LOW-COST SANITATION: AN OVERVIEW OF AVAILABLE METHODS

By Alicia Hope Herron

Unsanitary conditions and contaminated drinking water exact a crippling toll on both the health of the human population and the environment. Approximately 40 percent of the world's population does not have access to improved sanitation.[1] In addition to the indignity suffered by those lacking sanitation facilities, millions of people in the developing world die each year from diseases contracted through direct and indirect contact with pathogenic bacteria found in human excreta. Infectious diseases such as cholera, hepatitis, typhoid, and diarrhea are waterborne, and can be contracted from untreated wastewater discharged into water bodies. More than half of the world's rivers, lakes, and coastal waters are seriously polluted from wastewater discharge (UN Environment Programme, 2002). The cost of inadequate sanitation translates into significant economic, social, and environmental burdens.

Sanitation coverage has lagged behind water provision since the first International Decade of Water and Sanitation (1980–1990). We are far from meeting the Millennium Development Goal of halving by 2015 the proportion of people without sustainable access, as agreed upon in the Monterrey Consensus and reinvigorated as part of the "Water for Life" Decade (2005–2015). A mid-term assessment by the World Health Organization (WHO) and UNICEF (2004) suggests that 370,000 people will need to gain access each day until 2015 to fulfill this goal—an increase in performance of 90 percent—which will still only provide coverage to half of those lacking it.

As the world attempts to realize these goals, we must reassess the lessons learned, evaluate new technologies, identify research gaps, and critically discuss ways forward. Most of the World Bank's portfolio of $2.6 billion—the largest in the field—funds "traditional" sewage and wastewater treatment operations for urban populations. Since 2 billion of the 2.6 billion people lacking sanitation live in rural areas, we must complement large-scale urban investments with low-cost, on-site technologies that target rural communities (UN Economic and Social Council, 2005). Low-cost sanitation options have significantly improved, especially for the reuse of sewage for agriculture or aquaculture.

This article is not a technical review or a design manual; several already exist.[2] Rather, I attempt to consolidate the information available on several

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[1] According to the United Nations Millennium Development Goals, improved sanitation is defined as access to facilities that hygienically separate human excreta from human, animal, and insect contact.

[2] See Franceys, Pickford, and Reed (1992) and Kalbermatten et al. (1981).

low-cost options. I also attempt to frame these low-cost options within the context of necessary considerations, primarily the need to ensure community acceptability, cost-effectiveness, and sustainability. With sanitation—even more so than with water supply—determining which option will be most effective requires weighing a complex set of variables ranging from culture and cost to geology and climate. Not only are these considerations important for efficacy and sustainability, but the lack of consideration of one variable in sanitation planning has the potential to cause serious damage to community health, exacerbating—rather than ameliorating—an already dangerous situation.

UNDERSTANDING SANITATION: COMPOSITION AND REUSE

Understanding sanitation projects requires understanding human excreta's composition, hazards to human health, and potential for reuse. Human excreta are feces and urine, which consist of proteins, carbohydrates, and fats. Excreta contain moisture, organic matter, nitrogen, phosphorous, potassium, carbon, and calcium.[3] Excreta also contain pathogens that cause infectious diseases—such as cholera, hepatitis, typhoid, schistosomiasis, and diarrhea—through fecal-oral contamination. Helminthes (worm-like parasites, including human hookworms, roundworms, and whipworms) cause gastrointestinal infections that make up part of the excreta-related global health burden (Mara, 2004). It is estimated that approximately one-third of the world population has intestinal worms (Chan, 1997). The loss of blood from a human hookworm leads to iron-deficiency anemia and protein malnutrition, particularly in women of reproductive age and children.

The discharge of untreated sewage into water resources provides a vector for pathogens capable of sickening humans and animals. Pathogenic bacteria are able to survive in bodies of water for days or weeks, and eating contaminated seafood can cause typhoid fever, infectious hepatitis A and B, polio, and cholera (GESAMP, 2001).

