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Decentralized approaches to wastewater treatment and management: Applicability in developing countries

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ABSTRACT

Providing reliable and affordable wastewater treatment in rural areas is a challenge in many parts of the world, particularly in developing countries. The problems and limitations of the centralized approaches for wastewater treatment are progressively surfacing. Centralized wastewater collection and treatment systems are costly to build and operate, especially in areas with low population densities and dispersed households. Developing countries lack both the funding to construct centralized facilities and the technical expertise to manage and operate them. Alternatively, the decentralized approach for wastewater treatment which employs a combination of onsite and/or cluster systems is gaining more attention. Such an approach allows for flexibility in management, and simple as well as complex technologies are available. The decentralized system is not only a long-term solution for small communities but is more reliable and cost effective. This paper presents a review of the various decentralized approaches to wastewater treatment and management. A discussion as to their applicability in developing countries, primarily in rural areas, and challenges faced is emphasized all through the paper. While there are many impediments and challenges towards wastewater management in developing countries, these can be overcome by suitable planning and policy implementation. Understanding the receiving environment is crucial for technology selection and should be accomplished by conducting a comprehensive site evaluation process. Centralized management of the decentralized wastewater treatment systems is essential to ensure they are inspected and maintained regularly. Management strategies should be site specific accounting for social, cultural, environmental and economic conditions in the target area.

1. Introduction

Globally, billions of people lack access to safe water and adequate sanitation (WHO, 2002; Ho, 2003). About 40 percent of the world's population lacks basic sanitation and sanitation coverage is commonly much lower in rural areas than in urban areas (WHO, 2002). Estimates of the World Health Organization (WHO) and the Water Supply and Sanitation Collaborative Council indicate that 25 percent of the developing country urban dwellers lack access to sanitation services with a much higher percentage for the rural populations of developing countries reaching up to 82 percent (CNES, 2003). The lack of adequate sanitation services leads to several diseases (Fig. 1). The WHO estimates that 2.1 million people die annually from diarrheal diseases (WHO, 2002). Worldwide, significant development has been made in wastewater treatment for urban areas as compared to rural areas which lag far behind. Wastewater treatment plants represent one of the major investments due to high capital cost in addition to operation and maintenance cost. Restricted local budgets, lack of local expertise, and lack of funding, result in inadequate operation of wastewater treatment plants in developing countries (Paraskevas et al., 2002). Moreover, small and isolated villages or settlements with low population densities can be served by decentralized systems that are simpler and cost effective (Butler and MacCormick, 1996; Otterpohl et al., 1997; Hedberg, 1999; Wilderer and Schreff, 2000; Paraskevas et al., 2002; USEPA, 2005). The large capital investment of sewerage system and pumping costs associated with centralized systems can be reduced, thus increasing the affordability of wastewater management systems. The lack of research and development activities in developing countries leads to the selection of inappropriate technology in terms of the local climatic and physical conditions, financial and human resource capabilities, and social or cultural acceptability.

According to the United States Environmental Protection Agency's (USEPA) study findings, decentralized wastewater management systems are appropriate for low-density communities and varying site conditions and are more cost-effective than centralized systems. They may include the use of conventional

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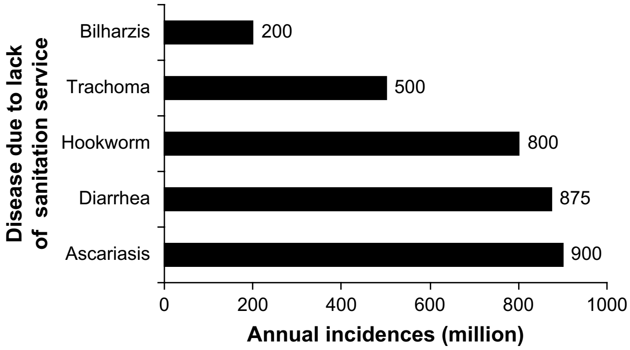

Fig. 1. The ranking of annual incidences of certain diseases due to the lack of sanitation (Wright, 1997).

septic systems, advanced designs of on-site systems and cluster or other land-based systems. Yet, the effectiveness of the decentralized approach depends on the establishment of a management program that assures the regular inspection and maintenance of the system. Collection, treatment and disposal are three basic components of any wastewater management system of which collection is the least important for treatment and disposal of wastewater. Nonetheless, collection costs more than 60 percent of the total budget for wastewater management in a centralized system, particularly in small communities with low population densities (Hoover, 1999). Decentralized systems keep the collection component of the wastewater management system as minimal as possible and focus mainly on necessary treatment and disposal of wastewater. While sustainable development includes a wide range of criteria including environmental, technical and socio-cultural factors; economics is the most important criterion in decision making in most developing countries. Decentralized wastewater management is being progressively considered because it is less resource intensive and more ecologically sustainable form of sanitation (Lens et al., 2001; Tchobanoglous and Crites, 2003). Given the limited technical and financial resources of most rural communities primarily in developing countries, even with the availability of funding to build centralized systems often technologies prove to be difficult and costly to maintain. Hence, it is essential to conduct research which is based on local requirements and conditions rather than adopting practices from other countries. This paper presents a review of the various decentralized approaches to wastewater treatment and management. A discussion as to their applicability in developing countries, primarily in rural areas, and challenges faced is emphasized all through the paper.

2. Wastewater treatment approaches

Wastewater treatment approaches vary from the conventional centralized systems to the entirely onsite decentralized and cluster systems. The centralized systems which are usually publicly owned collect and treat large volumes of wastewater for entire large communities, thus making use of large pipes, major excavations and manholes for access (Fisher, 1995; USEPA, 2004). On the other hand, decentralized onsite systems treat wastewater of individual homes and buildings (Crites and Tchobanoglous, 1998; Tchobanoglous et al., 2004; USEPA, 2004). While decentralized systems collect, treat and reuse/dispose treated wastewater at or near the generation point, centralized systems often reuse/dispose far from the generation point. Cluster systems, which can be either centralized or decentralized, serve more than a single household reaching up to 100 homes and more (Jones et al., 2001; USEAP, 2004). Contrarily to the onsite systems, piping systems are needed for the cluster systems, yet they are comparatively shorter than those used for the conventional centralized systems. Cluster systems are favorable in areas that are more densely populated or that have poor soil conditions and adverse topography. Generally, a cluster system may be considered as a centralized system if compared to the onsite system. However, a central wastewater treatment plant is more centralized than a cluster system (USEPA, 2004).

3. Centralized vs. decentralized wastewater treatment

As mentioned earlier, conventional or centralized wastewater treatment systems involve advanced collection and treatment processes that collect, treat and discharge large quantities of wastewater (West, 2001). Thus, constructing a centralized treatment system for small rural communities or peri-urban areas in low income countries will result in burden of debts for the populace (Parkinson and Tayler, 2003; Seidenstat et al., 2003). Decentralized or cluster wastewater treatment systems are designed to operate at small scale (USEPA, 2004). They not only reduce the effects on the environment and public health but also increase the ultimate reuse of wastewater depending on the community type, technical options and local settings. When used effectively, decentralized systems promote the return of treated wastewater within the watershed of origin. Moreover, decentralized systems can be installed on as needed basis, therefore evading the costly implementation of centralized treatment systems. Unlike centralized wastewater treatment systems, decentralized systems are particularly more preferable for communities with improper zoning, such as scattered low-density populated rural areas (USEPA, 2005).

Centralized systems are out of sight and hence, require less public participation and awareness (USEPA, 2004). However, to collect and treat the wastewater, centralized wastewater treatment requires pumps and piping materials and energy, therefore increasing the cost of the system (Wilderer and Schreff, 2000; Giri et al., 2006; Go and Demir, 2006). Nowadays, decentralized systems can be designed for a specific site, thus overcoming the problems associated with site conditions such as high groundwater tables, impervious soils, shallow bedrock and limestone formations. Moreover, decentralized systems allow for flexibility in management and a series of processes can be combined to meet treatment goals and address environmental and public health protection requirements. The objectives of wastewater management in relation to the characteristics of decentralized treatment systems are depicted in Fig. 2.

Despite the fact that decentralized treatment systems are more suitable, there exist problems as well. For example, septic tanks if not managed properly can lead to overflow of wastewater into the surrounding localities, causing detrimental health impacts (Kaplan,

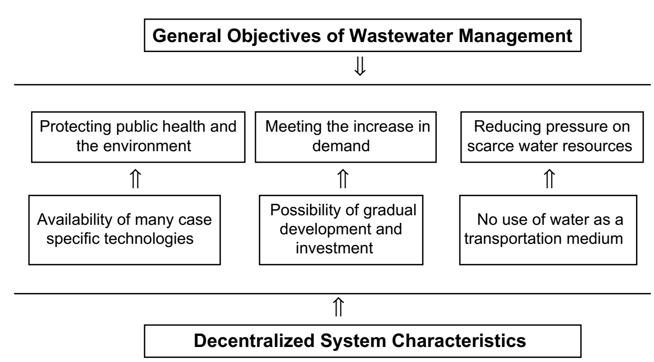

Fig. 2. General objectives of wastewater management versus decentralized systems characteristics.

