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Effectiveness of wastewater management in rural areas of developing countries: a case of Al-Chouf Caza in Lebanon

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Abstract Alike many developing countries, Lebanon lacks a national wastewater management strategy that can effectively protect public health and environmental quality. This has led the local communities and municipalities to plan and implement their own arrangements for wastewater treatment systems. However, most municipalities still lack the human and financial resources, management capabilities, and environmental awareness necessary to implement wastewater management in an environmentally sound manner. As such, the effectiveness of these systems, particularly with regard to the quality of the treated effluent, warrants evaluation. Accordingly, a performance evaluation of the treatment/disposal systems, taking three villages in Al-Chouf Caza in Lebanon as a case study, was carried out. The conducted field work, visual assessment, and laboratory analyses of effluent discharges revealed that the existing systems for wastewater treatment in the three villages are either not properly functioning or operational but ineffective and, consequently, hardly achieve any treatment higher than primary. Although developing countries are being encouraged to implement wastewater treatment systems with the promise of financial aid from developed nations, it is important that local conditions are considered carefully to make full use of any aid. It is very crucial to take into account the economic status of the community and the municipality in question. There is no point in adopting the most advanced technology for wastewater treatment if there is no mechanism to ensure maximum efficiency.

Keywords Wastewater · Rural areas · Management · Effectiveness · Developing countries · Lebanon

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Introduction

Hot climate, uneven rainfall distribution, and increasing drought periods in addition to population increase and consequent overutilization of fresh water resources led to global water shortage, with the Middle East and North Africa being the driest regions (World Bank 1996; Bakir 2001). The efficient allocation of resources and finding alternative resources of water are two main challenges that face the decision makers and planners of the region. Sewage disposal has long been and still remains a major factor in the deterioration of surface water bodies (Massoud et al. 2003). Therefore, a comprehensive strategy needs to be developed for cost-effective treatment of municipal wastewater in order to meet surface water discharge standards. Moreover, the treated effluent could be considered a substitute or a supplementary resource for freshwater in irrigation (Oron et al. 1999; Bazza 2003).

In Lebanon, water quality monitoring studies regularly identify that the organic and microbial pollutants are the major contaminants of surface water bodies (El-Fadel and Massoud 2001; Jurdi et al. 2002; Massoud et al. 2006a, b). The discharge of raw domestic wastewater is the major contributor of these pollutants. Almost all rural communities in Lebanon lack adequate sanitation services that can protect public health and environmental quality. While numerous projects are underway to construct wastewater treatment plants, up till now, there are practically no operational wastewater treatment plants (SOER/MOE 2000). The general trend for wastewater management in urban areas along the seashores where the majority of the population resides has been limited to a deteriorated wastewater collection system that typically discharges into the sea. In other urban and rural areas, septic systems are commonly used. Untreated wastewater is directly dumped into rivers, irrigation channels, and valleys, creating a severe risk for public health and the environment. From an institutional point of view, various bodies are responsible for the wastewater sector. Their responsibilities are intermingled and not well defined. Legally, no one comprehensive environmental law exists in the country; instead, specific issues are addressed separately.

Absence or delay in implementing a nationwide effective wastewater management strategy in Lebanon has led the local communities and municipalities to plan and implement their own arrangements for decentralized wastewater treatment systems. However, most municipalities still lack the human and financial resources, management capabilities, and environmental awareness necessary to implement wastewater management in an environmentally sound manner. As such, the effectiveness of these treatment systems, particularly with regard to the quality of the treated effluent, warrants evaluation. Accordingly, this research study was conducted taking three villages in Al-Chouf Caza (district) in Lebanon as a case study. The specific objectives of the study include:

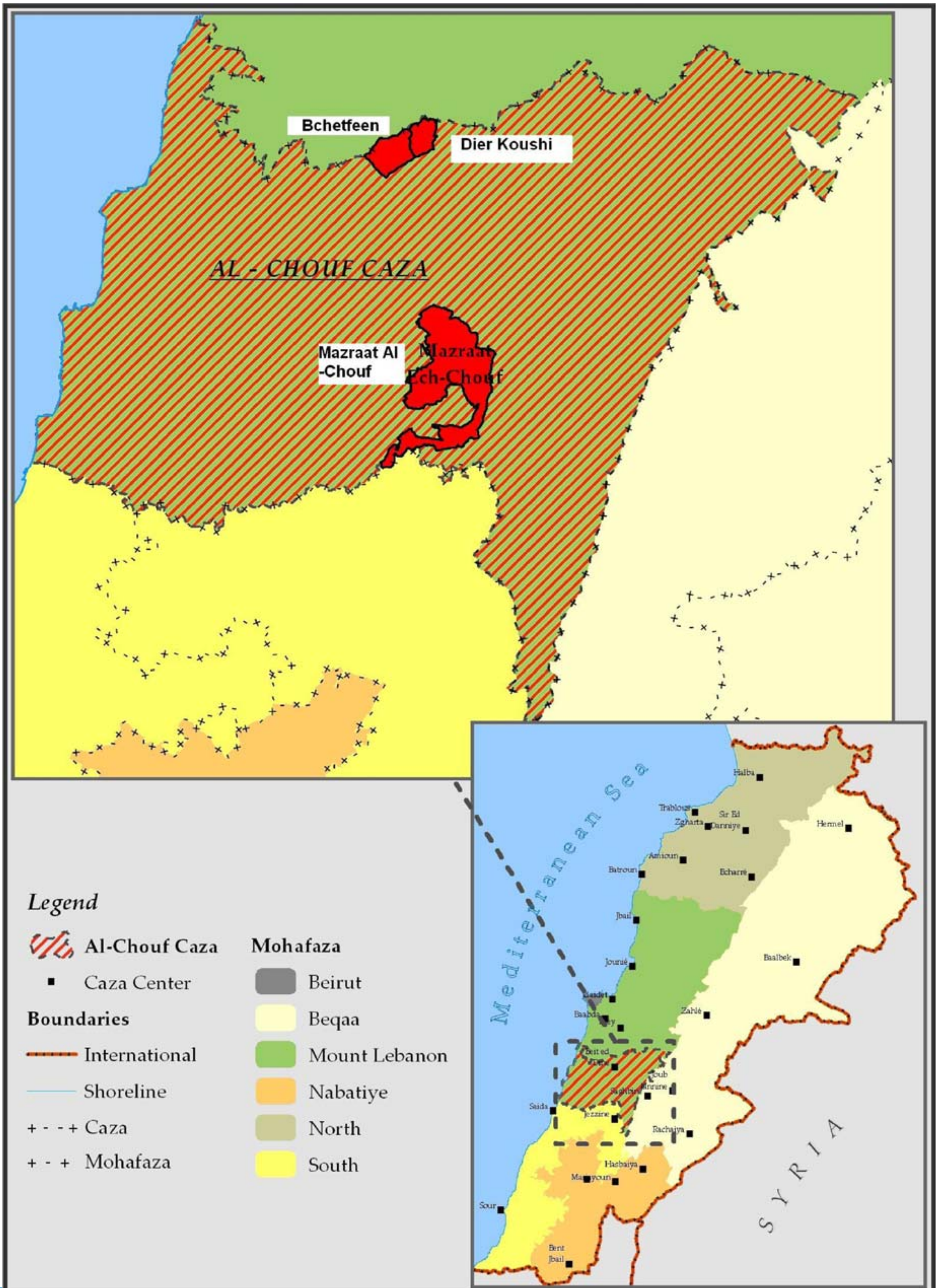
- Performance evaluation of the treatment/disposal systems, taking wastewater quality, receiving environment characteristic (site conditions affecting septic suitability, proximity to surface water bodies, population density, and land use patterns), and cost effectiveness and affordability issues into consideration
- Assessment of the existing administrative framework, as well as laws and regulations pertaining to domestic wastewater discharge limits and treatment requirements
- Assessment of the public health and environmental risks as a result of the existing sanitation services

Description of the study area

Al-Chouf Caza is located in Mount Lebanon Governorate with an estimated area of about 464 million square meters. It is characterized by a Mediterranean climate with a moderately warm dry summer and autumn and moderately cold, windy, and wet winters with almost 80% to 90% of total precipitation occurring between November and March. Scattered rainfall events begin to occur in October. Three villages in Al-Chouf Caza (Fig. 1) employing three different wastewater treatment systems were chosen. A form of secondary wastewater treatment (activated sludge) plant with a design population of 3,500 people is employed in the first village, Bchetfeen. The plant was designed to accommodate wastewater with a biochemical oxygen demand (BOD) load up to 240 mg/l and reduce it to about 30 mg/l. The treated effluent is discharged into a nearby river.