TABLE 1: ANNUAL EXCRETION OF ONE HUMAN, COMPARED WITH THE AMOUNT OF FERTILIZER NEEDED TO PRODUCE CEREAL

Fertilizer	500 liters urine	50 liters feces	Total Excreta	Fertilizer needed for 230 kg of cereal
Nitrogen	5.6 kg	0.009 kg	5.7 kg	5.6 kg
Phosphorous	0.4 kg	0.19 kg	0.6 kg	0.7 kg
Potassium	1.0 kg	0.17 kg	1.2 kg	1.2 kg
Total (N+P+K)	7.0 kg (94%)	0.45 kg (6%)	7.5 kg (100%)	7.5 kg (100%)

Source: Wolgast (1993), quoted in Austin & Van Vuuren (2001)

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3. For a complete percentage breakdown, see Gotaas (1956) and Mara (1976).

These pathogens are particularly deadly in developing countries; diarrhea alone kills some 1.3 million children under the age of five each year. The WHO estimates that poor sanitary conditions and practices cause 85–90 percent of diarrheal cases in developing countries (Prüss-Üstün et al., 2004).

Many low-cost methods are able to treat excreta and sewage so that it can be reused. Reducing pathogens, particularly human intestinal nematodes and fecal bacteria, is the most important step in treating human waste. The WHO's guideline limit for fecal coliform bacteria is 1000 per 100 milliliters (Havelaar et al., 2001). The Endgelberg guidelines limit nematodes to no more than one egg per liter. Once these standards are met, human excreta can be reused as fertilizer or for aquaculture. Table 1 illustrates the potential value of excreta as a productive resource: One person's annual average excreta—500 liters of urine and 50 liters of feces—equals the amount of fertilizer needed to produce a year's worth of cereal for one person (230 kilograms).

DRY SANITATION METHODS

Dry sanitation methods do not use water as a carrier; instead, excreta are broken down by anaerobic methods (i.e., decomposition or dehydration). In decomposition systems, bacteria, worms, and other organisms break down urine and feces. Dehydration methods separate urine and feces, and then scatter feces with ash, shredded leaves, or sawdust to absorb excess moisture and deodorize. The added material also improves the nitrogen content in the event that the feces are reused as fertilizer.[4]

Decomposition Systems: Pit Latrines and Ventilated Improved Pit (VIP) Latrines

Pit latrines are the most rudimentary form of sanitation. Structures made out of locally available materials cover a defecation hole—a pit dug in the ground to collect waste. Once full, the pit is covered with sediment. The water table should be no less than 0.5 meters below the surface of the pit or it could contaminate the ground water. Geological conditions are a primary concern when considering a pit latrine; rocky substrates and shallow water tables negate this option for many communities, and areas with non-cohesive soils require a lined pit.

The health problems posed by pit latrines have been widely documented.[5] The open defecation hole attracts mosquitoes and flies and produces a ghastly odor. Pit latrines often serve as breeding grounds for mosquitoes, thus increasing the incidence of malaria in some areas. These adverse conditions lead many communities to abandon latrines.

Ventilated Improved Pit (VIP) latrines are an improvement over traditional latrines in two important respects: they mitigate the noxious odor and reduce the number of flies and other insects that plague users of traditional latrines. In a VIP latrine, a vent pipe allows fresh air to flow through the latrine, reducing odor. The vent also allows light into the latrine, attracting insects into the pipe, where they are trapped by the fly screen at the top of the pipe. The screen also keeps out insects looking to enter the pipe from the outside. The VIP latrine has been successfully used in Zimbabwe since the mid-1970s, where it is known as the Blair Latrine (Robinson, 2002).

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[4] For reviews of dry sanitation technology, see Del Porto and Steinfeld (1999), Esrey et al. (1998), and Drangert et al. (1997).

[5] See, for example, Grimason et al. (2000), WHO (2004), Intermediate Technology Development Group (2003), and Bakir (2001).

Other dry decomposition options utilizing anaerobic breakdown have been developed to allow excreta to be reused for agricultural purposes. If VIP latrines are constructed with two pits, instead of moving the latrine when the pit is full, users switch to the other pit. After the waste in the full pit composts, it can be reused as fertilizer. The amount of time before the compost can be used as fertilizer depends on climate and ranges from 3–12 months.[6]

Other decomposition toilets include Reed's odorless earth closet (ROEC), the Clivus Multrum, the Pacific Island Carousel toilet, and the Mexican SIRDO. Variations in design include the use of aboveground vaults (constructed of concrete, brick, or other materials), solar energy to heat the compost, different seat designs, electric fans, mechanical vault rotation, and alternate vault locations. The vaults themselves can be emptied by hand or by mechanical means (e.g., with a vacuum). One of the lessons learned from the first Water and Sanitation Decade is the importance of keeping the latrine affordable (Cairncross, 1992). However, the product must also be desirable and able to serve the community's needs—a delicate balance.

