Decentralized sanitation systems for the southern Ecuadorian Andes, assessment and challenges

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Abstract
The decentralized treatment systems for domestic effluents are an economic and sustainable alternative in comparison to conventional wastewater collection and treatment systems in rural and peri-urban areas in developing countries. However, there are still many shortcomings in the planning, implementation, operation and maintenance (O&M) of those systems. This article aims, throughout a comprehensive bibliographic review, to analyze the current state of decentralized sanitation systems in several developing countries, comparing to the technological, environmental and socioeconomic characteristics present in the rural and sub-urban communities in the southeast Andean region of Ecuador, establishing recommendations for actual systems O&M and further investments in these areas.

Keywords
Sanitation; domestic; sustainable; decentralized; wastewater; Andes

INTRODUCTION

The global trend towards a universal improved sanitation is clearly growing in the last decades; however, 32% of the world population still lacks of any improved sanitation facility (WHO/UNICEF, 2015). In the rural area the gap is dramatically higher since 7 out of 10 people without improved facilities live in these areas. In Ecuador, despite of reaching the Millennium Development Goals (MDG) for sanitation by 2015, 19% of the rural population is still missing access to improved sanitation facilities (WHO/UNICEF, 2015). Considering the enormous advantages of the decentralized systems over the centralized ones from an economic point of view; and, the impossibility to build universal centralized sewerage networks even in the developed world (Tchobanoglous et al., 2004); the room for decentralized systems will surely increase in the coming years.

In Ecuador and several developing countries, the public investments in infrastructure for collection and treatment of domestic wastewater in the rural and peri-urban areas have increased regularly during the last decades. However, the majority of the decentralized systems located in those areas are still working under low efficiencies and facing several Operational and Maintenance (O&M) difficulties in comparison to urban areas and conventional systems (Nanninga et al., 2012). In Ecuador, three main reasons stand behind this behavior: i) the population dynamics and the illicit discharges into the collection systems which often change rapidly and significantly the design fluxes to the systems; ii) the inadequate or inexistent management and maintenance of the systems neither by the authorities nor by the direct users of the systems; and iii) the technological aspects and the failures in the design process. “Yet how many municipal engineers know what all the sanitations options are, how to choose between them and how to design the chosen option?” (Mara, 2013). The vast amount of resources invested in sanitation in the rural areas with relative low success, have motivated the analysis of the state-of-the-art of the decentralized systems in several countries, through an exhaustive bibliographic review of academic reports, scientific articles, interviews and current information of national and international entities, focusing in the technological options and good practices with comparable environmental and socio-economic characteristics to the rural and peri-urban communities of Ecuador, with a particular emphasis in the southern Andean region.

There is considerable information about technologies for Decentralized Wastewater Treatment (DWWT) (Massoud et al., 2009; Singh et al., 2015); and, there is also vast information about the feasibility of applying different technologies in different sites of developing countries, depending on weather, socio-economic and cultural factors (Molinos-Senante et al., 2012; Nansubuga et al., 2016). When choosing a particular technology, it must be considered that each successful wastewater treatment technology implemented in a particular site was influenced in the selection process and design by physical, chemical and biological influent characteristics, environmental conditions, land availability, energy conditions in the area, projected population for the design, budget constraints, discharge regulations, the potential reuse of effluents downstream and the final receiver body characteristics. On the other hand, there are several comprehensive studies in rural or peri-urban areas of developing countries, which highlight the implementation of decentralized technologies with focus into the particular socioeconomic conditions and the community participation to ensure an adequate O&M (Beausejour and Nguyen, 2007; Fach and Fuchs, 2010; Ghaitidak and Yadav, 2013) Therefore, the technology applied and the O&M efforts implemented successfully in one decentralized locality, should not be generalized and applied directly to the Ecuadorian Andes, even if the environmental conditions are comparable.

The resources allocated to sanitation are normally limited in developing countries; thus, it is encouraged to do the right investments in sanitation infrastructure and to keep them useful in time by an adequate O&M. A lot of resources are also expended in continuous evaluations of existing systems, Thus, this paper wants to bring to the decision makers stakeholders a clear view of the existing technologies and their feasibility to applied in the southern Andean region of Ecuador for distinct treatment objectives. For the analysis of the information, it was made a selection of relevant articles in two categories (i) analysis of implemented technologies in different sites of developing countries; and (ii) analysis of the O&M of DWWT systems with focus into the singular socioeconomic characteristics of each locality.

