

GLOBAL WATER PATHOGEN PROJECT

PART FOUR. MANAGEMENT OF RISK FROM EXCRETA AND WASTEWATER

PIT TOILETS (LATRINES)

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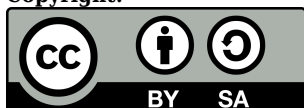
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Citation:

Orner, K.D., Naughton, C. and Stenstrom, T.A. (2018). Pit Toilets (Latrines). In: J.B. Rose and B. Jiménez-Cisneros (eds), *Water and Sanitation for the 21st Century: Health and Microbiological Aspects of Excreta and Wastewater Management* (Global Water Pathogen Project). (J.R. Mihelcic and M.E. Verbyla (eds), Part 4: Management Of Risk from Excreta and Wastewater - Section: Sanitation System Technologies - Pathogen Reduction in Non-Sewered (On-site) System Technologies), Michigan State University, E. Lansing, MI, UNESCO. <https://doi.org/10.14321/waterpathogens.56>

Acknowledgements: K.R.L. Young, Project Design editor; Website Design: Agroknow (<http://www.agroknow.com>)

Last published: October 19, 2018

Summary

Pit toilets (also referred to as latrines) are a sanitation technology used for onsite waste management. They consist of a hole in the ground, which may be unlined or lined, with a reinforcing material to contain human excreta. Depending on its design and frequency of use, pit toilets can be used for 10 to 30 years, though many are used for fewer than 5 years before they are full and must be emptied or covered. Pit toilets may have one pit or alternating twin pits, be unventilated or ventilated, and be adapted for single families or communal use. Although the faecal sludge contained in the pit undergoes some degradation with time, a pit toilet is not designed specifically to reduce pathogen concentrations, but to collect faecal material and limit human and environmental exposure. However, pathogen reduction can occur within the confines of the pit, in the surrounding unsaturated soil, or in the surrounding saturated soil. Residence time in the pit is believed to have the largest impact on pathogen reduction given the reality of unfavorable temperature and moisture levels existing in the pit. Faecal sludge from pit toilets in many cases needs to be emptied, and the emptying process can pose a risk to human health even after long-term storage. Of particular concern is exposure to helminths, specifically *Ascaris*. Because of filtration and adsorption provided by the soil that surrounds a pit, protozoa and helminths are much less likely to contaminate underlying groundwater than bacteria and viruses. However, a lack of measurements for non-indicator species in the subsurface downgradient of pit toilets, the uncertainty about pathogen transport due to insufficient data, and the fact that transport of microorganisms in the subsurface is dependent on many site-specific characteristics means that care should be taken when co-locating pit toilets and groundwater supply systems.

1.0 Brief Technology Description

Pit toilets (also referred to as pit latrines) are a widely employed sanitation technology used for onsite waste management and are an integral part of the sanitation service chain (Figure 1). They consist of a hole in the ground, which may be unlined or lined with a reinforcing material (e.g. bricks, concrete rings), to contain human excreta. They most often are integrated with a squatting slab or toilet seat and a superstructure that provides privacy. The pit volume is designed to accommodate excreta and anal cleansing materials for a specific number of users and time period (Expected solids accumulation rates are dependent on cultural considerations and the pit's relationship to the underlying groundwater table; one reference reported accumulation rates to range from 0.04 - 0.09 m³/person/year (Franceys et al. 1992). Although the recommended minimum depth of the pit varies among studies, it should generally not be dug deeper than to a vertical distance of at least 2 m above the groundwater, accounting for the water table's seasonal highest level (Franceys et al., 1992; Reed, 2010; Banks et al., 2002). A pit is considered full when the deposited excreta reaches a level corresponding to approximately 0.5 - 1.0 m below the ground surface. Depending on its design and frequency of use, pit toilets can be used for 10 to 30 years, though many are used for fewer than 5 years before they are full and must be emptied or covered (Franceys et al., 1992; Brouckaert et al., 2013). When the "filled" level of the pit is reached, the contents (i.e., faecal sludge) can either be removed, or the free 0.5 - 1.0 m upper space may be filled with soil. In this latter case the pit is no longer used and the upper structures (slab and privacy shelter) may be dismantled and moved to a new pit. Pit toilets come in many shapes and sizes. For example, they may have one pit or alternating twin pits, be unventilated or ventilated (i.e., improved), and be adapted for single families or communal use (Figure 2).

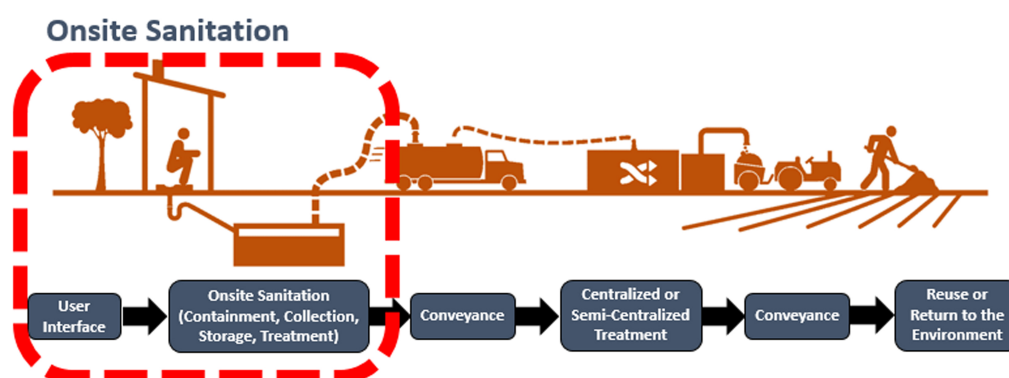


Figure 1. Location of Pit Toilets in the On-Site Sanitation Service Chain (This image is a derivative of "Sanitation Value Chain" by SuSanA Secretariat, which is licensed under CC BY 2.0.)