1991; Carroll et al., 2006). Currently, sustainability has become a core issue of wastewater management. Yet, the systems offered for sustainable management are expensive enough that a developing country cannot adopt (Wilderer, 2005). The application of conventional wastewater treatment and sewer system for rural communities is not only expensive in terms of provision of services but operation and maintenance as well. Last but not least, in the absence of the required technical and funding assistance, the implementation of centralized systems is not possible (USEPA, 1997; CEHA, 2004).

Centralized and decentralized wastewater treatment systems have coexisted over the past years (Wilderer and Schreff, 2000; Mancl, 2002; Nhapi and Gijzen, 2004). Despite the lack of water and enough funding necessary for a proper centralized treatment, still these systems are the most widely spread even in small communities in developing countries (Bakir, 2001). The most commonly used decentralized treatment system is the conventional septic tank/drainfield system. Although more than 70 different onsite systems exist and may be suitable for certain site characteristics (Ho, 2005), none of these technologies is specific and exclusive for developing countries (Grau, 1996). On the contrary, every appropriate and affordable technology could find an application everywhere. Wetlands, for example, which are affordable to the developing countries, are gaining popularity in the developed world (Grau, 1996). The applications of conventional mechanical wastewater systems which are too complicated and too expensive are not expected to provide a sustainable solution. The mechanical and the non mechanical systems should be well understood with all their pros and cons before taking a decision on treatment technologies. Mechanized treatment systems are efficient in terns of spatial requirements compared to natural treatment systems. Yet, they depend on economies of scale to make them economically feasible. Mechanized treatment systems require vast capital investments in addition to high operation and maintenance costs and accordingly are not feasible in developing countries (Rocky Mountain Institute, 2004).

In the United States, about 60 million people use some form of onsite wastewater treatment systems of which about 20 million use the conventional septic tank system (Bradley et al., 2002). Australia is of no difference, where about 12 percent of the population uses septic tank systems to get rid of its wastewater (Ahmed et al., 2005). In Canada, decentralized systems are employed in a number of locations. Around 14 percent of the population in Greece might be served by decentralized systems due to their location in rural areas (Tsagarakis et al., 2001). Turkey tries to avoid centralized treatment due to the high cost of construction and operation. Of all the Turkish municipalities, up to 28 percent are served by septic systems. In other areas, the cluster systems and the package systems also exist (Engin and Demir, 2006). Moreover, some countries encouraged wastewater reuse through some special programs. For instance, Cyprus initiated a subsidy program to the households that opted to install gray water recycling and reuse systems (Bakir, 2001).

The process of evaluating and selecting appropriate wastewater treatment technology should consider the life cycle cost of such a system including design, construction, operation, maintenance, repair and replacement. Over the operational lifetime of the system the operation and maintenance costs are equally important to construction costs. Cost estimates on a national basis for wastewater treatment systems are difficult to develop, primarily due to varying conditions of each community such as population density, land costs, and local performance requirements. The USEPA developed cost estimates of centralized and decentralized approaches to wastewater management for a hypothetical rural community (USEPA, 1997). The study revealed that decentralized systems (cluster or onsite) are generally more cost effective for managing wastewater in rural areas than the centralized systems (Table 1).

Table 1
Summary of hypothetical EPA rural community technology costs (1995 US$) (adapted from USEPA, 1997)

Technology	Total capital cost	Annual operation and maintenance cost	Total annual cost
Centralized system	2,321,840–3,750,530	29,740–40,260	216,850–342,500
Alternative small-diameter gravity sewers	598,100	7290	55,500
Collection and small cluster systems			
On-site systems	510,000	13,400	54,500

Assumptions:
All technology options presented are assumed to have a 30-year life span.
All of the options considered are capable of achieving the secondary treatment level.
The rural community consists of 450 people in 135 homes.

4. Most common decentralized treatment and disposal methods

4.1. Primary treatment methods

There are several onsite wastewater treatment systems which if designed, constructed, operated and maintained properly will provide adequate service and health benefits. The simple septic tank system is the most commonly known primary treatment method for onsite wastewater treatment because of its considerable advantages. Septic tanks remove most settleable solids and function as an anaerobic bioreactor that promotes partial digestion of organic matter. Their main cause of failure is the unsuitability of the soil and the site characteristics (Les and Ashantha, 2003). The Imhoff tank is another primary treatment method that can accommodate higher flow rates than the septic tank, but it is less common. Both systems are inexpensive and simple to operate and maintain. Yet, sludge may cause an odor problem if kept untreated for a long time. The conventional onsite wastewater treatment systems are not effective in removing nitrate and phosphorus compounds and reducing pathogenic organisms. As such, these systems can be used prior to further treatment and disposal.

The simple septic tank system could be modified to provide advanced primary treatment of wastewater. The result of the modification would be a septic tank with an effluent filter vault or a septic tank with attached growth. The filter is the additional component for the former septic tank. This filter prevents some solids from entering the effluent and consequently clogging the treatment system as a whole (USEPA, 2002). As for the latter, it is mainly an aerobic system used where the standard anaerobic septic tanks are not a good option. They are primarily used in places where the soil is poor, the groundwater is high, the land available is small or the site is sensitive.

4.2. Secondary treatment methods

Many secondary treatment methods exist for decentralized wastewater treatment, each having advantages and disadvantages (Table 2). Considering that sand is the most common and available media for filters, sometimes media filter is equivalent to sand filter. Generally, in areas with deep, permeable soils, septic tank–soil absorption systems can be used. On the other hand, in areas with shallow, very slowly permeable or highly permeable soils more complicated onsite systems will be required.

Table 2
Advantages and disadvantages of the most common secondary treatment methods (Brix, 1994; Crites and Tchobanoglous, 1998; Reed et al., 1995; Burkhard et al., 2000; USEPA, 2002; Tchobanoglous and Crites, 2003)

Unit	Main advantages	Main disadvantages
	Media filters: Intermittent Sand Filter (ISF) and Recirculating Sand Filter (RSF)	
	• Minimum and easy operation and maintenance	• Cost may increase if the media is not available locally
	• High quality effluent especially for BOD and TSS[a]	• Regular maintenance required
	• Nitrogen can be completely transformed to nitrate if aerobic conditions are present	• Clogging is possible
	• No chemicals required	• Electric power is needed
		• The land area required may be a limiting factor
	Lagoons	
Facultative Lagoons (FL) and Aerated Lagoons (AL)	• Effective in removal of settleable solids, BOD, pathogens, and ammonia	• Not very effective in removing heavy metals
	• Effective at removing disease causing organisms	• Do not meet effluent criteria consistently throughout the year
	• High-nutrient and low pathogen content effluent	• Often require additional treatment or disinfection to meet state and local discharge standards
	• Cost-effective in areas where land is inexpensive	• Sludge accumulation is higher in cold climates
	• Require less energy than most other wastewater treatment systems	• Mosquitoes and insects can be a problem if vegetation is not controlled
	• Can handle periods of heavy and light usage	• Odor may be a problem
	• The effluent can be used for irrigation because of its high nutrient and low pathogen content	• Require more land area than other wastewater treatment systems
	• Easy to operate and maintain	• Less efficient in cold areas and thus may require longer retention time
Anaerobic Lagoons (AnL)	• Effective at removing disease causing organisms	• Not very effective in removing heavy metals
	• More effective for strong organic waste	• Often require additional treatment or disinfection to meet discharge standards
	• Produce methane and less biomass per unit of organic loading	• Require a relatively large area of land
	• Cost effective (not aerated or heated)	• Odor production
	• Effluent can be used for irrigation because of the high nutrient content	• Not suitable for domestic wastewater with low BOD levels
	• Generally low sludge production	
	• Simple to operate and maintain	
Aerobic Lagoons (AoL)	• Effective at removing disease causing organisms (5e)	• Not very effective in removing heavy metals from the wastewater
	• Simple to operate and maintain	• Often require additional treatment or disinfection to meet discharge standards
	• Effluent can be used for irrigation because of the high nutrient and low pathogen content	• Require large land areas
	Aerobic treatment	
Suspended Growth (SG)	• Extended aeration plants produce a high degree of nitrification since hydraulic and solid retention times are high	• Some odor and noise may be issued
	• Extended aeration package plants are available on the market	• Require electricity
		• Require regular operation and maintenance
Sequencing Batch Reactor (SBR)	• Suitable for site conditions for which enhanced treatment, including nitrogen removal, is necessary for protecting local ground and/or surface water	• Relatively high initial capital costs
	• The lower organic and suspended solids content of the effluent may allow a reduction of land area requirements for subsurface disposal systems	• Operational control and routine periodic maintenance is necessary to ensure the proper functioning of this type of treatment system
		• May be most applicable to cluster systems
Attached Growth (AG)	• Better capturing of suspended solids than the suspended growth	• Nitrification can occur at low loading rates in warm climates
	• Less complex than extended aeration systems	• Very few commercially produced fixed films systems are currently available for on site application
	• Very minimal operation is needed	• Require electricity
Constructed Wetlands (CW)	• The lower organic and suspen0wded solids content of the effluent may allow a reduction of land area requirements for subsurface disposal systems	• Some maintenance of wetland units will be required periodically
	• Inexpensive to operate and construct	• The area of a site occupied by the wetland would have very limited use
	• Reduced odors	• Require a continuous supply of water
	• Able to handle variable wastewater loadings	• Affected by seasonal variations in weather conditions
	• Reduces land area needed for wastewater treatment	• Can be destroyed by overloads of ammonia and solids levels
	• Provide wildlife habitat	• Remove nutrients for use of crops

[a] BOD, Biochemical Oxygen Demand; TSS, Total Suspended Solids.