MATERIAL AND METHODS

The present review was constructed firstly by selecting a number of articles which presents some of the most relevant and updated technologies for DWWT in developed and developing countries with similarities to the southern Ecuadorian Andes and another group of articles covering the management, and O&M aspects of DWWT in rural and peri-urban areas of the world. In the first group was summarised and tabulated (where available) among other factors: population served, environmental conditions, objective of the systems, Wastewater (WW) characteristics, technological details, efficiency and the results obtained. While, in the management group (if available): population served, social organization conditions, existing infrastructure, socioeconomic status, actions implemented for the O&M and results. The subsequent analysis was constructed by comparison of the selected cases with the site and organization characteristics present in the focused zone of Ecuador. The articles are listed chronologically.

RESULTS AND DISCUSSION

Table 1. Technological aspects of some Decentralized Wastewater Treatment systems

	Place of study	Weather	Population	Objective / Methodology	Applied Technology	Water Type	Results /Analysis
(Elmitwalli et al., 2003)	Netherlands	T: 13 °C (Winter), 18 °C (Summer)	1000-20000	Feasibility of anaerobic wastewater treatment at low temperatures and low costs of investment and maintenance.	Two stage Hybrid Anaerobic Septic Tank	Domestic Wastewater.	87% reduction of COD at low temperatures. Sludge cleaning after one year.
(Parkinson, 2003)	Peri-urban areas in low-income dev. countries.	Variable.	Varies	Wastewater treatment at low cost and effluent reuse	Anaerobic Treatment, Reactor with baffles and stabilization ponds.	Domestic Wastewater.	Anaerobic treatment: no external energy, small pathogen reduction. Two chambers baffled reactor: similar to UASB. Stabilization ponds: pathogen removal and effluent reuse.
(Langergraber and Muellegger, 2005)	Peri-urban in: Uganda, Germany, Denmark y Finland.	Variable.	No Data	Introduction to EcoSan principles and concepts including re-use aspects	Dry toilets and reuse of nutrients.	Human wastes.	EcoSan systems minimize hygienic risks and protect the environment; help the return of nutrients to the soil, and conserve valuable water resources.
(Kujawa-Roeleveld and Zeeman, 2006)	Peri-urban areas in low-income DC	Temperature: 20°C y 13 °C.	Varies	Gray and black water are analyzed, comparing their composition with their location, lifestyle, customs and facilities	At 20 °C: A UASB, followed by a septic tank. 13 °C: Anaerobic filter (AF) followed by a AH	Gray, black and rainwater.	At high Temp, COD is removed up to 80-90%. At low Temp COD is removed up to 71%. By separating the gray and black waters, 80-95% of nutrients can be recovered..
(Abegglen and Siegrist, 2006)	Solothurn (Switzerland)	Temperature: 16°C,.	250,000	In-situ domestic wastewater treatment, effluent reuse, low drinking water demand.	Membrane reactor: primary clarifier and activated sludge with a submerged membrane plate. Both with aeration	Domestic Wastewater.	Nitrogen and Phosphorus are removed at 90%. Drying is good at low Temp (10°C), Total Organic Carbon (TOC) and COD removal from 90 and 95% respectively.
(Mendez et al., 2008)	Orizaba, Veracruz (Mexico)	Temp max 25; min 16°C; rainfall 2238 mm/y; 1232 m asl	120,995	After a primary and advanced treatment, the best conditions for pathogen removal and reuse	Hom Kinetic Model for fecal coliform (FC) and Salmonella inactivation by Ammonia doses	Municipal and agroindustrial wastewater.	At higher Temp, less ammonia required for microorganisms inactivation.
(Fach and Fuchs, 2010)	Gunung Kidul (Indonesia)	Temperature: between 21 °C and 32 °C	Varies	Potential of reuse of effluents and stabilized sludge from septic tanks	Anaerobic digestion in septic tanks and aerobic filtration. Sludge dehydration, reuse as fertilizer.	Domestic Wastewater.	Sludge obtained from a septic tank and from solid wastes used as fertilizer. Effluent used for irrigation.
(Rojas-Higuera et al., 2010)	Bogotá (Colombia)	Temp: 13 °C, Rainfall: 890 mm/y, 2600 m asl	36 km from Bogotá.	Treatment of sludge from oxidation ponds, and reuse in agriculture.	Chlorination and photo catalytic TiO_2 combined with high Temp.	Sludge from domestic wastewater.	In 8 hours, chlorination does not eliminate coliforms and E. Coli completely. The heterogeneous photocatalysis with TiO_2 remove pathogenic organisms in 30 minutes.
(Nanninga et al., 2012)	Xochimilco (Mexico)	Temp 15 °C, rainfall 60 mm/y, 2240 m asl	415,000	Acceptance of people to decentralized technologies for recover and reuse water, nutrients and energy.	Ecosan toilets, toilets with filters and wetlands.	Domestic WW, rainwater, waste, urine and feces.	Acceptance of people is essential for implementation of decentralized technologies. Recovery of nutrients, water and energy with low cost and protecting the environment.
(Ghaitidak and Yadav, 2013)	Perth (Aus), Calicut (Ind), Dakar (Sen), Amman (Jor), South Africa, Sana-a (Yem).	Different conditions	Varies	Advantages of treating gray water separated with a focus on reuse.	Anaerobic treatment, Wetlands and Filtration.	Gray water.	The best method to ensure reuse is an anaerobic system followed by aerobic system and post disinfection.
(Silva-Leal et al., 2013)	Cañaveralejo, Cali (Colombia)	Temp: 23°C, rainfall 908 mm/y, 1018 m asl	2,060,000	Elimination of pathogens in treated and drying biosolids to get class A qualification.	Thermal drying and alkaline treatment.	Domestic Wastewater.	Temp for thermal drying are 60, 65, 70 and 75°C , 8 to 16 hours. For alkaline treatment doses of quicklime to up 9% for 5 days, gets N reduction. Treatments qualify as class A.