Dehydration Systems

Dehydration systems separate urine and feces using a special pedestal or urine diversion pan. Urine is diverted into a holding pot or into a soak field, while a watertight vault collects the feces. After defecation, ash or another absorbent (e.g., lime, dry soil, husks, organic matter) is sprinkled into the vault. Material used for anal cleansing is put into another container rather than dropped into the vault. Once the vault is three-quarters full, the feces is covered with dry earth. Both the urine and the dehydrated feces can be reused as fertilizer. Urine is often used immediately, but it should ideally sit for six months to ensure that nematode eggs are destroyed. Dehydrated feces should not be used for at least a year, although case studies identify different amounts of storage time.

One advantage of dehydration systems is better groundwater protection due to the use of watertight and aboveground vaults, which can be used in areas that have geotechnical limitations. The absorbent material also helps to deodorize the chamber and reduce flies. Dehydration can be employed in a wide range of climates. Due to the specific nature of the technology, however, the most common problem is moisture entering the dehydration chamber, either from leaks, urine splashing into the chamber, or other accidental spills. Children might find the latrines more difficult to use, and blocked urine separators also pose problems.

The Vietnamese double-vault latrine has been in use since the mid-1950s, and dehydration systems can be found in South Africa, China, Mexico, El Salvador, Ecuador, Yemen, Guatemala, Ethiopia, Zimbabwe, and Sweden. Specific models include the Mexican Dry Ecological toilet, the Ethiopian EcoSan toilet, and the EcoSanRes. Depending on the materials available, the urine diversion pedestals can be constructed or prefabricated from concrete, plastic, and fiberglass. Models such as the Mexican Dry Ecological toilet can be designed for use inside a home, complete

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[6] Although pH level and time are the most important factors, the rate of pathogen destruction is also influenced by temperature, competition for nutrients, antibiotic action, and toxic byproducts of decomposing organisms (Winblad, 1985).

with a conventional toilet seat (Esrey et al., 2000). In Yemen, a one-chamber dehydrating toilet has been adapted for use in a building that has several floors (Winblad, 1985). Solar panels, ventilation pipes, and other building materials can be used to tailor this technology to a community's specific needs.

Health Aspects of Dry Sanitation

Unfortunately, no systematic analysis documents the rate of pathogen and nematode egg die-off in dry sanitation systems. Anne Peasey (2000) reviewed the existing literature on the subject and found that the two most influential factors are pH level and the amount of storage time needed before the material can be reused, which varied from 3–12 months. A study cited by Strauss and Blumenthal (1990) asserts that 10–12 months are needed in tropical regions, while 18 months is suggested for highland areas. Studies of the prevalence of nematode eggs also did not take into account the health of the users, which is crucial to determining whether nematode eggs were already present. This lack of information could be significant, depending on the product's end use. In areas where a proportion of the population hosts intestinal worms, secondary treatment may be necessary.

Reuse: Dry Sanitation

Both dehydrated and composted human excreta can be used for many different purposes at the community and individual levels. By selling excreta for agricultural or aquacultural use, a community can recoup the costs of its initial investment in sanitation. Excreta can serve not only as a fertilizer, but also as a soil conditioner, due to its high organic content. Many countries—including India and China—use human excreta and wastewater to help grow fish and vegetables (Edwards, 1985). Ponds using wastewater have been found to be productive, possessing high pH and oxygen levels; in addition, the fish are not susceptible to enteric bacteria (Hepher & Schroeder, in Rybcynski et al., 1982). Using excreta to grow duckweed, algae, and water hyacinth are other options; duckweed can be used in animal feed or fish food (Leng et al., 1995). Reused excreta and wastewater are increasingly recognized in Europe as valuable resources (Langergraber & Muellegger, 2001; Johansson et al., 2001).