Figure 2. Pit Toilets (left, middle) (Cameroon and Timor-Leste) and Ventilated Improved Pit Toilet (right) (Panama) (photos provided by Jesse Shapiro, Lauren Fry, and Kevin Orner with permission)

The introduction of a ventilation pipe in the pit toilet, as shown in Figure 3, is a variation of the pit toilet concept. A straight vertical ventilation pipe is present in a Ventilated Improved Pit (VIP) toilet (Reed, 2014a) that extends 0.3 - 0.5 m above the highest point of the superstructure's roof

and is capped with a screen. This improves airflow out of the pit, which reduces both odor and the presence of insects. The door should face the most prevailing direction of the wind to promote airflow unless other criteria, such as cultural appropriateness, prevails.

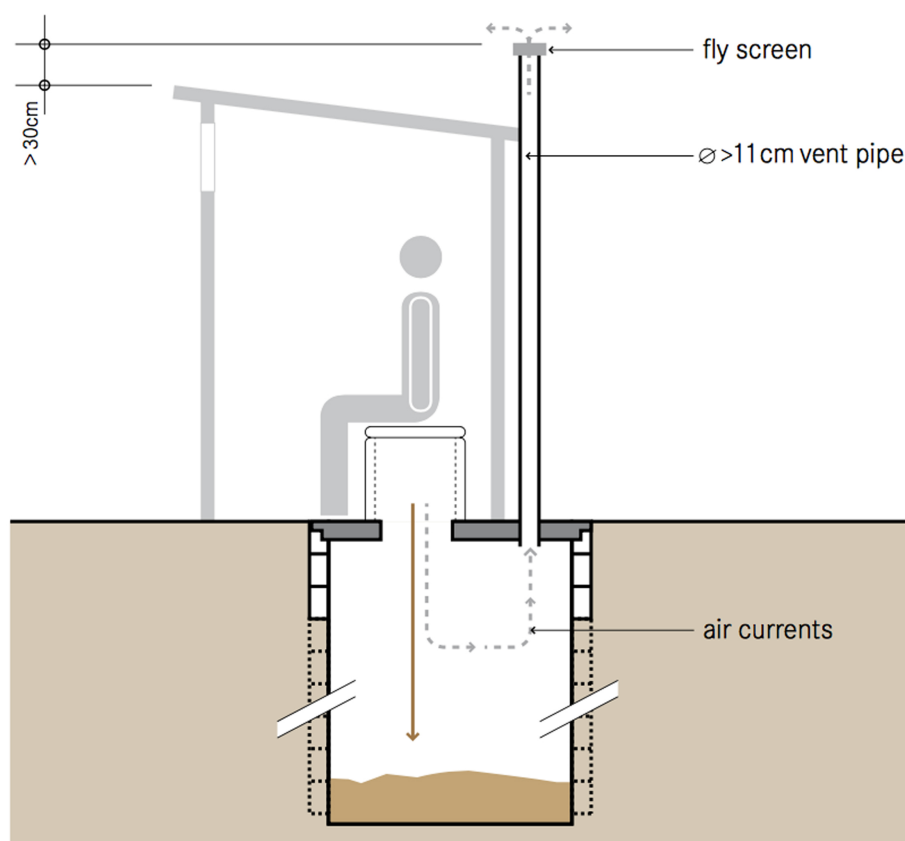


Figure 3. Schematic of a Ventilated Improved Pit (VIP) Toilet (diagram reprinted from Tilley et al. 2014 with permission)

Several variations of the single pit latrine exist. Double alternating pits are sometimes utilized (referred to as double VIP toilets), especially when the pits are shallow, allowing for pathogen die-off in the filled pit and thus safer emptying after an appropriate withholding time and before the second pit is full. Another variant of a shallow single pit

is the Arborloo; a tree is planted in the nearly full pit, which is thereafter covered with soil. This is generally only applicable when the superstructure can be moved. For more information on pit toilet design and construction, refer to Mihelcic et al. (2009), Tilley et al. (2014), CAWST (2014), Reed (2014b), or WHO (2017).

2.0 Inputs and Outputs

Inputs to the system, as shown in Figure 4, include urine, faeces, anal cleansing water, and dry cleaning material. The use of anal cleansing water depends on water availability, religion, and local habits. The pit contents may

be affected by runoff from heavy rains and, when improperly designed, by changing groundwater levels (Nwaneri et al., 2008). The input of flush water associated with pour-flush toilets or aqua privies is not considered here. Dry cleaning material is typically some type of paper material, but may locally be exchanged with other materials such as corncobs, leaves, or stones.

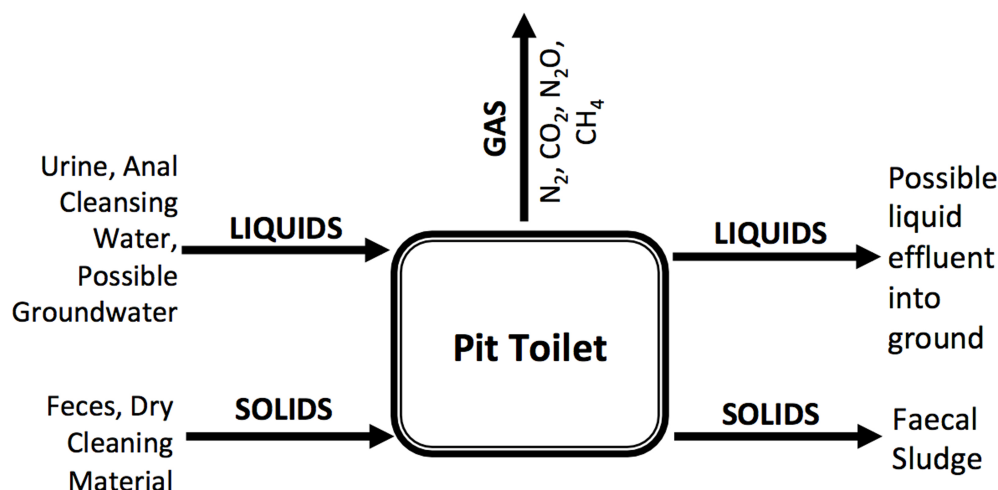


Figure 4. Typical Inputs and Outputs from Pit Toilets

The user interface is a pedestal for sitting (as shown in Figure 3) or a squatting slab and the combined inputs are collected in a single or double pit.