In the second village, Mazraat Al-Chouf, the treatment plant comprises three successive ponds. The ponds are excavations in the ground with no waterproof liners to prevent leaching into groundwater. The raw sewage enters the first pond and

Fig. 1 A GIS map of the study area ▶


Bchetfeen
Dier Koushi
AL - CHOUF CAZA
Mazraat Al -Chouf
Mazraat Ech-Chouf
Legend
Al-Chouf Caza
Caza Center
Boundaries
International
Shoreline
Caza
Mohafaza
Mohafaza
Beirut
Beqaa
Mount Lebanon
Nabatiye
North
South
Mediterranean Sea
SYRIA
Halba
Trablous
Zgharta
Sir Ed Danniye
Hermel
Amioun
Batroun
Bcharré
Jbail
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Baalbek
Zahlé
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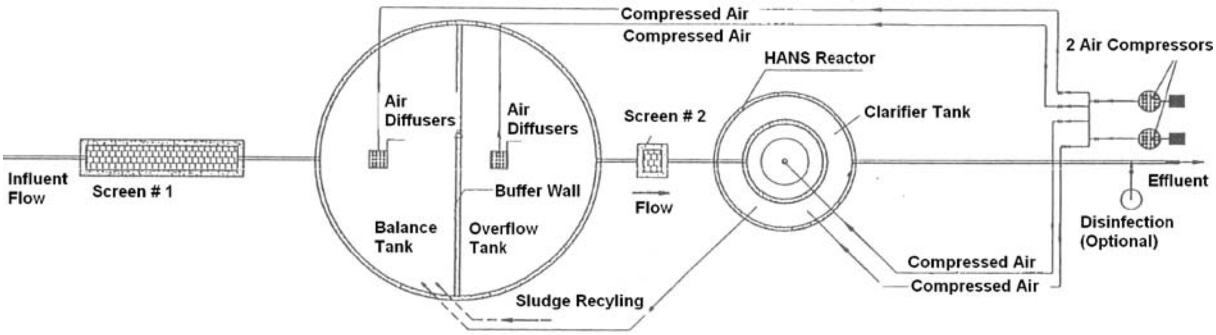
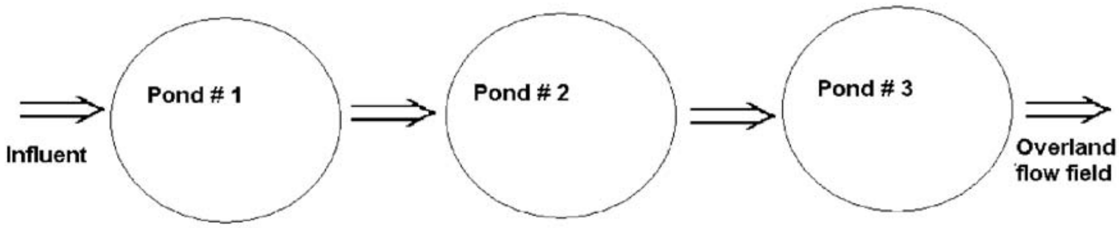
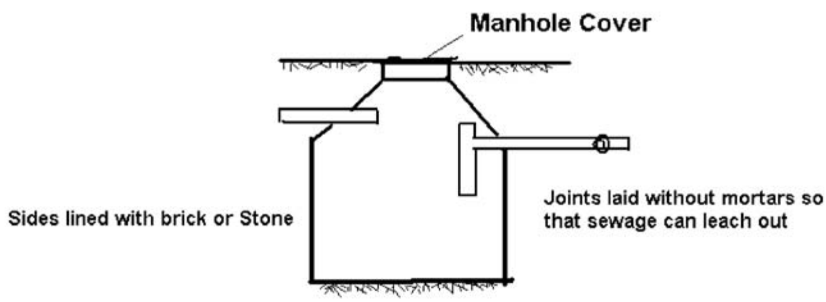


(a) Bchetfeen activated sludge treatment plant



(b) Mazraat Al-Chouf treatment system



(c) A commonly used cesspool

Fig. 2 Schematic diagram of both treatment plants and a commonly used cesspool (**a**–**c**)

follows continuous treatment in successive ponds. The process is natural and is carried out by the action of algae and bacteria. Around 400 households are connected to the treatment system. The effluent percolates into the ground or flows into a nearby river. Both plants are located at the bottom of valleys adjacent to the village. Transportation to the treatment plants is very difficult and a significant distance beyond the concrete road has to be covered on foot. The municipality is responsible for the operation and maintenance of the treatment plants. The third village, Deir Koushi, is limited to cesspools and sanitary pits, as is the case in almost all the other villages in Al-Chouf Caza. Noticeably, a small number of villages have wastewater treatment plants that are not operational, awaiting the completion of the sewerage network, or that are under construction. A schematic diagram of both treatment plants and a commonly used cesspool is depicted in Fig. 2.