4.3. Treatment/disposal methods

Disposal methods can be simple disposal methods such as the evaporation and evapotranspiration, surface water discharge and reuse. They can also be treatment and disposal methods concurrently such as the subsurface wastewater infiltration, the land application and the constructed wetlands. The various treatment/disposal methods provide additional treatment to the wastewater before the final disposal. A summary of the most widespread disposal methods is depicted in Fig. 3. Given the suitable site conditions, subsurface soil absorption is usually the best method of wastewater disposal for single dwellings because of its simplicity, stability and low cost. There are several types of subsurface soil absorption systems (USEPA, 2002). Trenches and beds, seepage pits, mounds, and fills are all covered excavations filled with porous media with a means for introducing and distributing the wastewater throughout the system (USEPA, 2002). Subsurface wastewater infiltration systems may be the best alternative for sites with appropriate soil conditions, groundwater characteristics, slopes and other features.

The trenches and beds can operate effectively in almost all climates, do not need electricity for operation and are less costly than the other systems of subsurface wastewater infiltration. However, they can't be used in areas with highly permeable soil.

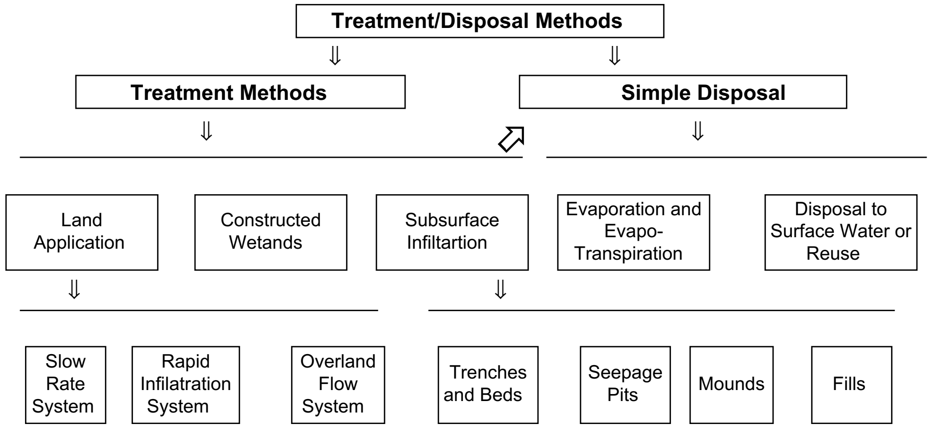

Fig. 3. Major treatment/disposal methods.

The seepage pits can be used where the water table is too low and the land is not readily available. While the mound system performs well in areas with high water table, very shallow soils, and porous or karstic bedrock, the fill system is effective with different types of soil, bedrock and water table (Garcia et al., 2001; USEAP, 2002). The land treatment systems utilize natural physical, chemical and biological processes within the plant-soil-water matrix to achieve a designed degree of treatment (Crites and Tchobanoglous, 1998). Such systems are simple, inexpensive and reliable. Their pollutant removal level is high and the nutrients are maintained in the soil.

Dry sanitation systems that do not use water for the treatment and transport of human excreta are new emerging technologies which will increase with repeated successful experiences of the system. Their main advantages are water resources conservation and pollution prevention of water bodies. The most common type of dry sanitation is referred to as the composting toilet. There is substantial controversy with regard to the evidence of establishing the safety and practicability of dry sanitation with reuse as an everyday practice. As such, it is very crucial to identify under what circumstances dry sanitation technologies are functioning safely and effectively in communities on a long-term basis (Peasy, 2000).

5. Choosing a technology

Choosing the "Most Appropriate Technology" is not an easy task but it could reduce the risk of future problems and failures. The two key issues in choosing a treatment technology are affordability and appropriateness (Grau, 1996). Affordability relates to the economic conditions of the community while appropriateness relates to the environmental and social conditions. As such, the "Most Appropriate Technology" is the technology that is economically affordable, environmentally sustainable and socially acceptable. The different factors affecting the selection of the most appropriate technology are described in Fig. 4. Environmentally sound development requires appreciation of local cultures, active participation of local peoples in development projects, more equitable income distribution, and the choice of appropriate technologies. Many factors fall under the economic aspect and are used to decide on the affordability of a system. The community should be able to finance the implementation of the system, the operation and maintenance including the capital improvement needed in the future, and the necessary long-term repairs and replacements (Bradley et al., 2002; Ho, 2005). Hence, population density and location and the efficiency of the technology as compared to its cost should be considered. Reasonably, in sparsely populated areas decentralized systems may provide cost-effective solutions (Parkinson and Tayler, 2003). The affordability of centralized systems in such areas may be doubtful due to the high cost of the conventional sewer lines. Among the different components of a centralized wastewater treatment system, collection, which is the least important in terms of treatment, costs the most. An assessment of the cost effectiveness of the selected system should be undertaken taking into consideration the capital cost for planning and construction the costs of operation and maintenance and the value of the land used.

For a system to be environmentally sustainable, it should ensure the protection of environmental quality, the conservation of resources, and the reuse of water as well as the recycling of nutrients (Ho, 2005). Understanding the receiving environment is crucial for technology selection and should be accomplished by conducting a comprehensive site evaluation process (Jantrania, 1998). This evaluation determines the carrying capacity of the receiving environment. Various environmental components should be evaluated including but are not limited to: surface and groundwater quality, aquatic and land-based ecosystems, soil quality, air quality, and energy use. Correspondingly, the following indicators should be assessed: biochemical oxygen demand,

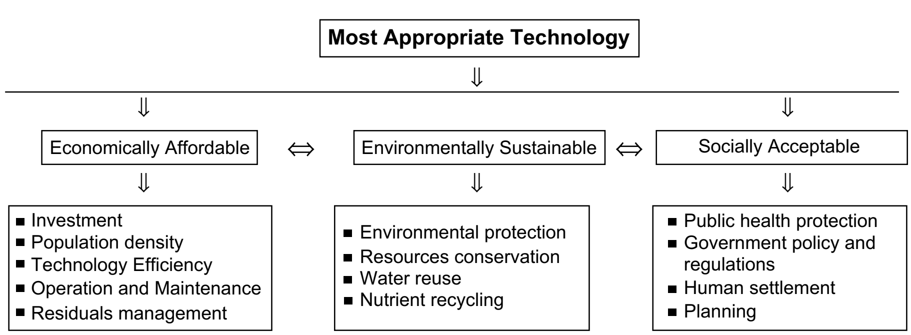

Fig. 4. Characteristics of the Most Appropriate Technology.

nutrients, changes in ecosystem distribution, soil productivity and permeability, permitted limits of toxic compounds and percent of energy supplied (Bradley et al., 2002). Analysis of samples for nitrogen and phosphorous are usually done to detect environmental risks. For the detection of public health risks, the samples are mainly analyzed for fecal coliforms and more precisely *Escherichia coli*. In case the area falls within low risk then no problems exist and the current standards would be enough. More detailed assessment is needed for areas with high risk. A detailed and comprehensive soil, water and site assessment would be needed. The social aspect mainly relates to local factors that can directly affect the operation and maintenance of a certain system. These include, but are not limited to, the local community habits and lifestyle, public health protection, government policies and regulations as well as public acceptance (Jantrania, 1998).