2.1 Inputs and Uses which are not recommended

Toilet pits may collect substantial amounts of other degradable (e.g. food scraps) or non-degradable waste (e.g. bottles, plastic wrappers, etc.) that accumulate when the users also use the pit for disposal of solid waste. These habits are problematic because the accumulated solid waste can fill up the pit prematurely (Brouckaert et al., 2013). Likewise, pits are also not designed to receive menstrual hygiene products. Other methods of sanitary disposal should be provided to girls and women for managing this waste. Bucket showering should not take place within the pit toilet superstructure, nor should shower water be conveyed into the pit. This is because it not only increases the moisture levels of the pit contents, causing odor problems, but also supports migration of chemicals and microorganisms out of the pit to the surrounding subsurface in unlined pits. A toilet pit should also not be used to dispose of medical and pharmaceutical residues and/or organic chemicals (Graham & Polizzotto, 2013).

2.2 Managing Outputs

Several options are available to manage outputs from the pit toilet. If the single pit is filled, a new pit is then normally excavated in the area or, in the case of a double pit, the alternate pit is put into use. Sometimes this involves moving the slab and superstructure over the alternative pit.

Alternatively, the faecal sludge in the pit can be emptied manually (referred to as human-powered emptying and transport), or mechanically (referred to as motorized emptying and transport). Afterwards, the sludge should be safely stored, treated locally, or transported to a location for treatment. However, several challenges exist in managing faecal sludge, especially in urban areas. For example, latrines may overflow due to continued use or abandoned without new latrine construction (Nakagiri et al., 2015; Blackett et al., 2014). Pathogen reduction during the management of faecal sludge is covered in the Sludge Management: Biosolids and Faecal Sludge chapter. A framework for selecting appropriate faecal sludge treatment technologies is provided in Strande et al. (2014). Pathogen reduction is covered in other GWPP chapters: Collection and Conveyance of Excreta, Faecal Sludge, and Wastewater in Onsite and Offsite Systems.

The area above the slab (i.e., pedestal for sitting or squatting slab) and the pit may contain substantial amounts of pathogens, which vary based on the toilet use, geographical location, and incidence of infectivity. Within the pit, the highest number of pathogens are often found in the top section of the accumulated sludge because it has the most recently delivered excrement; however, pathogens may migrate downwards in the pit or percolate with urine and thus lower parts should not be considered risk-free (Feachem et al., 1983).

Persistence of pathogens varies between different bacterial, viral and parasitic organisms and further documentation of die-off rates are lacking in the pit toilet literature (Auer and Niehaus, 1993; Decrey and Kohn,

2017; Eriksen et al., 1996; WHO, 2006; Nabateesa, 2017). Independently, the outputs of a single toilet still often contain large numbers of pathogenic organisms, especially the resistant helminth eggs. An example from Accra (Ghana) reported that faecal sludge collected from the chambers of communal VIP toilets contained approximately 200 – 400 helminth eggs per gram of total solids (Strauss et al., 2000).

3.0 Factors Affecting Pathogen Reduction in Pit Toilets and Surrounding Soil

Pathogen reduction can occur within the confines in the pit, in the surrounding unsaturated soil, or in the surrounding saturated soil. Within a deeper pit, the faecal sludge can be divided into four different layers (or zones),

as shown in Figure 5. The content of the uppermost zone is thought to be more readily biodegradable and the organic matter in the sludge undergoes aerobic degradation. The next zone below may also support aerobic degradation of the organic fraction of the sludge into simpler compounds, but is likely rate-limited by the transfer of oxygen into this zone. It is expected that more airflow above the pit contents takes place in a VIP toilet. The third zone below the surface is thought to be anaerobic (i.e., void of oxygen) because the upper two layers that consist of newer pit contents cover this older sludge and thus restricts the transfer of oxygen into this zone. Anaerobic processes, which are generally slower than the aerobic ones, produce carbon dioxide and methane gas. Very little additional pathogen reduction is believed to occur in the bottom layer, which contains mostly less readily degradable materials (Dey et al., 2016; Nwaneri et al., 2008).

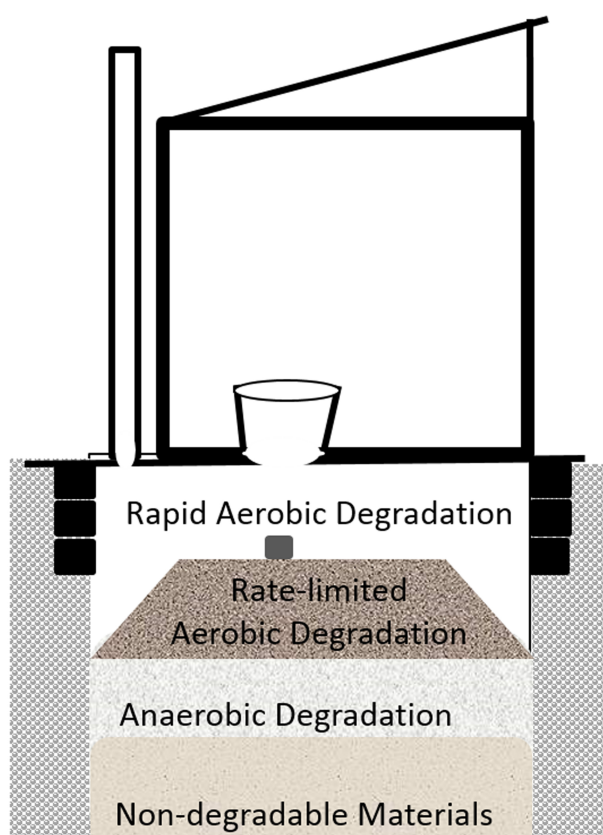


Figure 5. Four Different Layers (or Zones) Believed to Exist in a Toilet Pit (based on Nwaneri et al. 2008)

