sludge storage (5 g for 1 time per yr)	9×10^{-1}	
					Adult spreading sludge (2 g for 30 times per yr)	1	

.1 D-INFECTION RISK ASSOCIATED WITH THE OPERATION OF WASTEWATER TREATMENT PLANT

Facility	Country	Treatment condition	Risk group	Pathogen	Exposure pathway	Annual infection risk	Reference
WWTP	Hassleholm, Sweden	- 28 600 connected with mean daily input of 12, 500 m^3 – 32, 300 m^3 per day Primary-secondary-tertiary treatment	Treatment plant workers	EHEC	Aerosols from pre-aeration (1mL for 52 times)	6×10^{-4}	Westrell *et al.*, 2004
					Aerosols from belt press (5mL for 208 times)	2×10^{-3}	
				Salmonella	Aerosols from pre-aeration (1mL for 52 times)	3×10^{-5}	
					Aerosols from belt press (5mL for 208 times)	1×10^{-4}	
				Giardia	Aerosols from pre-aeration (1mL for 52 times)	1×10^{-3}	
					Aerosols from belt press (5mL for 208 times)	4×10^{-3}	
				Cryptosporidium	Aerosols from pre-aeration (1mL for 52 times)	2×10^{-4}	
					Aerosols from belt press (5mL for 208 times)	9×10^{-4}	
				Rotavirus	Aerosols from pre-aeration (1mL for 52 times)	9×10^{-2}	
					Aerosols from belt press (5mL for 208 times)	1	
				Adenovirus	Aerosols from pre-aeration (1mL for 52 times)	2×10^{-1}	
					Aerosols from belt press (5mL for 208 times)	1	

SEI - Africa
Institute of Resource Assessment
University of Dar es Salaam
P.O. Box 35097, Dar es Salaam
Tanzania
Tel: +255-(0)766079061

SEI - Asia
15th Floor Witthyakit Building
254 Chulalongkorn University
Chulalongkorn Soi 64
Phyathai Road Pathumwan
Bangkok 10330
Thailand
Tel: +(66) 22514415

SEI - Oxford
Suite 193
266 Banbury Road,
Oxford, OX2 7DL
UK
Tel: +44 1865 426316

SEI - Stockholm
Kräftriket 2B
106 91 Stockholm
Sweden
Tel: +46 8 674 7070

SEI - Tallinn
Lai 34, Box 160
EE -10502, Tallinn
Estonia
Tel: +372 6 276 100

SEI - U.S.
11 Curtis Avenue
Somerville, MA 02144
USA
Tel: +1 617 627-3786

SEI - York
University of York
Heslington
York YO10 5DD
UK
Tel: +44 1904 43 2897

The Stockholm Environment Institute

SEI is an independent, international research institute. It has been engaged in environment and development issues at local, national, regional and global policy levels for more than a quarter of a century. SEI supports decision making for sustainable development by bridging science and policy.

sei-international.org

ISBN 978-91-86125-36-3

Spine, width as required, text centred

Microbial Exposure and Health Assessments in Sanitation Technologies and Systems

Stenström, Seidu, Ekane, and Zurbrügg