Generally, the main driving forces for the selection of a treatment technology at a certain site are performance requirements, site conditions, and wastewater characterization (source, daily average flow, peak flows and seasonal variability). In case a site is not suitable for the conventional septic tank/drainfield decentralized treatment system, one of the various alternative decentralized systems could be suitable (Jantrania, 1998). Expensive nutrient removal technologies can be targeted to only the locations that are nutrient sensitive (Burde et al., 2001). A summary of the removal efficiency of various decentralized wastewater treatment technologies is presented in Table 3. Moreover, many factors related to the wastewater itself can play a major role in the suitability of a certain environment to a certain treatment technology. As such, checking some of the wastewater parameters in parallel with site evaluation is crucial. The wastewater source, the daily average flow, the peak flow, the characteristics and the seasonal variability in quality and quantity are among the parameters that should be assessed (Jantrania, 1998).

There are several successful and sustainable research and development projects on wastewater treatment. The reasons for success or failure most often depend on the appropriateness of the implemented technology. For example, an experiment on real wastewater treatment by baffled septic tank with anaerobic filter proved to be the most feasible option for wastewater treatment in residential areas of Vietnam (Anh et al., 2002). Since the 1970s, China has been promoting the use of underground, individual household scale, anaerobic digesters to process rural organic wastes. The digesters produce biogas that is used as an energy source by the households, and produce fertilizer that is used in agricultural production (FAO, 2000). So far, anaerobic treatment has been applied in Colombia, Brazil, and India, replacing mostly the activated sludge processes. In various cities in Brazil, the interest in applying anaerobic treatment as a decentralized treatment system for sub-urban, poor, districts is increasing (Van Lier et al., 1998).

6. Management of decentralized wastewater treatment systems

Traditionally, the operation and maintenance of onsite systems was left to homeowners resulting in many cases in system failure due to improper maintenance. Since onsite septic systems were considered as temporary solutions awaiting centralized treatment and collection, many systems currently in use do not provide a treatment level that is needed to protect public health and the receiving environment. Hence, it is essential to develop policies, programs, guidelines, and institutions to ensure the proper design, construction as well as operation and maintenance of decentralized wastewater treatment systems. With rapidly increasing population and decreasing water resources, wastewater is becoming a significant resource. Accordingly, there is a substantial need for more integrated management of both onsite and cluster wastewater treatment systems. An integrated management approach ensures that all the perspectives of effective management that include economical, social, technical and environmental dimensions are taken into consideration. It is important to note that the needs and conditions of wastewater management vary from country to country and sometimes within the same country. Properly managing a system helps in protecting public health and local water sources, increasing the property value and avoiding expensive repairs. Such management systems should address the major problems related to wastewater treatment approaches primarily in developing countries. These include but are not limited to:

- Funding
- Public involvement and awareness
- Inappropriate system design and selection processes
- Inadequate inspection, monitoring and program evaluation components

Adequate funding and clear environmental and public health goals are vital for developing, implementing and sustaining a management program. In addition good knowledge of the political, social and economic context of the community as well as the institutional structure and available technologies are necessities for successful long-term operation. Wastewater management decisions often generate controversy and public concern as a result of negative attitudes and incomplete knowledge. Public awareness

Table 3
Removal rates of various decentralized wastewater treatment technologies (Bitton, 1994; Brix, 1994; USEPA, 2002)

		BOD % [levels achieved][a] (mg/l)	TSS % [levels achieved] (mg/l)	Nitrogen % [levels achieved] (mg/l)	Phosphorous % [levels achieved] (mg/l)	FC % [levels achieved] (counts/100 ml)
Media filters	ISF	[3–30]	[5–40]	18–50	Limited	99–99.99
	RSF	85–95 [10 or more]	85–95 [10 or more]	50–80	NA	NA
Lagoons	FL	75–95	90	Up to 60	Up to 50	[2–3]
	AoL	NA	NA	NA	NA	Effective
	AL	75–95 [35]	90 [20–60]	10–20 [30]	15–20	[1–2]
	AnL	50–80	NA	NA	NA	Effective
Aerobic treatment	SG	70–90 [20–50]	70–90 [7–22]	NA	< 25	Highly variable
	AG	[5–40]	[5–40]	0–35	10–15	[1–2]
Constructed wetlands	Up to 98 [5–10]	Up to 98 [10–20]	Up to 98	Up to 98	NA	
Subsurface infiltration systems	High	High	Limited	Removed	High	
Land application[b]	SRS	90–99 [1]	90–99 [1]	50–90 [3]	80–99	99.99
	RIS	[5]	[1]	[10]	[2]	90–99
	OFS	[5]	[5]	[3]	[5]	90–100

[a] Levels achieved = the concentration of the contaminant in wastewater after treatment.
[b] OFS, Overland Flow Systems; RIS, Rapid Infiltration System; SRS, Slow Rate System.

and participation programs leads to more acceptable decisions to all parties involved. Given that the capacity of the community to manage the selected technology was factored into the decision making process and that the appropriate technology was selected, the chances of system failure are minimal. An effective management program can reduce the potential risks to public health and the receiving environment during the installation, operation and maintenance phases of the decentralized wastewater treatment system. Throughout the installation phase it is crucial to choose the appropriate site and the proper design and construction. Periodic monitoring and strong regulatory enforcement are essential during the operational phase. Last but not least, during the maintenance phase systematic inspection is fundamental to detect any system that fails to function properly. Because impaired and failing systems are costly to a community, proper maintenance of a decentralized wastewater treatment system is essential. Similar to centralized wastewater systems, decentralized systems require effective operation and maintenance that should not be under estimated.

Centralized management of the decentralized wastewater treatment systems is essential to ensure they are inspected and maintained regularly. While rigorous management strategies are suitable for high-risk areas, simple homeowner awareness and education programs suit the non sensitive areas. An integrated risk assessment should be regularly conducted in order to manage and mitigate any emerging problem. Often, coordinating the centralized management of decentralized wastewater treatment systems with integrated river basin management as well as other entities enhances overall land use planning and development processes and ensures protection of public health and water resources. To succeed, a management strategy requires a delivery mechanism and resources to support change. The selection of a management organization primarily depends on local needs and preferences. It is very crucial to account for the needs, constraints and practices of local people in order to define problems, set priorities, select technologies and policies and monitor and evaluate impacts. Environmental issues do not always command a high priority in light of the severe social, political, and economic problems that face most developing countries. It is important that environmental policies are integrated with development planning and regarded as a part of the overall framework of economic and social planning. Even when laws are well drafted and jurisdictional mandates are clear, implementation problems arise primarily when environmental requirements target economically important activities particularly those owned by the government. Thus, institutional arrangements would be needed to implement these environmental control policies.

7. Issues of concern in developing countries

Often, the high cost of wastewater treatment and management is a major impediment towards implementing such projects. Governments in developing countries have more pressing needs than wastewater management such as dealing with war and conflicts, health care and food supply. Wastewater management is frequently low on the list of priorities. Many developing countries suffer from political interference in environmental decisions such as site selection and other aspects related to construction and operation. Even the most advanced technology should be supported by the appropriate institutions and enforced legislation to ensure maximum efficiency. The financial support of international organizations and developed countries is essential, yet it is imperative that local conditions are considered to make full use of any aid. Otherwise, there is no point of funding such projects. The adoption of inappropriate technology and failure to take into consideration the local conditions of the targeted community result in project failure that is often blamed on the lack of technical know-how and financial resources. Sometimes millions are spent on construction and a few dollars on gathering reliable design data. Replication of successful projects is beneficial but the system should be adjusted to the local conditions, especially climatic conditions. More often than not, the low-cost technology is chosen without any other consideration. Rural areas in developing countries cannot meet current and future sanitation requirements with just one funded project. A comprehensive and long-term strategy that requires extensive planning and implementation phases is vital for sustainable wastewater management.

Given the huge differences between developed and developing countries in political structures, national priorities, socio-economic conditions, cultural traits, and financial resources, adoption of developed country's strategies for wastewater management is neither appropriate nor viable for developing countries. Environmental planners and decision makers need appropriate legislation to support and facilitate the development of successful wastewater management plans for developing countries. Moreover, the institutional framework must allow adaptation of the plan to meet changing national, regional, and local priorities. Considering the limitations of external and domestic financial resources in developing countries, it will be necessary to develop new innovative financial schemes. Besides, public awareness relating to the extent of adverse health impacts as a result of improper sanitation is minimal in these countries. Therefore, environmental education as well as public awareness and participation primarily of resource users should be given high priority to achieve sustainability. Providing local people with access to resources, education and information necessary to influence environmental issues that affect them is a necessity.

