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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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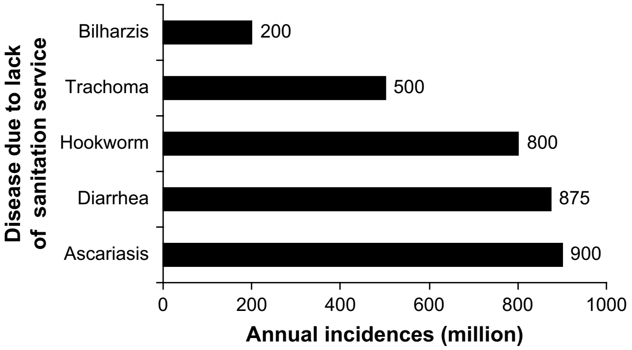

Fig. 1. The ranking of annual incidences of certain diseases due to the lack of sanitation (Wright, 1997).

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,

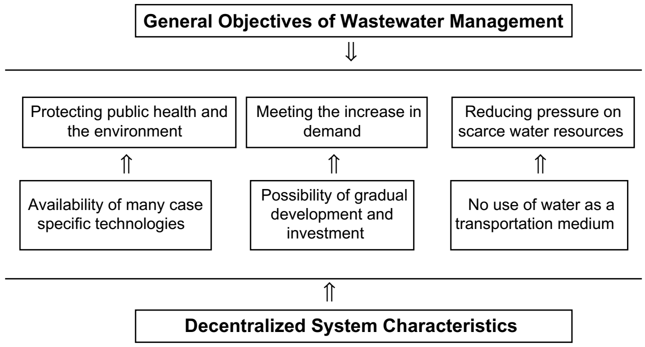

Fig. 2. General objectives of wastewater management versus decentralized systems characteristics.

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.

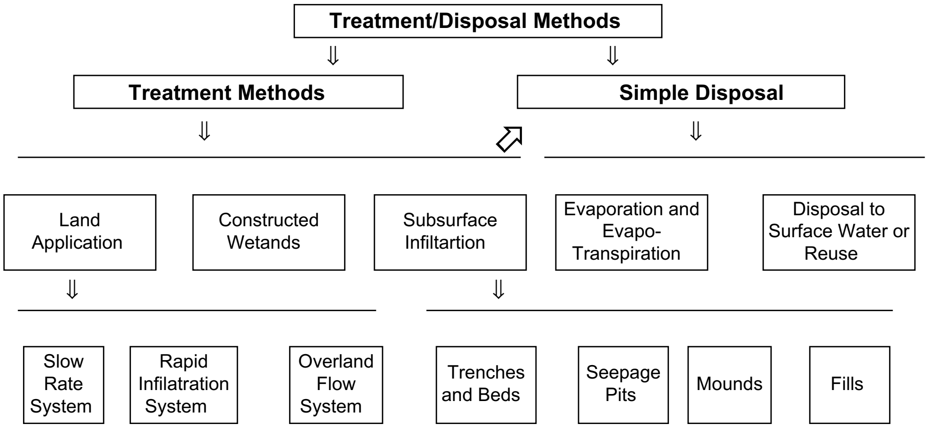

Fig. 3. Major treatment/disposal methods.

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,

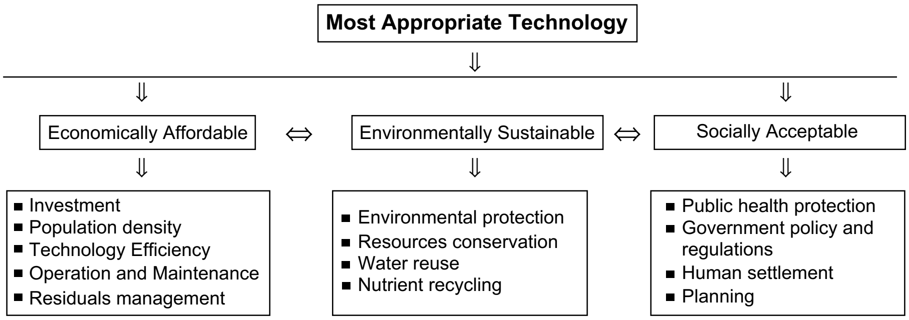

Fig. 4. Characteristics of the Most Appropriate Technology.

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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