Research methodology

Study design

Firstly, an assessment of information sources was conducted to review existing data pertaining to the study area. Field visits were conducted to examine the current situation and the wastewater treatment needs of the targeted community. Concomitantly, a review of available wastewater treatment technologies for small rural communities and their applicability in the study area was carried out. The existing institutional and regulatory framework was analyzed to identify barriers and other shortcomings to sustain the wastewater management systems. A performance evaluation of the treatment/disposal systems in the three villages was carried out.

Sampling strategy

Influent and effluent wastewater samples were collected from the secondary wastewater treatment plant in Bchetfeen village and the natural treatment system in the form of ponds in Mazraat Al-Chouf. Sampling activities were conducted once during the month of March 2007 and once during the month of April 2007. The results of both sampling activities were averaged for use in this study. It was not possible to collect wastewater samples from the third village Deir Koushi due to the difficulty in accessing the cesspools.

Analytical procedures

All sampling equipment and containers were thoroughly cleaned. Except during processing, all samples were kept chilled (4°C) from the time of collection until analysis. Physico-chemical analyses were conducted at the American University of Beirut following standard and recommended methods (APHA/AWWA/WEF 1998). Water temperature, pH, electrical conductivity, and total dissolved solids (TDS) were measured on site using a Hach Model 44600 Conductivity/TDS Meter. In addition, the dissolved oxygen was also measured on site using a membrane electrode Hach Model Sension6.

Wastewater samples were analyzed for indicator parameters including total and fecal coliform bacteria, BOD_5, nitrate–nitrogen (NO_3^-_N), ammonia–nitrogen (NH_3_N), orthophosphate (O-PO_4^{3-}), chlorides (Cl^-), and sulfates (SO_4^{2-}). A spectrophotometer was used for NH_3_N (Direct Nesslerization, Standard Methods 4500 NH_3 C), NO_3^-_N (Cadmium reduction; Standard Methods 4500-NO_3^- E), SO_4^{2-} (Turbidimetry; Standard Methods 4500-SO_4^{2-}E), and O-PO_4^{3-} (Ascorbic acid; Standard Methods 4500-P E). The BOD was based on 5 days incubation at 20°C. The bacteriological analyses were determined by the membrane filtration technique (Millipore) (APHA/AWWA/WEF 1998).

Results and discussion

Performance evaluation of the treatment/disposal systems

Influent and effluent samples taken from the treatment plant in Bchetfeen village showed no significant difference, with minimal removal efficiencies of almost all the parameters. While the levels of TDS showed a reduction of about 10%, the other indicators showed no difference to less than 5% removal rates. Noticeably, the influent concentration of Cl^- increased from 250 to 254 mg/l effluent concentration. The BOD levels in the effluent of the treatment plant (220 mg/l) exceeded by far the national acceptable level for wastewater to be discharged into surface water bodies (25 mg/l). Similarly, influent and effluent wastewater samples taken from the natural treatment system in Mazraat-Al-Chouf village have exhibited insignificant variation of the physical and chemical indicators. Yet, a remarkable reduction of more than 50% was observed for the microbiological indicators. The levels of TDS and BOD exhibited removal efficiencies of 26% and 14%, respectively. An increase in effluent concentration was observed for NH_3_N, Cl^-, and SO_4^{2-}. The concentrations of NO_3^-_N and O-PO_4^{3-} did not exhibit any variation. Table 1 summarizes the results of physical, chemical, and microbiological analysis of influent and effluent samples taken from the wastewater treatment plant and the natural treatment system.

As mentioned earlier, it was not possible to collect wastewater samples from the third village due to the difficulty in accessing the cesspools. However, field observations and interviews with the local community confirmed that the residents in this village are facing the problems of waste-

Table 1 Physical, chemical and microbiological results of the influent and effluent samples

Parameter	LNS	Bchetfeen wastewater treatment plant		Mazraat Al-Chouf ponds system	
		Influent	Effluent	Influent	Effluent
Temperature (°C)	35	19.8	20.0	19.9	19.3
Turbidity (NTU)	NR	245	237	114	116
(mg/l)					
BOD	25	225	220	206	177
TDS	60	483	435	300	221
NO_3^-_N	90	28.8	29.0	25.5	25.5
NH_3_N	10	2.50	2.49	2.27	2.43
SO_4^{2-}	1,000	66.7	66.7	68.7	69.7
O-PO_4^{3-}	5	2.53	2.53	2.50	2.50
Cl^-	NR	250	254	238	250
(Colonies/ml)					
Total coliform	2,000[a]	492	484	254	127
Fecal coliform		271	269	160	74