8. Conclusions and recommendations

- Management strategies should be site specific accounting for social, cultural, environmental and economic conditions in the target area.
- The "Most Appropriate Technology" is the technology that is economically affordable, environmentally sustainable and socially acceptable.
- The community should be able to finance the implementation of the system, the operation and maintenance including the capital improvement needed in the future and the necessary long-term repairs and replacements.
- Understanding the receiving environment is crucial for technology selection and should be accomplished by conducting a comprehensive site evaluation process.
- Developing guidelines for the selection of small community wastewater treatment systems could facilitate decision making.
- Centralized management of the decentralized wastewater treatment systems is essential to ensure they are inspected and maintained regularly.
- Providing local people with access to resources, education and information necessary to influence environmental issues that affect them is a crucial step toward sustainable management of wastewater. Strengthening the knowledge base of environmental problems and solutions in developing countries, reflecting scientific thought and country empirical experience, is required.
- Training programs for municipality employees are essential for the proper operation and maintenance of equipment and facilities including monitoring of wastewater quality.
- While there are many impediments and challenges concerning wastewater management in developing countries, these can be overcome by suitable planning and policy implementation.

- Institutional strengthening and administrative reforms through reduced government involvement and bureaucratic control coupled with user participation should be instituted to enable the proper and sustainable management of wastewater.

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Bloomberg

India's Toilet Race Failing as Villages Don't Use Them

By Kartikay Mehrotra - Aug 4, 2014

Sunita's family in the north Indian village of Mukimpur were given their first toilet in February, one of millions being installed by the government to combat disease. She can't remember the last time anyone used it.

When nature calls, the 26-year-old single mother and her four children head toward the jungle next to their farm of red and pink roses, to a field of tall grass, flecked with petals, where the 7,000 people of her village go to defecate and exchange gossip.

Only dalits, the lowest Hindu caste, should be exposed to excrement in a closed space, "or city-dwellers who don't have space to go in the open," said Sunita, who uses one name, as she washed clothes next to the concrete latrine. "Feces don't belong under the same roof as where we eat and sleep."

Sunita's view reveals one of Prime Minister Narendra Modi's biggest challenges in combating the world's biggest sanitation problem, one that costs India 600,000 lives annually from diarrhea and exposes a third of the nation's women to the risk of rape or sexual assault. With no toilets for half the population, Modi promised to build 5.3 million latrines by the end of his first 100 days in office -- one a second until Aug. 31, according to the Ministry of Drinking Water and Sanitation. Without education, they'll make little difference.

Irrelevant Target

"Targets for construction of toilets are somewhat irrelevant to resolving the sanitation problem," said Yamini Aiyar, director of policy research group Accountability Initiative in New Delhi. "Building toilets does not mean that people will use them and there seems to be a host of cultural, social and caste-based reasons for that. People need to be taught the value of sanitation."

In most cases, that isn't happening. More than half of the country's sanitation education budget since 1999 hasn't been spent, according to the Ministry of Drinking Water & Sanitation. In at least five of India's poorest states, the majority of people in households with a government latrine don't use it, according to a survey of 3,200 rural households by the Research Institute for Compassionate Economics in the capital.

The government has set Mahatma Gandhi’s 150th birthday in 2019 as its target for achieving “total sanitation,” including access to toilets for all 1.2 billion residents, Finance Minister Arun Jaitley said in his budget speech on July 10. While Jaitley doubled spending on new toilets to 40 billion rupees, the ratio of those funds that can be spent on information, education and communication, remains at 15 percent.

Unused Funds

Of the 18.3 billion rupees set aside for that purpose in the past 15 years, only 45 percent has been used, partly because local authorities can’t get more funds until they prove how they spent the previous year’s money and partly because the central government often simply ran out of cash, said Avani Kapur, an analyst with New Delhi-based Centre for Policy Research.

“This often creates a vicious cycle as funds get released in the last quarter or even the last month of the financial year,” Kapur said. “Then it becomes difficult to spend all that money during the same financial year, resulting in a cut in funds the following year.”

While villagers remain ignorant of the dangers, about 100,000 tons of their excrement heads to markets every day on fruit and vegetables, according to Unicef, the United Nation’s children’s fund. Each gram of feces in an open field contains 10 million viruses, 1 million bacteria and 1,000 parasite cysts.

The excrement contaminates groundwater, causing illnesses such as diarrhea and cholera, and deters tourists whose immune systems are at the highest risk from the drug-resistant strains of fecal bacteria, according to the World Bank report.

Workers Shunned

About 800,000 Indians worked as feces removers in 2008, often carrying excrement in baskets on their heads, an occupation that causes them to be excluded from parts of society.

For women, heading to the fields alone raises the risk of assault, a danger that gained international attention in May when two girls from the village of Badaun in Uttar Pradesh were raped and hanged from a mango tree after they went to defecate outdoors.

“This vicious, horrifying attack illustrates too vividly the risks that girls and women take when they don’t have a safe, private place to relieve themselves,” said Barbara Frost, the London-based chief executive of WaterAid, a charity that helps poor communities get access to sanitation. “Ending open defecation is an urgent priority.”

India accounts for about 60 percent of the world's residents without toilets, according to a report released in May by the World Health Organization and Unicef. The country's 50 percent open defecation rate compares with 23 percent in Pakistan, 3 percent in Bangladesh and 1 percent in China, the report said.

Cultural Shift

"The problem has gotten worse with the government thinking this is a supply driven problem," said Archana Patkar, program manager at the Water Supply & Sanitation Collaborative Council in Geneva. "The problem is that germs are invisible, and so understanding the threat of open defecation is far removed from reality until they are sick and dying. And even then, they don't really understand."

India's previous government in 2012 created a five-year "Sanitation and Hygiene Advocacy and Communication Strategy Framework" to advise states on how to counter the culture of open defecation, including setting up local education committees.

Health Minister Harsh Vardhan said more needs to be done by government and private agencies to build national awareness of the dangers of poor sanitation.

Granddad's Latrine

"The fact that India's health administrators failed to spread mass awareness on diarrhea management speaks volumes of the inefficiency of previous programs," he said in a written statement on July 28.

India spent 2.6 billion rupees in fiscal 2013 on a campaign to help eradicate polio after 44 cases were reported between 2010 and 2011, according to the World Health Organization. In the same year, the nation spent half that amount on education for toilets and sanitation.

Some rural residents are constructing their own latrines. In Saunda, a village of about 6,000 people, 30 miles northeast of New Delhi, 70-year-old Hemraj Kumar sits on a cot near his new, 12,000-rupee, porcelain toilet.

"My son built it for me," he said, wearing a tattered white shirt, as cows tethered to trees defecated in the space between him and the concrete cubicle. "It's because I can't walk all the way out into the fields."

The rest of the family still prefer to head to the mustard field, including Hemraj's 20-year-old grandson Sonu, who's studying engineering in college.

’Clean’ Villages

Saunda is among 7,971 villages -- about 1 percent of India’s total -- labeled “clean” by the government in the year ended in March.

With little access to running water, government latrines typically consist of a large, concrete septic tank with a ceramic squat-toilet on top, enclosed by a cement or brick cubicle with a narrow door. The government says it has built 138 toilets in Mukimpur since February.

Sunita finds them disgusting.

“Locking us inside these booths with our own filth? I will never see how that is clean.” She points to the field. “Going out there is normal.”

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How to transform the practice of engineering to meet global health needs

Deb Niemeier *et al.*
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means to guide mHealth into this next era of maturity, with integrated solutions becoming the norm. WHO and other stakeholders will need to issue guidance to help prioritize and accelerate government mHealth adoption. Already, multiple efforts are under way to synthesize evidence, from WHO's mTERG to USAID's periodic Evidence Summits. In the future, these efforts could be guided by this framework to direct strategic investment toward key foundational layers of struggling health systems in an integrated manner. Our modified Tanahashi model facilitates a systematic approach toward constructing integrated mHealth strategies that together address multiple gaps in the pathway to UHC, improving performance in the quality, cost, and coverage necessary to provide care to all in need.

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PERSPECTIVE

How to transform the practice of engineering to meet global health needs

Deb Niemeier,[1] Harry Gombachika,[2] Rebecca Richards-Kortum[3]*

More of the world's population has access to cell phones than to basic sanitation facilities, a gap that can only be closed if the engineering and international aid communities adopt new approaches to design for scarcity and scalability.

Engineers have known how to produce safe drinking water and how to build toilets and roads in developing countries for more than 100 years. Yet, global access to such technologies is far from uniform. Approximately 768 million people do not have access to safe drinking water; 2.5 billion lack basic sanitation, and 1 billion practice open defecation (*1*). More than 50% of people who have no access to water and sanitation live in middle-income countries (*1*). Use of these technologies can mean the difference between life and death; diarrheal illness, 90% of which is related to inadequate access to clean water and sanitation, kills more children under 5 than AIDS, malaria, and measles combined (*2*).