Table 2. Social and organizational aspects of some Decentralized Wastewater Treatment systems

Reference	Place of study	Population	Current infrastructure	Social aspects	Actions / method	Results
(Sundaravadivel and Vigneswaran, 2001)	India: Andipatti, Bodinayakkanur, Cumbum and Theni.	5000-10000	Dry latrines. WW collected in open channels; effluent used in irrigation.	The communities receive little attention from authorities.	Surveys and registration of diseases, water analysis.	With low investment, removal of 70-80% of BOD, and up to 2 log units of FC. O&M acceptable for authorities
(Parkinson, 2003)	Peri-urban, low-income areas in developing countries	Different range	Not access to safe drinking water and sanitation facilities.	WW in direct contact to people, No interest for environment and health problems.	Coordination between government, privates and community, identifying local skills and creating knowledge	Information and knowledge created in the residents for treating their wastewater. Responsible suppliers and technical support were considered in centralized areas.
(Heymans et al., 2004)	South Asian countries: Bangladesh and Vietnam.	No Data	A small percentage of homes have latrines and septic tanks.	deficient environment and public health knowledge in communities, disconnection to government	Community participation guarantees an appropriate management with support of local authorities.	An agreement between the community and governments, has been achieved for a long term management of the DWWT
(N. Viet Anh et al., 2004)	Hanoi, Vietnam	1,7 millions	65% have sewage connection. Black waters are treated in STs and discharged in a river.	The population density is rapidly growing, due to industrialization. High pressure on natural resources	Preparation of system managers for the O&M. Citizen participation without exclusion.	The government is compromised to support and follow up the actions. The community pays a fee for wastewater treatment.
(Beausejour and Nguyen, 2007)	Kim Chung- Lai Xa, Vietnam	4000	In Vietnam 55% of inhabitants had access to latrines in 2006	Rural sector faces urgent sanitation needs, demanding flexible solutions adapted to their local conditions.	Management of solid wastes (from 2003) and Management of liquid wastes (from 2005).	Better hygiene practices at homes. Trained people from the community involved in decision making and system maintenance.
(Kamal et al., 2008)	Urban and Peri-urban areas of south and southeast Asia	1-100 homes	Big cities have poor treatment. Small towns without any collection or treatment.	Lack of coordination between different levels of government with rural communities.	Coordination between the central and local government. The reuse as the key objective with community participation	Coordination between all water companies in each country. Selection of simple and cheap technologies.
(Kema et al., 2012)	Mtwara rural district, Tanzania	203000 people 375 homes	Scarce or no access to ventilated or traditional latrines.	Only 40 out of 118 villages have access to sanitation. Low quality of life	Surveys to collect demographic, socioeconomic, hygiene practices and the type and status of latrines in use.	Less than 50% of the members in each household use latrines. There is lack of education about the importance of personal hygiene.
(Meleg, 2012)	Bahía, Ceará, Piauí, Brazil	No Data	There are access to latrines and primary treatment to small scale.	Low-income communities accept help from private entities or governments.	Model SISAR: the income of big systems, compensates the costs of O&M of small systems, providing also overall support	There was a great acceptation of the SISAR model by inhabitants, and the support of external organisms.
(Fam et al., 2014)	Melbourne, Australia	3,6 millions	Separate sewerage systems (sanitary and storm). Artificial wetlands systems.	Melbourne inhabitants are well aware of planning and collaboration for a good quality of life.	Educational campaigns for a price scheme to compensate the water conservation in homes and industries	Training to local leaders in workshops for decentralized wastewater treatment and reuse of effluents.
(Van Dijk et al., 2014)	Dar es Salaam, Tanzania and Kampala, Uganda	Dar es Salaam (5 millions), Kampala (1,2 millions)	Shared toilets and latrines in poor condition. Open defecation.	Unhealthy environments and high rate of diseases. No investment in sanitation from authorities	Qualitative and quantitative surveys about life style and financial organizations in each neighborhood.	35% willing to improve sanitation, 40% with their self-work and 25% will not contribute by their economic condition.
(Kouamé et al., 2014)	Yamoussoukro, Côte d'Ivoire.	300,000 people (492 homes)	Dry latrines, STs. No sludge disposal. Effluent reuse in agriculture without any treatment.	High levels of diarrhea and malaria, directly associated with the lack of sanitation.	Transdisciplinary research, workshops and mapping. An analysis of the risk factors and health.	A network was created for sharing information between interesting parts, authorities and the local community, in order to improve the quality of life.