Biogas is another way to reuse human excreta—and provide a much-needed resource. The anaerobic decomposition of human excreta produces methane gas, which can be harnessed by biogas plants to produce energy (Singh et al., 1987; Gustavsson, 2000). These plants can be designed to operate at the individual household level and produce tanks of biogas for domestic cooking and lighting. One person produces one cubic foot of biogas per day—enough to meet the daily energy needs of a person in the developing world (Food and Agriculture Organization, 1996).

WET SANITATION METHODS

Wet sanitation methods utilize water to treat waste. These methods are only recommended for communities that have liberal supplies of water. The most widely used models are the pour flush latrine, the aquaprivy, and the septic tank. These systems are usually more expensive than the VIP latrine, although some argue that the cost of the pour flush latrine is comparable. Primary treatment produces effluent and sludge; ability to reuse the effluent depends on household land-use patterns. However, a second treatment using natural processes can be easily achieved.

POUR FLUSH LATRINES

A pour flush latrine consists of a cover slab and a special pan that provides a water seal. A U-shaped pipe is used to maintain the water seal. Approximately 1–3 liters of water are needed for each flush. The latrines can be constructed with pits directly underneath or offset, or with two pits. They can also be built inside a dwelling, with the pit located outside. If properly built and maintained, pour flush latrines reduce odors and flies. They should be considered in communities where anal cleansing habits require the use of water. Disadvantages of pour flush latrines include the high water requirements, higher cost, and problems caused by clogged pipes.

The pour flush latrine is used in parts of Asia and the Caribbean, and most widely in India, where it is called the Sulabh toilet (Jha, 2005). The Sulabh toilet replaced the bucket system, saving more than 60,000 people (mostly women) from manually handling waste. In addition, public pour flush latrines connected to biogas plants generate electricity.

Aquaprivy

An aquaprivy is an underground watertight tank, filled with water, which is connected to a flush toilet or defecation hole. The tank is located directly underneath the toilet and separates solid matter from liquids. The tank can also be used to dispose of greywater. Over time, the solid matter in the tank degrades anaerobically. A soak field absorbs the effluent; however, sludge must be removed from the tank every 1–5 years. Usually a vacuum tanker or service crew performs this difficult and potentially dangerous task. A bucket of water must be poured down the drop pipe daily to clear any buildup and maintain the water seal.

Aquaprivies, found in more than 39 countries, can be set up inside a home and connected to a sewage system at a later date (Brikke et al., 1997). If operated properly, there are usually no problems with flies or odors. The tank must be maintained; if the tank is leaking, odor can become a problem. The aquaprivy, which requires the use of water, is more expensive than the sanitation methods discussed above. The soak fields used by aquaprivies and septic tanks can also cause problems, which are described below.

Septic Tank

A septic tank is similar to an aquaprivy, except that a septic tank can be located outside the house. The toilet used with a septic tank also has a U-trap water seal. As with the aquaprivies, septic tanks can be used to dispose of greywater and must be periodically emptied of sludge. They also require the use of a soak field for the secondary treatment of effluent. Septic tanks may have two chambers to separate and promote further settlement of liquid and solid excreta.

Septic tanks are more costly than aquaprivies; given the higher initial investment required, plus the recurring costs of emptying the tanks, this method is not generally recommended for poor rural communities. For peri-urban areas, the ability to connect the household to a sewage system at a later date is a major benefit. The disadvantages include faulty or leaking septic tanks, water requirements, higher costs, and the use of a soak field. If the septic tank is faulty, flooding can cause hydraulic overloading. Septic tanks are used widely across the United States; it is estimated that only 4–6 percent of these tanks are watertight. U.S. EPA (2002) estimates suggest that 10–20 percent of these systems are failing and that rates of groundwater contamination may be even higher.

Health Risks Related to Soak Fields

Soak fields, also known as soil absorption systems, treat the effluent from aquaprivies and septic tanks. A soak field is comprised of drainage ditches or gravel-lined trenches that allow effluent to percolate through the soil, achieving secondary treatment by absorption and biodegradation. A conventional soil absorption system allows the effluent from a septic tank to outflow into perforated pipe laid in the bottom of trenches two-feet deep; stoneware can also substitute for pipe.