Factors affecting pathogen reduction and removal in the upper three zones of the pit can be categorized as environmental and microbiological. Pathogen reduction also occurs due to environmental and microbial factors in the unsaturated and saturated soil surrounding and

below the pit, as shown in Figure 6. Other GWPP Part IV chapters on specific sanitation technologies that employ aerobic and anaerobic biological processes are available and a reader should refer to these for more established information on pathogen reduction in similar environments.

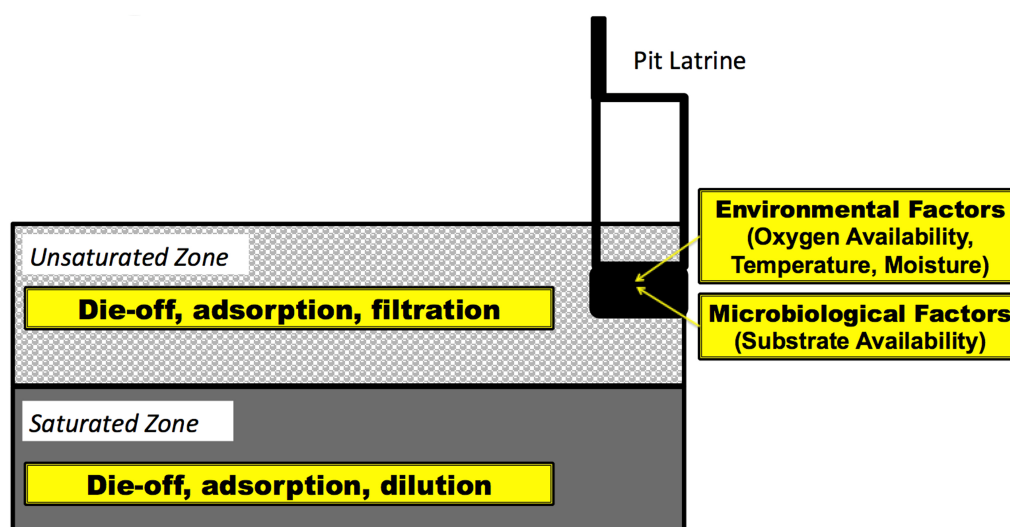


Figure 6. Pathogen Removal Processes in the Unsaturated and Saturated Zones Surrounding the Toilet Pit (based on BGS, 2002)

3.1 Environmental and Microbiological Factors in the Toilet Pit

Environmental factors that may affect pathogen reduction in a toilet pit include oxygen availability, temperature, moisture content, storage time, pH, and volatile fatty acid content. If oxygen is present in the upper two layers of the pit (Figure 5), decomposition of the organic waste may occur by many different types of aerobic microorganisms (Franceys et al., 1992; Henze et al., 1997). Pathogens may be inactivated by competition from other microorganisms. Microorganisms found in pit toilets, especially bacteria, generally originate from either the human gut and/or the soil surrounding the pit toilet. Approximately 90% of microorganisms from the human gut are anaerobic; only 10% are aerobes or facultative anaerobes. Thus, the majority of microorganisms would have a survival advantage under the environmental conditions found in the lower anaerobic layers of the pit depicted previously in Figure 5. Adaptability is dependent on the bacteria's physical properties, mechanisms of stress response, and cellular physiology (Torondel, 2016).

The rate of inactivation will increase with higher temperatures and lower moisture content; however, these two factors do not constitute significant causes of pathogen reduction in a pit toilet. Nabateesa et al. (2017) found that the temperature of the pit contents was around ambient and only decreased approximately 20°C over 1.5 m in depth.

Excluding these two factors as less significant, the die-off with time during storage will be a general factor of importance. Thus, longer residence times will be needed to support better reductions in pathogens. Therefore, the double pit toilet will perform better than a single pit because the second pit can provide a longer storage time of the pit contents. The following general statements can thus be made (adapted from Oakley et al., 2017):

- Higher temperatures in the pit would increase the rate of other pathogen inactivation, but pit toilets are mostly operated at ambient temperatures and temperature does not change significantly with depth.
- Shorter storage times will decrease reaction times required for pathogen inactivation.
- Uncharged aqueous ammonia (NH_3) has microbicidal effects, especially at high pH values (when this form of ammonia is present in high concentrations); however, the pH levels encountered in a toilet pit are typically closer to neutral, supporting the formation of NH_4^+ . Therefore, ash can be added to raise the pH and increase the $\text{NH}_3/\text{NH}_4^+$ ratio. Likewise, NH_3 can be added through urine separation (Nordin et al., 2009; Fidjeland et al., 2013)
- Volatile fatty acids have microbicidal effects at low pH values; however, the pH levels encountered in toilet pit are typically near neutral, potentially minimizing these effects.

3.2 Pathogen Transport and Reduction in Soils that Surround or are Below the Pit

As pathogens are transported by vertical and horizontal movement of liquid out of the pit and percolates to soil below and surrounding the pit, pathogen reduction may occur through several processes (Figure 6). Firstly, the soil that surrounds a pit is biologically active and competitive actions will occur from the indigenous microbial communities where the percolating liquid from the pit enters the soil (Kreissl, 1978). Predatory microorganisms can also thrive and reduce pathogen concentrations (Krone et al., 1958; BGS, 2002).