LNS Lebanese National Standards for discharge to surface watercourses, *NR* not reported
[a]Coliform bacteria 370C in 100 ml

water overflow from the cesspools due to undersized or nonexistent drain fields. Considering that home owners are responsible for managing the cesspools, they rarely empty them on a regular basis. Almost all cesspools discharge their effluents into the ground or onto ground surfaces. All of these discharges inevitably lead to degradation of land, surface waters, and ground waters, and ultimately pose potential risks to public health and the environment.

The conducted field work, visual assessment, and laboratory analyses of effluent discharges revealed that the existing systems for wastewater treatment in the three villages in Al-Chouf Caza are either not properly functioning or operational but ineffective and consequently hardly achieve any treatment higher than primary. Although the influent BOD load of the wastewater treatment plant in Bchetfeen was within the design criteria, the BOD effluent load was far above the design criteria. As a result of electric current interruption, the treatment plant was almost not operational at all. Almost all rural areas in Lebanon suffer from routine electricity disruption. As such, there is a need for a backup generator for such wastewater treatment plants with mechanical processes that are energy intensive and need continuous electrical power. Moreover, the municipality employee who is responsible for the operation and maintenance of the plant lacks the technical skills to properly operate it, resulting in system failure. Considering that most systems fail largely because of inadequate monitoring or poor maintenance, training programs for municipality employees are essential for the proper operation and maintenance of equipment and facilities.

Field observations in the Mazraat Al-Chouf village revealed that farmers have changed the wastewater flow entering the ponds towards their fields by blocking the pipes. Seemingly, farmers wanted to irrigate their crops with water rich in nutrients. Existing wastewater treatment systems are designed to meet people's demand for convenience by removing wastewater from the immediate household and community environments with little or no concern for the receiving environment. Hence, the problems related to wastewater in rural areas cannot be solved simply by constructing treatment plants. These plants must also be operational and effective. A major issue that should be considered is the generation of sewage sludge that will require adequate management to prevent environmental problems.

Likewise, the individual household cesspools and the improperly designed septic tanks offer no effective treatment. They fail to protect the water resources and environment because of their poor design, lack of maintenance, and increased loading. Malfunctioning septic systems can cause contamination of groundwater, as well as algae growth and other problems in rivers, streams, and coastal waters. Emptying of onsite facilities is often neglected and wastewater overflows from the pits to the streets, agricultural fields, and wadis, presenting health risks to the local community. The reason for this is not necessarily the cost involved but, more likely, ignorance. Unfortunately, no laws concerning emptying the tanks are being implemented. Improving the septic tank system by applying upward flow and gas–solid–liquid separation at the top is a low-cost and low-technology option that can be adopted in developing countries. It differs from the conventional septic tank system by the upflow mode, which results in improved physical removal of suspended solids and improved biological conversion of dissolved components (Chernicharo and Nascimento 2001; Florencio et al. 2001).

Assessment of policy, legal, and administrative framework

Policy concerning development of wastewater management concepts in Lebanon was set out in the 1982 National Wastewater Management Plan. The project revealed the urgent need for the development of wastewater collection, treatment, and disposal systems through the year 2000 for most of the Lebanese regions. In 1994, a report entitled the Lebanon Staged Wastewater Program, which is essentially a revision of the earlier 1982 Master Plan, was produced. The report notes that most of the communities remained without sewerage, and even many of the largest, including Beirut City, have extensive areas of no or inadequate sewerage. One significant change from the 1982 report is the higher priority now given to properly designed and constructed sea outfalls in order to protect coastal resort beaches and other tourist industry related activities. For treatment of wastewater, it recommends using Imhoff tanks or extended aeration, or stabilization ponds where space is available. It also recommends strict enforcement on the prohibition of direct discharge of sewage or other noxious waste to irrigation or drainage channels or other watercourses.