Environmental Sanitation of the Ecuadorian rural sector

Ecuador accounts the highest population density among the South America countries. From its 15 million of inhabitants, the rural population represents the 37%. In the rural area, only the 23% of households are connected to a public sewerage system (INEC, 2014). The 30% are connected to a septic tank (ST) or a secondary treatment, and around 28% of houses are served by other minor improved sanitation facilities. As seen, the 19% of households in the rural sector (around 250000 houses) do not have any sanitation infrastructure (INEC, 2014). There is no information about the number of WWT systems that are functioning in the rural sector of Ecuador. However, in the whole country, currently only two of the big cities (Quito and Cuenca), have full scale Wastewater Treatment (WWT) systems already built or under construction. The Ecuadorian Andes cover a wide range of environmental conditions, which vary from snow peaks to humid subtropical. For the analysis presented in this manuscript, the southern Andean region of Ecuador with moderate rainfall and temperatures from 12 to 24 °C is selected.

Environmental conditions for technological viability

Temperature is a key factor for the selection of a particular technology for wastewater treatment. It is well known that the biological processes in wastewater treatment are enhanced at high temperatures; besides, the gases solubility and water viscosity are also positively influenced at such temperatures (Von Sperling and Chernicharo, 2005). Among the wastewater technologies, the anaerobic processes exhibits a higher sensitivity to the water temperature. However, at low and temperate climates, the treatment of domestic sewage by anaerobic processes is still considered a challenge (Chernicharo et al., 2015). This is mainly because at low temperatures the hydrolysis step occurs at very low rates (Foresti et al., 2006). The use of anaerobic reactors at subtropical zones in the Andes is certainly feasible; nevertheless, these technologies present technical difficulties for its application in certain zones of the Ecuadorian mountain range with mean temperatures below 18°C (INAMHI, 2010). Kujawa-Roeleveld and Zeeman (2006) summarizes several technological options to overcome the obstacle of low temperature in treating domestic wastewater, among them, the use of granular seed sludge and two stages for the anaerobic digestion.