Why is it so difficult to translate technologies that have improved public health in wealthy countries into solutions that equitably improve lives around the world? It is primarily because these solutions were developed to satisfy constraints of high-resource settings. In many cases, they cannot be easily adapted to work in low-resource settings; they are too expensive or rely on infrastructure or expertise that does not exist. For example, a recent survey of anesthetists in Uganda reported that only 20% had a constant supply of electricity for the equipment necessary for basic surgery (*3*). Between 2005 and 2011, the President's Emergency Plan for AIDS Relief (PEPFAR) invested over $1 billion to strengthen clinical laboratories to improve HIV/AIDS care, primarily in sub-Saharan Africa (*4*); yet maintenance and repair of the necessary laboratory equipment, designed for high-resource settings, is a continued challenge across PEPFAR countries (*4*), where intermittent power can render equipment unusable, and there is limited in-house technical support to repair medical equipment (*5*). If we are to resolve global inequities in access to innovations that improve health, we must adopt new approaches to engineering design that reflect the unique needs and constraints of low-resource settings.

Design for scarcity

Engineers design new technologies to meet societal needs in the face of economic constraints; in contrast, frugal design—designing through the lens of scarcity—begins first with the assumption that material and human infrastructure are limited and not systematically integrated. These resource and infrastructure limitations dictate the constraints that frugal designs must satisfy but may also lead to reuse or repurposing of available commodities in ways that are not anticipated. For example, early efforts to scale up provision of injectable vaccines in low-resource settings led to a wave of unsafe injections, where disposable syringes were reused. It has been estimated that as many as 30% of injections in low-resource settings are unsafe because of reuse of syringes (*6*); this practice continued despite efforts to educate practitioners about the dangers of reusing disposable syringes. A "cultural resistance to waste" drove continued reuse of syringes, "regardless of training, advocacy, and regulatory factors" (*7*).

Next, it's important to engage users early. Projects pursued from the perspective of adapting high-resource design principles to low-resource settings without firm evidence of user need beg the question of adoption and can lead to one-off projects that are scaled on the basis of donor priority without evidence that they improve outcomes. For example, the nongovernmental organization (NGO) PlayPumps (Fig. 1) was initially heralded for its ability to use children's play on a merry-go-round to provide a much-needed community service: pumping of water to a community storage tank. With relatively little target community feedback, the U.S. government and other donors committed $16 million to scale up the implementation, and PEPFAR announced a plan to raise an additional $44 million. However, it quickly became apparent to users that, not only were the spare parts and technical expertise required to fix the PlayPump difficult to find, but also that the 27 hours of playtime needed to meet the required minimum daily water requirement was simply infeasible (*8*). In the end, the community users preferred the efficiency and reliability of traditional hand pumps.

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Finally, there are numerous design trade-offs to be made in developing and scaling frugal technologies; rigorous experimentation is required to understand which features are most important to support positive impact at scale. For example, the rapid growth in global access to cell phones provides an opportunity to use mobile phone technology to improve health in low-resource settings. Yet, despite more than 500 pilot studies of mobile technologies for health (mHealth), there is still not sufficient programmatic evidence to inform scale-up (*9*). In most pilot studies, investigators treat the mHealth application as a "black box" and examine the effects of using or not using the intervention. As a result, there are no data to indicate which individual mHealth features might be most effective. There is an important need for multifactorial pilot study designs that identify and empirically test a range of features that might contribute to variation for a particular application (*9*).

Design for scalability

Although successful frugal design begins with constraints that are dictated by scarcity, it must also integrate this perspective with a systems-level approach centered on how new designs can be successfully implemented, scaled, and sustained. The frugal design cycle begins with a user-centric focus that accounts for the available infrastructure and economic resources. Scale-up requires evidence of efficacy at the community and national levels. Whereas aid from the international community can help jump-start efforts to scale up a project or program, business development and private sector partnerships are required to sustain implementation. Ensuring long-term access to new health technologies requires a coordinated architecture that integrates efforts to make new technologies affordable, makes certain the technologies are available where they are needed, and facilitates adoption of the technologies within health systems (*10*).

Developing a compelling value proposition requires both data to support the health benefit of a new technology and identification of a paying customer—a significant challenge within the context of the world's poorest health systems. Yet, there are examples of success. Unsafe injection practices have been dramatically reduced by developing new injection technologies that cannot be reused. One example is Uniject, a blister pack prefilled with the proper dose of vaccine and connected to a needle via a one-way valve that prevents the device from being refilled and reused (*11*). By eliminating the need to properly fill a syringe, Uniject simplifies injection practices for users like midwives and community health workers in rural communities. Tests of the device to deliver the hepatitis B vaccine to newborns in Indonesia showed that use of a prefilled device simplified logistics of vaccine delivery immediately after birth by midwives, reduced vaccine wastage, and was preferred by midwives and mothers (*6*).

The role of the international and business communities was central to the development and scale-up of Uniject. Indeed, the technology was developed in response to a 1987 meeting convened by the World Health Organization (WHO) to highlight the challenges of unsafe injection practices. With support from the U.S. Agency for International Development (USAID), the NGO PATH worked to improve technology originally developed by Merck. Merck transferred its intellectual property rights to PATH, which licensed the technology to Horizon Medical and went into pilot production of the Uniject device. On the basis of the positive results of early implementation trials, the Uniject technology was licensed to Becton Dickinson & Company (BD) in 1996 (*11*). BD invested $25 million to establish a dedicated manufacturing line for empty Uniject packages in Singapore and $10 million to launch the product on the global market; today, vaccine manufacturers buy empty Uniject containers and prefill them for global distribution (*11*). Since 2000, millions of doses of hepatitis B and tetanus vaccines have been delivered with Uniject, and efforts are under way to use Uniject to expand access to injectable contraceptives in low-resource settings (*12*). Through a partnership with Biodel, Uniject is now being developed for emergency delivery of liquid glucagon to treat severe hypoglycemia, where a simple, portable solution is of particular importance for first responders or parents of children with diabetes.

> ***"If we are to resolve global inequities in access to innovations that improve health, we must adopt new approaches to engineering design that reflect the unique needs and constraints of low-resource settings."***

Yet, the technology still faces the challenge of articulating an effective value proposition for purchasers in health systems, who are often evaluated on the basis of their ability to maximize the number of lots of vaccine they can purchase with a fixed sum. The incremental cost to deliver prefilled vaccine in Uniject packaging is approximately $0.06 higher per immunized child than with disposable syringes (*11*). Although Uniject packaging is more costly than disposable syringes, its use for newborn hepatitis B vaccination saves money when one takes into account reductions in vaccine wastage and costs of home visits. Nonetheless, critical gatekeepers often resist suggestions to purchase Uniject because of higher initial costs (*11*).

Template for success

Design simple solutions

Sometimes inexpensive, nontechnical solutions are best. Roughly 1.3 million people die annually in road traffic accidents, 90% of whom live in low- and middle-income countries. The number of deaths due to road traffic accidents is anticipated to double by 2030, rising to the third leading cause of global mortality; most of this increase will occur in low- and middle-income countries, where the number of motor vehicles is projected to increase sixfold without improvements in road infrastructure or traffic safety (*2*). Modifying driver behavior is an inexpensive alternative to building better road systems. For example, in an experiment aimed at examining the influence of social pressure on driver safety in Kenyan minibuses, signs were posted in half of a fleet of vans encouraging passengers to collectively speak out about unsafe driving practices (*13*). When compared with the control group, passengers riding in vans with signs filed about one-third as many insurance claims, and injury and fatality claims dropped nearly 50%. Behavior as a frugal design solution is low cost and easily adapted to different contexts, which makes it highly scalable.

Don't overlook traditional solutions

Investments to eradicate malaria have resulted in dramatic reductions in mortality, as much as 42% globally since 2000, with child mortality rates in Africa dropping by nearly 54% during the same time period (*14*). But with this has come increasing resistance to antimalarial medicines and heavily used insecticides such as pyrethoids. With the likelihood that new drugs are still many years out, environmental management could emerge as a key means of vector control. In the early 20th century, engineers worked with malaria control personnel to manage the mosquito population through environmental design features, many of which still show efficacy. For example, mosquito-proofing houses and better water management and irrigation methods have been highly successful at helping to reduce the incidence of malaria (*15*). This low-cost approach to governance, combining simple water resource management together with public education, can be successfully applied globally. In places like California, outreach is now emphasizing environmental controls: the elimination of standing water and using biological control measures (e.g., mosquito larvae–consuming fish) (*16*).

Think long-term, while solving short-term

Point-of-use water treatment with chlorine is widely considered one of the most effective strategies for providing safe drinking water in water-scarce settings (*17*). As much as a 29% reduction in diarrheal illness in children was seen with point-of-use chlorine treatment compared with traditional disinfection methods, a protective effect that was nearly universal across populations and conditions in short-term trials. But with rapidly increasing urbanization, it might be more efficient to begin to extend design innovation to technologies that increase the production of potable water through reuse, which would also help to address water scarcity. In Windhoek, Namibia, highly treated reclaimed water has been combined with potable water directly in the water distribution system since the late 1960s (*18*). The reclaimed water meets all drinking water standards, which makes it a viable option under both financial and water provision terms.