Environmental laws and regulations in Lebanon require updating and integration within a well-articulated environmental policy framework. Regarding the protection and preservation of water, there are a number of decrees and resolutions dating back to 1925. However, enforcement is weak and responsibilities are unclear. Management of water resources and wastewater has been fragmented and incompatible for many years. Numerous governmental, semiautonomous, and autonomous agencies are involved in water, sewage, and storm water sectors. Their responsibilities are interrelated in such a way that it is extremely difficult to distinguish a clear authoritative system linking decrees to appropriate agencies to implement them. Under Law No. 221 of 2000, future responsibility for wastewater issues lies with the Ministry of Energy and Water through five new Regional Water Establishments. The Ministry of Environment is responsible for developing an environmental protection policy through national standards and guidelines for wastewater facility management and performance, and for treated effluent reuse and disposal.

Risks and challenges

The fact that the existing systems for wastewater treatment in the three villages in Al-Chouf Caza are operating ineffectively is primarily attributed to the inapplicability of the existing systems applied to the managerial and financial conditions in the villages, as well as technical suitability. A major problem reported by municipalities in these villages is the lack of human resources with technical operating experience, financial resources, management capabilities, and political commitment necessary to implement wastewater management in an effective manner. Strategic planning and appropriate policy for wastewater management in rural areas does not exist despite the high number of people in these areas that lack adequate sanitation. The applications of conventional mechanical wastewater systems that are too complicated and too expensive are not expected to provide a sustainable solution. The technologies used are most often beyond the capabilities of the local people to operate and maintain effectively and efficiently. Moreover, often, the nongovernmental organizations responsible for the project have a low capability to choose the design, thus leading to a choice of technology that is not successful.

The mechanical and the nonmechanical 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 (Rocky Mountain Institute 2004). As such, they are not feasible in developing countries. A comprehensive environmental impact assessment study should be conducted before the implementation of any project. A cost–benefit analysis component resulting in data that can be used to inform and educate planners and municipal-level officials regarding the potential benefits and costs of the project should be included. The uncritical adoption of international criteria for design of wastewater treatment plants and ignorance of the local conditions could result in wasted capital. Funding capital investment is very important; yet, issues of sustainability and capacity building should not be ignored.

In line with available resources, phased expansion of sewerage and municipal wastewater treatment capacity based on known and proven technology and cost–benefit analysis is essential. A household septic system properly designed, installed, and maintained on suitable soil is as effective as a sophisticated sewage treatment plant. Several factors should be considered for the determination of the best wastewater management strategy including, but not limited to, availability of sewage network, population densities, groundwater or surface water pollution, institutional manageability, and financial sustainability. Management strategies should be site-specific, accounting for social, cultural, environmental, and economic conditions in the target area (WHO/CEHA 2001; Engin and Demir 2006). Developing guidelines for the selection of small community wastewater systems could facilitate the decision making process (Bakir 2001).

Public awareness relating to wastewater issues is minimal in developing countries. Strengthening the knowledge base of environmental problems and solutions in developing countries, reflecting scientific thought and country empirical experience, is required. Public education and participation in decision making are fundamental elements of any wastewater management program. Neither in Bchetfeen nor in Mazraat Al-Chouf village was the local community well informed about the projects through formal explanatory lectures. 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.

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. In order to provide supportive information on the appropriateness of wastewater management options in small rural communities and refine or adapt these options, applied research and demonstration projects are imperative. While there are many impediments and challenges towards sustainable wastewater management in rural areas, these can be overcome by suitable planning and policy implementation. Getting research findings into policy and practice and bridging research and decision making processes is a major challenge.

Conclusions and recommendations

Influent and effluent samples taken from the treatment plants showed no significant difference with minimal removal efficiencies of almost all the parameters. The conducted field work, visual assessment, and laboratory analyses of effluent discharges revealed that the existing systems for wastewater treatment in the three villages in Al-Chouf Caza are either not properly functioning or are operational but ineffective and consequently hardly achieve any treatment higher than primary.

Existing wastewater treatment systems are designed to meet people's demand for convenience by removing wastewater from the immediate household and community environments with little or no concern for the receiving environment. Environmental laws and regulations in Lebanon date back to 1925 and responsibilities are unclear in addition to weak enforcement.

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. It is very crucial to take into account the economic status of the community and the municipality in question. Regulatory authorities should give a higher priority to the needs of small communities, recognizing that they have fewer resources and less financial support.

Although developing countries are being encouraged to implement wastewater treatment systems with the promise of financial aid from developed nations, it is important that local conditions are considered carefully to make full use of any aid. Development of appropriate policies, institutional strengthening, and training are crucial to overcome the constraints to sustainable wastewater management in rural areas.

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