In the unsaturated zone of the subsurface the major pathogen reduction occurs. The three primary reduction mechanisms are pathogen die-off, adsorption to soil surfaces (Corapcioglu & Haridas, 1984), and filtration by soil (BGS, 2002). In addition to the microbial competition, die-off of pathogens occurs due to a changing redox environment combined with a set of environmental conditions that the pathogens in the feces are not adapted to withstand (BGS, 2002).

Filtration primarily takes place in the soil directly below and surrounding the pit. The effects of filtration as a removal mechanism are important when the microorganism size is greater than 5% of the mean pore size (Harvey & Garabedian, 1991). Here the percolating effluent from the pit results in “clogging” due to:

- 1) small particles that fill the empty spaces in the soil
- 2) accumulation of biomass due to the abundance of nutrients
- 3) production of biofilms (BGS, 2002).

Saturated soils exist when the pore space between individual soil particles are permanently or temporarily filled with water. In saturated soil, pathogen reduction primarily occurs because of die-off and adsorption to soil surfaces. Dilution from intense rainwater events that infiltrate into the subsurface can also reduce pathogen concentrations (

BGS, 2002; Islam, 2016). If pathogens reach saturated soil, they can be transported downgradient in the groundwater, depending on the hydrogeological conditions of the subsurface, and the size and surface properties of the strains and species in question. Factors affecting the transport of pathogens in saturated porous media include pH, soil composition, the hydraulic loading rate, the presence of dissolved organic carbon and cations, and the hydraulic conductivity of the porous media (Gerba et al., 1975; Bitton and Harvey, 1992; Islam et al., 2016). Depending on the soil conditions, larger sized pathogens like protozoa and helminths are not transported out of the pit into surrounding soil to any large extent.

The type of subsurface media is also a factor in transport of microorganisms. Fractured rocks act as preferred conduits for fluid flow. Their surfaces have less adsorptive properties, which may result in rapid transport over long distances, although it depends on the hydrological gradient. Also, rocky or clayey soil may allow for contaminated liquid to travel along preferential pathways that occur from fractures or cracks that form in the subsurface matrix (Buckley et al., 2008).

4.0 Design, Operation, Maintenance of Pit Toilets and Transmission, and Exposure Guidelines for Pathogen Reduction

4.1 Pit and Slab Design and Construction

Although the faecal sludge undergoes some degradation with time, a pit toilet is not designed specifically to reduce pathogen concentrations, but to collect faecal material and limit human exposure. The pit should be sited to avoid or limit contamination of underlying groundwater, especially in cases where the groundwater is pumped back to the surface for human use or is hydraulically connected to a spring or other surface water. A vertical distance of at least 2 m between the bottom of the pit and the highest groundwater level has been recommended to achieve a substantial or partial reduction of bacteria and viruses, dependent on the soil characteristics (Lewis et al., 1982; Cotton et al., 1995; Tilley et al., 2014). This distance is site specific and is affected by local hydrogeological conditions.

For example, where percolation of pit contents out of the pit is rapid or the soil material has lower adsorptive properties (like coral sand in East Africa), the buffering distance needs to be increased or additional safety measures applied to use of the groundwater. Lining or raising a pit can also minimize the contamination of groundwater (Dzwairo et al., 2006).

The pit itself should be lined with brick, concrete, mortar, stones, or timber (unless the soil is stable), especially if the pit is to be emptied and/or the content reused (Tilley et al., 2014). Section 2 of this chapter mentioned what materials are added to a pit toilet besides urine and faeces. Use of water for anal cleansing adds moisture to the pit contents, whereas dry cleaning material increases the solids accumulation rate up to 90 liters/person/year (Tilley et al., 2014). The rate of solids accumulation can be estimated as 40-60 liters/person/year depending on the type of anal cleansing materials employed by users, although the range can be as variable as 19-90 liters/person/year (Nakagiri et al., 2015). Therefore, to allow sufficient time for filling, the pit volume should be $\geq 1,000$ L (Tilley et al., 2014).

Proper construction of a pit toilet can prevent or reduce the spread of pathogens at the user interface of the sanitation service chain. Parts of the toilet (besides the pit) that can impact transmission of pathogens include the points of hand-contact in the toilet, the roof, and the slab. An easy to clean concrete slab is preferred over a dirt floor to prevent transmission of pathogens (Baker & Ensick, 2012). A less-rough concrete slab that slopes slightly to the hole allows for easier cleaning and can decrease disease transmission via the faecal-oral route (Exley et al., 2015). The slab should be constructed so that it prevents intrusion of stormwater. If the pit will be in the same location, as is the case in most urban areas, the pit should be lined and designed to have access for emptying. If the pit will be in a new location, the slab should be designed so that it can be lifted and moved after the old pit fills (Tilley et al., 2014). The slab itself should have the proper concrete mix design to maintain its strength (Mihelcic et al., 2009). Pit toilets are also not recommended in flood-prone locations, or areas of shallow groundwater (e.g., coastal location). This is because the pit contents can mix with shallow groundwater, overflow from the pit, or serve as a potential insect-breeding site (Tilley et al., 2014).

4.2 Operation and Maintenance

Proper operation and maintenance of toilet facilities is important for controlling the transmission of pathogens through the faecal-oral route. Unclean areas in and around the toilet facilities can contribute to transmission of hookworms and other pathogens (Baker & Ensick, 2012). The hole should be covered to reduce odors and prevent pathogen transmission from flies and other insects that reside in or enter the pit (Tilley et al., 2014). A properly designed and operated VIP toilet can further reduce fly populations as can the roof of the privacy structure (Irish et al., 2013). Section 2 of this chapter also gave options for

managing the pit after it is filled.