Engage students in frugal design

Students must be educated to become successful practitioners of frugal design from a systems perspective (*19*). Curricular reforms are even more crucial in low-resource settings where a lack of engineering capacity and infrastructure severely limits economic development (*20*) and where knowledge of contextual constraints is paramount to the success of frugal designs. Sub-Saharan Africa suffers a chronic lack of indigenous engineering capacity: In the early 2000s, the number of engineers emigrating annually from South Africa matched the number of engineers graduating (*21*). Where available, tertiary education in engineering has not received anywhere near the investment required to keep pace with the developed world. Learning foci are too theoretical, based on outdated curricula, and not relevant to local needs. The teaching and learning approaches that emphasize rote memorization stunt students' potential to be innovative. Faculty lack resources for providing lab experiences and salaries are often so low that many take on additional jobs. Students who graduate from such programs face notable levels of unemployment, most likely because they graduate without needed skills and experience to be employable. Over $130 million has been invested to strengthen medical school education through the Medical Education Partnership Initiative by the U.S. National Institutes of Health, with a focus on developing human capacity, retaining faculty and graduates, and developing regionally relevant research programs (*4*); similar investments are critical if tertiary engineering education is to develop sufficient and relevant engineering capacity in the region. To fully leverage such investments, preuniversity science and math education must also be strengthened.

Design for context

Sustained implementation of a new frugal technology that performs well compared with technologies designed for higher-resource settings requires successful navigation of a number of contextual and political challenges. The explosive global growth in the availability of mobile phone technology illustrates the kind of success that is possible when the value proposition of a new technology is clear at all levels—users were willing to pay for inexpensive handsets and airtime; communities where electricity was not widely available established charging banks; and countries and the private sector invested in both the necessary private and public infrastructure to establish a network of base stations, powered by diesel generators where reliable electricity was not available (*22*). Today, 6 billion of the world's 7 billion people have access to a mobile phone, whereas only 4.5 billion have access to a latrine or toilet (*23*).

Why do more people have access to mobile phones than toilets? In part, it is more difficult to overcome the implementation challenges for technologies that require substantial investment in public infrastructure. The infrastructure to provide clean water and sanitation in developed countries requires robust vertical governance, from national to local levels. In most low-resource settings, local governments have insufficient capital to build community-level infrastructure and even less human capital for long-term maintenance. Resource constraints exist in every setting, but the nature and type of constraints in developing countries requires rethinking traditional processes. For example, the traditional design cycle for public infrastructure projects may require adjustment. Civil engineers are currently trained to optimize a design, then bid the project and accept the low bid. An alternative approach where the design engineer and end-user participate directly in a design process with feedback that is aimed at lowering the end-user costs could help designers maintain perspective about context and yield innovation that is more frugal in nature.

Adoption is facilitated when end-users see a direct personal benefit associated with purchase of a new technology. Access to mobile phones increased profits for fishermen in India and market participation for farmers in Uganda (*22*). In contrast, the benefits of health or sanitation technologies may not be as apparent to end-users. The public sector, which is usually charged with promoting such technologies, is not good at market research.

Finally, adoption is facilitated in competitive markets that can drive down the price of technology services; market liberalization was associated with a 90% drop in average mobile phone call prices and an increase in traffic volumes (*22*). In the global health care industry, two recent trends may help to accelerate the implementation of promising technologies. First, rapidly expanding health care markets in emerging economies are drawing the interest of multinational corporations (*3*). Inflation-adjusted biomedical research and development expenditures increased in India and China by 6.7% and 32.8% per year, respectively, from 2007 to 2012; in contrast, expenditures in the United States, Canada, and Europe decreased over the same period (*24*). Likewise, an increase in accountable care organizations may drive investment in resource-saving technologies in the United States.

Fig. 1. Meeting the need. Approximately 768 million people do not have access to safe drinking water; new engineering approaches are needed to develop point-of-use technologies that meet the needs of community users and can be sustained over time. Efforts by aid organizations to scale the PlayPump (shown) failed because community users preferred the efficiency and reliability of traditional hand pumps. [Photo credit: German Chauluka]

Conclusion

We are not the first to suggest a transition to frugal design—a number of recent "grand challenges" design efforts have engaged the technology development community in frugal design efforts. Efforts like The Gates Foundation's Reinvent the Toilet Challenge reflect the kind of integrative thinking that must occur at the beginning of a design initiative; support is being directed toward strategies to create a next-generation toilet that can not only manage waste but also harvest water and energy resources. The toilet will also need to operate without the usual infrastructure, be financially sustainable, and be valued by users. Although such competitions highlight important challenges, funders often solicit solutions with a high degree of technical innovation. An unintended consequence of this premium on innovation can be to complicate downstream implementation efforts. It is time for the engineering and international aid communities to adopt approaches that can improve global health in ways that can be sustained.

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PERSPECTIVE

Strengthening the evidence base for health programming in humanitarian crises

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Given the growing scale and complexity of responses to humanitarian crises, it is important to develop a stronger evidence base for health interventions in such contexts. Humanitarian crises present unique challenges to rigorous and effective research, but there are substantial opportunities for scientific advance. Studies need to focus where the translation of evidence from noncrisis scenarios is not viable and on ethical ways of determining what happens in the absence of an intervention. Robust methodologies suited to crisis settings have to be developed and used to assess interventions with potential for delivery at scale. Strengthening research capacity in the low- to middle-income countries that are vulnerable to crises is also crucial.

Health interventions in humanitarian crises—situations where disasters or conflicts constitute a critical threat to the health, safety, security, or well-being of a population—are an important focus within the broader field of global health. Such crises affect increasingly large numbers of people worldwide (*1*). There have been notable advances in programming, specifically in immunization and treatment of acute malnutrition, over the past 20 years. However, despite the increasing professionalization and standardization of humanitarian work (*2*), there is a consensus that the evidence base for much current practice remains weak (*3*, *4*).

It is not coincidental that the evidence base for health programming is frail in crisis conditions that cause high mortality and morbidity. Such health care contexts also present many challenges to scientifically rigorous research. Prime among these challenges is the acute vulnerability of populations (*5*), which requires prompt intervention rather than exploration of the comparative benefits and limitations of alternative approaches. In the face of acute needs and against a typical backdrop of limited funding, poor security, and shortages in human resources and logistics, simply providing immediate minimal standards of health services becomes an overriding concern. The space for research—particularly that involving experimental interventions or randomization or, more generally, offering different standards of care within the same population—dramatically shrinks (*6*, *7*). Acutely vulnerable populations have a compromised capacity to give meaningful informed consent. Refusing study participation may be seen as rejecting vital medical assistance (*8*, *9*).

The rapid response required in humanitarian crises contributes to an unpredictable programming environment. Although many health risks in the aftermath of disasters or conflict are predictable and minimum standards for response and best-practice interventions have already been established, health needs can evolve rapidly, and adaptable program strategies are required. Political sensitivities and security concerns may also have a substantial influence on the timing, coverage, and delivery of health interventions (*10*). Different sectorial interventions that affect health (including provision of shelter, water and sanitation, food security, livelihoods, nutrition, and vaccination) may be introduced with limited coordination and varying population coverage (*11*). This makes identification of comparison or control groups and attribution of outcomes to any single intervention methodologically challenging.

Difficulties in coordination are not only cross-sectoral but also reflect the more general complexity of multiple intervening actors and initiatives that characterize humanitarian responses. A population will typically receive services through a complex web of national and local governmental institutions, local civil society partners, United Nations agencies, nongovernmental organizations, and, in some emergencies, foreign

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COVER STORY

In many low- and middle-income countries faecal sludge is untreated and if collected, disposed of directly into the environment. Credit: Linda Strande.

Faecal waste: the next sanitation challenge

● The management of faecal sludge from onsite sanitation systems in many areas of the world has yet to be properly addressed, with subsequent impacts on human health and the environment. **LINDA STRANDE**, an editor and author of the new IWA Publishing book 'Faecal Sludge Management – Systems Approach to Implementation and Operation', explains how the importance of faecal sludge management is finally being acknowledged, introduces some of the unique challenges of working in the field, and looks at the steps required for sanitation to move forward.

The sanitation needs of 2.7 billion people worldwide are served by onsite sanitation technologies, one billion of these living in urban areas across Africa, Asia and Latin America. This total is expected to grow to five billion by 2030. In many cities, onsite technologies have much wider coverage than sewer systems. For example, in Sub-Saharan Africa, 65-100% of sanitation access in urban areas is provided through onsite technologies. However, in low- and middle-income countries there is typically no management system in place for the resulting faecal sludge (FS). Faecal sludge management (FSM) is therefore essential to the future development of global sanitation.