The soak field presents health risks, as the effluent coming out of the tank could contain pathogens or nematode eggs (Wolverton & Wolverton, 2001). The effluent is potentially hazardous to humans and the area's groundwater. In addition, the effluent could overflow the trenches if it exceeds the absorptive capacity of the soil. The soak field also requires that the user possess an adequate amount of land with certain geological characteristics; septic tanks and soak fields cannot be located on a slope, in flood zones, or in areas with shallow water tables. In addition, areas with non-permeable soil do not allow the percolation necessary to achieve secondary treatment.

Other natural treatment processes have been shown to complement septic tanks and aquaprivies to achieve tertiary treatment of waste. Wolverton and Wolverton's (2001) work with phytoremediation provides one model: planting the trenches of a soak field with native semi-aquatic plants, flowers, or vegetables. This process ensures that the soak field maintains equilibrium and will not overflow; provides a safe conduit for effluent; and also produces end products that can be decorative, used for food, or sold.

LESSONS LEARNED

Given the traditionally poor performance of efforts to achieve widespread sanitation coverage, we must evaluate lessons learned. The literature I reviewed highlights several critical aspects of a sustainable sanitation program:

1. Sanitation must be addressed together with hygiene and water to fully stop disease transmission;
2. Success depends on responding to consumer demand;
3. Educating consumers on sanitation and hygiene practices is essential; and
4. Women should be involved at every level of the process.

It is not enough to provide a sanitation facility; a great deal of care must go into the "soft" aspects of a program, as successful low-cost sanitation systems must adapt to local cultural traditions and have clear project management (Evans, 2004; Manikutty, 1998). Projects should educate the broader community about sanitation and hygiene's role in stopping the transmission of disease, as well as promote consumer demand (Okin & German Agency for Technical Cooperation, 1988). Women should be incorporated into projects and involved in selecting the site and technology, as they wield major influence over children's hygienic practices (Evans, 2004). Training users to operate and maintain the technology is also critical, due to the risk of contaminating ground water with seepage from septic tanks and pit latrines, and other health risks associated with misuse of waste in closed systems.

It is important to provide a community with two or more options in the pilot phase to ascertain the acceptability of a particular technology

(Cairncross, 1992). To provide the technology at a low cost and ensure sustainability, the facilities must be constructed out of locally available materials, adhere to the land-use patterns of the community, and conform to the geotechnical demands of the area. Human excreta do not necessarily have to be waste products, but can be reused for agriculture or aquaculture. The desire of the community to reuse excreta will affect the choices and operation of a sanitation program. Sanitation programs cannot simply be transplanted, but must be molded to fit the needs of each community, and thus they rely on innovation (Cairncross, 1992).

FUTURE WORK

There are many research gaps that prevent a comprehensive understanding of sanitation technologies, including survey methods, implementation, cost-benefit analysis, and health risks within specific contexts. The health risks associated with the reuse of excreta need to be further evaluated. Researchers should study cost-incentive structures for community-based approaches and examine the roles of the stakeholders. Little research details the motivations of those who reuse human excreta and wastewater or the different modes of collaboration with stakeholders (Allison, 1998; Strauss & Blumenthal, 1990). The process of project integration and eventual scaling-up should also be considered. Many sources assert that water, sanitation, and hygiene should be approached holistically, but few case studies point the way forward. Much work has studied low-cost models for peri-urban and urban regions, particularly Mara (1996), Bakalian et al. (1994), Melo (1996), and Wolverton & Wolverton (2001); however, the process of scaling-up has not been examined. With the tremendous amount of population growth projected for these areas, research on this subject would be particularly timely.

CONCLUSION

Meeting the sanitation Millennium Development Goal will require an investment of at least $2 billion per year to mobilize the resources for 370,000 people to gain access to basic sanitation services a day until 2015 (UN Millennium Project Task Force on Water and Sanitation, 2005). This article has sought to provide an overview of current low-cost sanitation methods, covering both wet and dry technologies, in an effort to promote a broader understanding of available options. The tremendous challenge of providing services to rural areas with diverse climate, geology, water usage, and cultural practices requires innovative approaches that account for these differences. The reuse of human excreta should be considered in relation to cost-incentive structures, as well as cultural practices.

BIOGRAPHY

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