4.3 Pathogen Transmission and Exposure

Faecal sludge from pit toilets in many cases needs to be emptied, and the emptying process can pose a risk to human health. For example, compared with people who did not work with faecal sludge, those who engage in removing faecal sludge from bucket and pit toilets were found to be 1.9 times more likely to contract Hepatitis A (Rulin, 1997). Of particular concern is exposure to helminths, specifically *Ascaris*, *Trichuris*, and *Taenia* (Buckley et al., 2008; WHO, 2006). Facemasks worn by workers emptying toilet pits have even been found to have helminth eggs present due to the dust or aerosolisation that may occur (Buckley et al., 2008; Bhagwan et al., 2008).

The risk is most likely reduced in double or alternating pits, where the material in one of the pits is closed and has a longer storage residence time that allows for greater pathogen reduction. Storage for 1-2 years should reduce the pathogen content; however, additional treatment is still recommended in many situations (Tilley et al., 2014), especially to remove helminths like *Ascaris* (Bhagwan et al., 2008; WHO, 2006).

Transmission of pathogens and exposure to them can also occur during conveyance and treatment of faecal sludge from a filled pit toilet (see Chapter on Collection and Conveyance of Excreta, Faecal Sludge, and Wastewater in Onsite and Offsite Systems). The collected faecal sludge can lead to additional contamination if disposed without treatment near residential areas (Chowdhry & Kone, 2012; Klingel et al., 2002). Exposure to pathogens during conveyance can occur through many routes that include contacting the skin (Stenström et al., 2011). Stenström et al. (2011) describe in detail routes of exposure and health risks associated with pit toilets and other sanitation technologies. Strande et al. (2014) provides guidance on the technologies available for managing faecal sludge. The World Health Organization also provides guidelines for safe use of faecal sludge (WHO, 2006; Strauss and Montangero, 2002).

5.0 Summary of Data on Pathogens in Pit Toilets

Pathogens excreted from humans that cause diarrhoea and other illnesses are described in the Overview: Managing Pathogens along the Sanitation Service Chain chapter and other GWPP Chapters.

Although the primary objective of a pit toilet is faecal containment and not pathogen reduction, they are expected to reduce pathogen levels to a much higher degree than bucket toilets (Stenström et al., 2011). It was previously thought that faecal sludge in a pit that was not immersed in the groundwater and was left in an idle stage for one year would be free of pathogens “apart from a few *Ascaris* eggs” (Feachem et al., 1983). However, pathogens can be present even after long-term storage, as shown in Table 1 (WHO, 2006; Franceys et al., 1992).

Table 1. Primary removal mechanisms of Pathogens in Toilet Pits and Important Factors leading to Reduction in Soil. Also shown is the Risk of Different Pathogens to Groundwater, at the User Interface, and during Conveyance and Treatment of Faecal Sludge

Pathogen Group From Smallest to Largest in Size	Survival at 20-30 °C in Feces and Sludge in Days (Feachem et al., 1983)	Important Factor(s) Leading to Reduction in Pit Toilet	Important Factor(s) Leading to Reduction in Surrounding Soil	Risk to Groundwater via Subsurface Transport	Risk Incurred With Exposure From Pit Toilet	Risk Incurred With Emptying Pit
Viruses	<100	Residence time and temperature in pit	Adsorption to and filtration by soil	●●●	●●	●●●
Bacteria	<90	Residence time and temperature in pit	Adsorption to and filtration by soil	●●●	●●	●●●
Protozoa	<30	Residence time and temperature in pit	Data less certain, protozoa are less likely to transport out of pit compared to bacteria and viruses because of greater impact of filtration by soil	●●	●●	●●●
Helminths	months	Residence time and temperature in pit. Will accumulate in sludge.	Most likely not transported out of pit because of large size and filtration by soil	●	●●	●●●

Comparative contribution of pathogen group to risk: ● = lower contribution; ●● = moderate contribution; ●●● = large contribution

5.1 Bacteria

Rather than test for specific bacteria, many studies use bacterial indicators such as *E. coli*, total coliforms, or faecal coliforms to detect the presence of potential bacterial pathogens in groundwater near latrines because they are easier to monitor than pathogens and because both are co-transported from latrines. For example, sampling of faecal sludge stored in double pit toilets for over one year (in Bangladesh) revealed that 20 out of 70 cases had *E. coli* concentrations between 1,001 and 10,000 colony-forming unit (CFU) per gram of faecal sludge, while 44 of the remaining cases had *E. coli* concentrations between 1 and 1,000 CFU/gram of faecal sludge, and only 4 cases had non-detectable levels of *E. coli* (Dey et al., 2016). Fortunately, bacteria are reported to have higher reduction rates than other pathogens in toilet pits because of their metabolic activities (BGS, 2002; Kibbey et al., 1978); however, during cool, moist conditions, the survival times are extended.

5.2 Viruses

Viruses are present in faecal sludge (Strande et al., 2014) obtained from pit toilets and may be transported out of the pit by percolation and hydrogeological conditions; because of their smaller size, viruses (10-100 nm) can often be transported greater distances from the pit than bacteria (1000 nm) (WHO, 2011). Although filtration is not very effective, adsorption to soil particles will still occur (BGS,

2002; West et al., 1998; Gerba et al., 1975; Schijven and Hassanizadeh, 2000).