FS comes from onsite sanitation technologies and has not been transported through a sewer. It is raw or partially digested, a slurry or semi-solid, and results from the collection, storage or treatment of combinations of excreta and blackwater, with or without greywater. Examples of onsite technologies include pit latrines, unsewered public ablution blocks, septic tanks, aqua privies and dry toilets. FSM includes the storage, collection, transport, treatment and safe end use or disposal of FS. FS is highly variable in consistency, quantity, and concentration. Without an FSM structure in place, when onsite systems become full, the untreated FS typically ends up directly in the local environment. This results in the pervasive contamination of the environment with pathogens and does not provide a protective barrier to human contact and hence protection of public health. For example, in Dakar, Senegal only 25% of FS that accumulates in onsite facilities is being collected and transported to FS treatment plants. Frequently occurring problems in the service chain that prevent FS from being transported to designated treatment facilities for treatment and safe end use or disposal include: households not being able to afford professional emptying services; collection and transport trucks not being able to access narrow lanes and paths leading to houses; operators not able to afford the transport of FS over large distances to treatment facilities; and the lack of legitimate FS discharge locations or treatment facilities.

Manual emptying of cess pit in Dakar, Senegal. Credit: Linda Strande.

Looking beyond the household level

Progress towards the Millennium Development Goals (MDGs) has been successful in increasing access to improved sanitation facilities. However, providing adequate access to sanitation facilities does not end when onsite technologies are built – it is imperative to also take a longer-term focus which moves beyond the household level. A lack of funding for comprehensive FSM has resulted in the current sludge management crisis.

Onsite technologies can be a viable option, but only if the entire service chain, including collection, transport, treatment and safe end use or disposal, is managed adequately. Thinking within the wastewater industry worldwide has started to shift, with onsite or decentralised technologies being considered long-term viable options and possibly the more sustainable alternative compared to sewer-based systems, which are prohibitively expensive and resource intensive. In urban areas it has been demonstrated that the cost of FSM can be five times less expensive than conventional sewer-based solutions (Dodane et al., 2012). In addition, sewer systems and FSM can be complementary, and frequently do exist side-by-side in low-income countries. A very successful example of this management model is in urban areas of Japan where the systems successfully co-exist, which allows for the onsite treatment and reclamation of wastewater in large buildings (Gaulke, 2006). The Japanese model is a success due to the strong enabling environment that includes regulation, enforcement and subsidies.

Inhibitors to sustainable development

The following bottlenecks at the crossroads of technology, management and planning are currently inhibiting the sustainable development of FSM systems:

- Acknowledging the importance of FSM: this includes governments taking responsibility, donor agencies providing funding and large intergovernmental organizations promoting FSM.
- Instituting frameworks and responsibilities: responsibilities should be streamlined with one entity of a city government taking on the responsibility and this can eliminate overlap or gaps in stakeholders roles.
- Increasing knowledge dissemination and capacity development: there is a lack of affordable and accessible reference materials; developing methods that increase local expertise is imperative.
- Creating sustainable business models and fee structures: different business models than the traditional municipality-driven for sanitation services need to be considered to reduce the financial burden at the household level.
- Implementing integrated planning methodologies: this is required for city-wide FSM systems that can address rapid growth rates, the heterogeneity of income level, sanitation technologies, and formal and informal settlements, and weak enabling environments.
- Developing appropriate technologies: key research areas include: characterization and quantification, collection and transport, semi-centralized treatment technologies, onsite treatment technologies and resource recovery.

Systems approach to faecal sludge management

The solution to overcoming these problems requires a systems-level approach that addresses every step in the service chain and integrates technology, management and planning. From a technical perspective the first step in designing FSM systems is determining the final end use or disposal option of sludge and liquid streams, so systems can be designed to achieve the appropriate level of treatment for the desired end use. Resource recovery from treatment products should be a treatment goal whenever possible, but the number one goal is obviously the protection of public health. Once the final end use or disposal options are selected the treatment technologies that achieve the treatment objectives can then be chosen or designed. Similar to designations for Class A and Class B biosolids, FS is treated for levels of pathogen reduction that makes it appropriate for different end uses. For example, pathogen reduction and sludge dryness requirements are different for compost used on food crops versus as an industrial combustion fuel. These decisions are context specific, based on local regulations and market demand for end products. This approach is important to ensure that effluents and end products achieve adequate and appropriate levels of treatment, systems are not over-designed wasting financial resources, and that systems are not under-designed risking public and environmental health.

Effective management will help to ensure the long-term success of FSM technologies, including institutionalisation, technical capacity, legal frameworks and cost recovery mechanisms. Even if environmental regulations are in place, they require adequate enforcement for them to be adhered to. Financial structures that can sustain the system ensure financial viability, including appropriate financial incentives and sanctions. Methods to ensure running costs and financial transfers are covered throughout the entire service chain are required for the system to function. Examples are management concerns being incorporated into technology decisions, such as locally available or reparable pumps being selected, or resource recovery from treatment products being an incentive to operate the treatment plant effectively.

An integrated planning approach helps to ensure vested participation and management, without which technologies in low-income countries tend to fail. Planning starts with the first phase of designing a system, but is necessary to ensure a continuum of success throughout the life of a project. Planning is essential to engage key stakeholders, including public authorities, entrepreneurial collection, transport and treatment service providers, and the serviced communities. Stakeholder engagement will help to ensure a long-term investment in the success of the system and continued feedback on future improved solutions. Planning covers organisational, institutional, financial, legal and technical aspects of the entire service chain, and is necessary to coordinate and ensure varied and complex levels of service among stakeholders with diverse interests. These interests need to be matched with an appropriate institutional framework, financial mechanisms and capacity. Planning can prevent failures, such as locating a FS treatment plant on the outskirts of a

Discharge of faecal sludge into the environment in Yaounde, Cameroon. Credit: Linda Strande.

Collection of dried sludge for reuse as fertilizer in Kampala, Uganda. Credit: Linda Strande.

city where land is available and relatively inexpensive, but which means that haulage time and distance for transport is prohibitive, ultimately resulting in direct dumping of FS to the environment and the treatment plant being unused.

The way forward

Bottlenecks at the crossroads of technology, management and planning that are currently inhibiting the sustainable development of FSM systems are listed in the accompanying box. Creativity will be key to developing innovative solutions for technology, management and planning that are globally transferable. Research in FSM is currently undergoing rapid developments, and examples of current research are included in the recently released book Faecal Sludge Management (see box).

Three projects that Sandec, the Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute of Aquatic Science and Technology (Eawag), is currently working on include PURR (Partnership for Urban Resource Recovery), FAQ (Faecal Sludge Quantification and Characterization) and FaME (Faecal Management Enterprises). The goal of the PURR project is to identify effective co-management strategies for FS and wastewater sludge in urban areas in Vietnam and to train local stakeholders on methodologies for monitoring. The goal of the FAQ project is to develop a methodology to accurately quantify and characterize FS at a city-wide scale and is currently being field-tested in Hanoi and Kampala. The goal of the FaME project is to identify innovative end uses for FS, and to equip stakeholders with the capacity to sustainably implement and operate these. Conducted in Senegal, Ghana and Uganda, results from this research show that the energy content of FS is comparable to other biofuels (Murray Muspratt et al., 2014), combustion of FS in industrial kilns may create more revenue than use as a soil conditioner, and a model of financial flows throughout the service chain can be used to identify obstructions and policy requirements (Diener et al, in press). For more information about this research, FSM, and on the FSM book visit www.sandec.ch.

Developing solutions for FSM can close a 100-year gap in knowledge in comparison to wastewater management, and will lead to safer sanitation for billions of people around the world.●

Upcoming conference

3rd International Faecal Sludge Management Conference

Taking place 18-22 January 2015 in Hanoi, Vietnam, FSM3 will bring together world-class research and science and donors, cities, utilities, investors, consultants, governments, service providers, and industries, with the aim of fostering an effective dialogue on solving the problem of dealing with human waste and identifying replicable solutions working at scale.

Themes that will be discussed at the conference include: the enabling environment for FSM; ensuring city-wide FSM service delivery; FSM as a business; FS desludging and transportation; sustaining FSM services; innovation in FS treatment; maximizing resource recovery; health and environmental risks of faecal sludge management; and socio-cultural aspects of onsite sanitation.

For more information, visit: **www.fsm3.org**.

Note

[1] Target 7C – reducing by half the number of people without access to 'improved' sanitation. Improved is defined as systems that hygienically separate human excreta from human contact, and includes; flush toilets, connection to a piped sewer system, connection to a septic system, flush / pour-flush to a pit latrine, ventilated improved pit (VIP) latrine, and composting toilet.

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