5.3 Protozoa

The literature is limited on the reduction of parasitic protozoa in pit toilets, but reduction is expected to be higher than for viruses and bacteria due to filtration in the surrounding soil since their size is relatively larger (BGS, 2002). One study (Mawdsley et al., 1996) supports this expectation, reporting that the majority of *Cryptosporidium parvum* oocysts were contained in the top two centimeters of surface soil to which livestock leachate had been applied. In a gradient down to 30 centimeters of depth, on average the surviving oocysts were reduced by 1.3 log₁₀ compared to the surface concentrations. Although not much inactivation of protozoa is expected in the pits, protozoa can still be physically removed through pit emptying.

5.4 Helminths

High quantities of helminths in soil surrounding pit toilets and faecal sludge collected from the pit has been reported (See Table 2). Helminths in general, and *Ascaris* eggs in particular, are highly persistent in soil and faecal sludge, and are not readily inactivated in pit toilets due to their thick protective shells (Jimenez & Wang, 2006; Feachem et al., 1983). Helminth percolation is expected to be absent or low from the pit because of their large size and is dependent on the type of soil (Sobsey et al., 1980).

Table 2. Review of Studies that Identified Helminths in Faecal Sludge or Surface Soils Near Toilets

Location	Helminth	Percent Positive and/or Concentrations (Eggs/gram of Faecal Sludge)	Reference
Bangladesh	<i>Ascaris lumbricoides</i>	In 70 faecal sludge samples stored for 14 to 18 months the content was $\leq 1.0 \text{ E}+02/\text{g}$ in 54% (of samples) $1.0 \text{ E}+02$ to $5.0 \text{ E}+02/\text{g}$ in 30% $5.0 \text{ E}+02$ to $6.0 \text{ E}+03/\text{g}$ in 16%	Dey et al., 2016
Cameroon	<i>Ascaris lumbricoides</i>	41/g	Nzouebet et al., 2016
Cameroon	<i>Ankylostoma</i>	32/g	Nzouebet et al., 2016
Cameroon	<i>Fasciola hepatica</i>	35/g	Nzouebet et al., 2016
Cameroon	<i>Trichuris trichiura</i>	33/g	Nzouebet et al., 2016
Malawi	faecal sludge samples from pit toilets contained helminths	86.3%	Kumwenda et al., 2017
Malawi	<i>Ascaris</i>	5/g	Kumwenda et al., 2017
Malawi	Hookworm	21/g	Kumwenda et al., 2017
Malawi	<i>Taenia</i> spp.	5/g	Kumwenda et al., 2017
Mozambique	<i>Ascaris</i>	23% of soil samples had eggs identified in in yards of homes near pit toilets.	Muller et al., 1989
Tanzania	<i>Ascaris</i> spp.	Helminths were identified in soil samples around the outer edge of toilets 16%	Exley et al., 2015
Tanzania	hookworm larvae	51%	Exley et al., 2015
Tanzania	hookworm ova	21%	Exley et al., 2015
Uganda	<i>Ascaris</i>	Faecal wet sludge in urban unlined pit toilets $1 \text{ E}+02$ to $1.6 \text{ E}+03/\text{g}$ 55%	Nabateesa et al., 2017
Uganda	<i>Strongyloides</i>	$2.0 \text{ E}+02$ to $4.1 \text{ E}+03/\text{g}$ 98%	Nabateesa et al., 2017

6.0 Do Pathogens and other Contaminants Reach the Groundwater Near Pit Toilets?

Section 3 of this chapter brought up the mechanisms that can lead to pathogen transport out of the toilet pit into the surrounding subsurface environment. Anthropogenic chemicals, such as nitrogen in the form of nitrate (NO_3^-), are known to be transported to groundwater from excreta that are deposited in pit toilets (Jacks et al., 1999; Banks et

al., 2002; Mafa, 2003; Wright et al., 2013; Zingoni et al., 2005). Other studies have determined a positive correlation between toilet density and groundwater contamination (Banks et al., 2002; BGS, 2002; Girard & Hillaire-Marcel, 1997; Wright et al., 2013; Tandia et al., 1999). However, nitrate as a soluble chemical does not reflect the presence and transport of pathogens.

In terms of pathogens in groundwater near pit latrines,

viruses were recorded in both wet and dry seasons in Benin when pit toilets were situated within 50 m of a pump or well (Verheyen et al., 2009). *Giardia* was detected in tubewells in India and was likely contaminated by excreta from nearby toilets (Odagiri et al., 2016). The detection of faecal indicators has repeatedly been associated with proximity to toilets (Escamilla et al., 2013; Wright et al., 2013; Gandidzanwa, 2003). As expected, a shallower groundwater table is expected to result in detection of microbial constituents originating from a toilet pit (Gandidzanwa, 2003; Dzwauro et al., 2006).

Figure 7 summarizes a review of 24 studies that identified the microbial water quality of groundwater that was impacted by pit toilets (Graham & Polizzotto, 2013). All but one of the reviewed studies focused on the faecal indicators: total coliforms, faecal coliforms, and *E. coli*. This figure suggests that, as expected, viruses may be transported farther away from their source than bacteria. However, only one virus study was reported and, as stated in this chapter, transport of microorganisms in the subsurface is dependent on many site-specific characteristics.

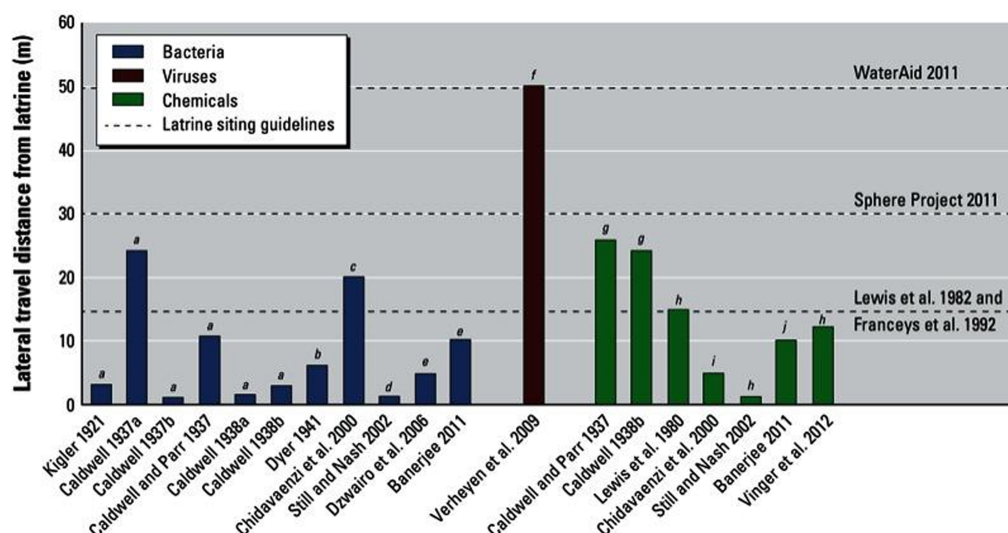


Figure 7. Transport Distances Reported in Literature for Microbiological and Chemical (e.g., nitrate, chloride) Contaminants Compared to Selected Pit Toilet Siting Guidelines. (reproduced from the public domain from Graham and Polizzotto (2013), references listed on x-axis are available in Graham and Polizzotto). The small letters above each bar represent different contaminants: a=*B. coli*; b=total coliforms; c=coliforms; d=fecal coliforms; e=total and fecal coliforms; f=adenovirus and rotavirus; g=chemical stream (Nitrate, nitrite, and chloride); h=nitrate; i=nitrogen; j=salt tracer.

7.0 Epidemiology and Health Risk Evidence Associated with Pit Toilets

The relationship between use of pit toilets and decreased incidence of disease and helminth infection compared to open defecation has been addressed in the literature. Pit toilet usage can protect public health in two ways: 1) it can protect the health of the members of the household that uses the pit toilet (individual effect) or 2) it can protect the health of the community members surrounding the household that uses the pit toilet (community effect) (Komarulzaman et al., 2017; Jung et al., 2017; Oswald et al., 2017). It is unknown whether the individual effect or the community effect has greater influence. For example, in a systematic review and meta-analysis, Ziegelbauer et al. (2012) concluded that toilet users and/or owners would have 50% less risk for soil-

transmitted helminth infection. Similarly, Esrey et al. (1991) reported a decreased likelihood of hookworm infection and a reduction in both morbidity and mortality due to diarrhea with use of a toilet. Strunz et al. (2014) found a decreased likelihood of soil-transmitted helminth infection if sanitation facilities were accessible. Other studies from Stenström et al., 2011 (Table 3) similarly report positive correlations between pit toilet usage and reduction of disease. In contrast, one study concluded that even with increased pit toilet coverage and use, faecal pathogens (and associated exposure) were still present in homes and local groundwater and surface water sources (Odagiri et al., 2016). That study thus points toward the additional factors such as toilet usage, household hygiene, education, and access to safe water that need to be addressed in parallel with provision of a sanitation improvement such as a pit toilet (Odagiri et al., 2016; Clasen et al., 2014).

Table 3. Review of Studies that Indicate Positive Correlations between Pit Toilet Usage and Reduction of Disease as Compared to Open Defecation (from Annex 6 and Single Pit Latrine Chapter in Stenström et al., 2011)

Area	Conclusion	Reference
Brazil	Children who used pit latrines in a shantytown were 1.5 times less likely to have diarrhea compared to children who practiced open defecation.	Gross et al., 1989
East Africa	Households with pit latrines had a 22.5% reduction in diarrheal incidence compared to households that had no toilet facility.	Thompson et al., 2001
El Salvador	Transmission of <i>Giardia</i> via the faecal-oral route was reduced by using pit latrines.	Corrales et al., 2006
Lesotho	The provision of VIP latrines reduced diarrheal morbidity in young children. Compared to children from households without a VIP latrine, children in households with a VIP latrine produced 24% fewer episodes of diarrhoea (odds ratio=0.76; 95% confidence interval of 0.58 - 1.01).	Daniels et al., 1990
Nigeria	Children who used pit latrines were less likely to be infected by helminths compared to those who practiced open defecation. However, children who used pit latrines were more likely to be infected by helminths compared to those who used flush toilets.	Asaolu et al., 2002
Southern Tanzania	Compared with households who had toilet facilities, households who practiced open defecation were 11.4 times (95% confidence interval of 6.3- 20.5) more likely to contract cholera during a cholera outbreak.	Acosta et al., 2001
N/A	The proper construction of pit latrines reduced the ability of flies to transmit <i>Shigella</i> spp in the faeces	Levine et al., 1991 Chavasse et al., 1999; Emerson et al., 1999

8.0 Conclusions

Pit toilets may contain substantial amounts of pathogens. A pit toilet is not designed specifically to remove pathogens, but rather to contain the faecal matter and thereby minimize or reduce human exposure. With time, pathogens are inactivated and/or removed in pit toilets by a number of different mechanisms. Table 1 summarizes the primary mechanisms of pathogen removal in the toilet pit and the surrounding subsurface soil. Residence time in the pit is believed to have the largest impact on pathogen reduction given the reality of unfavorable temperature and moisture levels existing in the

pit. Table 1 also shows that, because of filtration and adsorption provided by the soil that surrounds a pit, protozoa and helminths are much less likely to contaminate groundwater than bacteria and viruses. However, a lack of measurements for non-indicator species in the subsurface downgradient of pit toilets, the uncertainty about pathogen transport due to insufficient data, and the fact that transport of microorganisms in the subsurface is dependent on many site-specific characteristics means that care should be taken when co-locating pit toilets and groundwater supply systems. Additional research is needed to limit these uncertainties and provide more actionable recommendations to users.

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