Temperatures lower than 13°C require different technological challenges such as modifications in conventional systems of anaerobic digestion that regularly are efficiently implemented in high temperature zones. A good alternative is the use of an anaerobic filter (AF) with a fixed bed that retains high quantities of particulate Chemical Oxygen Demand (COD) followed by an anaerobic hybrid tank (AH) which consists of a sludge bed in the bottom of the reactor and a filter material in the upper part. Elmitwalli et al. (2003) presents in a research done in rural communities with a mean annual temperature of 15°C, the use of a two-step ascendant AH septic tank. Although the decline of the temperature down to 13°C produces a decrease in the COD removal, high levels of removal were reported up to 87%. Another two step anaerobic system is a Upflow Anaerobic Sludge Blanket (UASB) reactor followed by a traditional anaerobic digester. In the UASB reactor, the suspended solids from the influent are captured and then transported to the digester. The stabilized sludge together to methanogenic bacteria is recirculated from the digester to the UASB reactor to maintain high levels of methanogenic activity (Mahmoud, 2002). When the temperatures are not a constraint, which is the case of the subtropical zones, various successful applications of combined anaerobic and aerobic low cost technologies are reported. In Gunung Kidul, Indonesia (27°C), (Fach and Fuchs, 2010) propose a composite system formed by a ST followed by a filtration unit with sand and gravel media (1 to 8mm). The second tank receives the supernatant from the first tank intermittently. Besides the sedimentation, anaerobic digestion and a considerable reduction of pathogen organisms are produced. Von Sperling et al. (2005) states that an effluent with E. coli concentrations below 1000 MPN/100ml (limit stablished by WHO and Ecuadorian regulations for agriculture use), is feasible to obtain with this system. Ghaitidak and Yadav (2013), also suggest the combination of anaerobic and aerobic units, but with application only to a gray water. In the southern subtropical zones of the Ecuadorian Andes, with temperatures between 20 and 24°C (INAMHI, 2010), the technical feasibility of systems combining anaerobic and aerobic technologies is definitely guaranteed; however, the limited resources for construction and O&M would be an obstacle for their implementation as discussed in the next sections of this document. With regard to decentralized high efficient conventional biological systems, Abegglen and Siegrist (2006) propose a membrane reactor formed by two tanks. The first one is a clarifier tank with a defector on its base, where the resulting sludge is dehydrated for reuse. The second is an activated sludge tank with a thin submerged plate membrane. In both cases, air is injected to avoid anaerobic conditions. High removal of Biochemical Oxygen Demand (BOD) at 16°C has been observed and up to 90% removal of nitrogen and phosphorus. The energetic demand was estimated in between 5 and 10 kilowatts per hour (kWh). The energetic demand of aerobic treatments is, despite of the higher treatment efficiency at low temperatures, a major constraint for the implementation of such technology in the rural communities of the Ecuadorian Andes. In view of O&M sustainability, the anaerobic and natural systems offer the best suitability, although, some technological variations and units combination is needed when treating domestic sewage at low temperatures.

Disinfection

The elimination of pathogen organisms in solid and liquid effluents from the DWWT systems, is still a primary objective of the wastewater treatment that is scarcely fulfilled in Ecuador and many other developing countries. The mechanisms for pathogen reduction increase considerably the cost of the projects, mainly due to: i) the land and the technological investment (e.g. vast extensions of land for maturation lagoons); ii) the treatment processes which implies the addition of chemical agents, external energy or light irradiation. Nevertheless, there are many positive experiences of low cost disinfection by different technological approaches. In Orizaba, Mexico, Mendez et al. (2008) determined the inactivation of pathogenic microorganisms and Salmonella, using different amount of ammonia in sludge with diferent degrees of dehydration, obtaining better results at higher temperatures and higher sludge dehydration. Alma and Cota (2008) presented a sludge treatment with solar radiation which removed 6 log units of fecal coliforms and 10 log units of Salmonella with a small investment in Ciudad Juarez, Mexico. Silva-Leal et al. (2013) proved in Canaveralejo, Colombia, that a termic drying treatment or an alcaline treatment previously applied to a dehydrated sludge are very efficient eliminating the microorganisms indicators of fecal contamination. With regard to the effluent disifenction, in Colombia, Rojas-Higuera et al. (2010) highlights a greater effectiveness of Titanium Oxide TiO_2 in comparison to chlorine for eliminating pathogenic organisms. The cost of chlorine is slightly less than the cost of TiO_2; however, toxicological and public health studies are needed to verify the safe loads for the application of TiO_2.

It is well known that small anaerobic reactors hardly reduce pathogenic organisms (Chernicharo et al., 2015); moreover, the effluents from anaerobic reactors have normally a significant turbidity concentration which would obstruct the effectiveness of traditional disinfection methods. Therefore, for the southern Andean region of Ecuador, an affordable and sustainable disinfection method for places with small land availability would need to consider the use of solar irradiation as the primary energetic source.

Nutrients re-use in the soil

As an alternative to bring the nutrients back to the soil, and to preserve the water resources, Langergraber and Muellegger (2005) present the carateristics and advantages of using the ecological sanitation (Ecosan) toilet. Nanninga et al., (2012), also highlighted the viability of these toilets, emphazing the need of a properly design and management. They also presents the viability of the urine treatment in constructed wetlands, aiming to the reuse of the effluent in irrigation and the sludge as fertilizer in the soil.

Operation and Management of decentralized systems.

From the analysis of several evaluations of DWWT systems around the developing world, and the contribution of several prominent authors in the field: Mara (2013, 2004, 1996); Peña and Mara (2004); Von Sperling (2007); (Crites and Tchobanoglous, 1998; Tchobanoglous et al., 2004), the first main relevant conclusion is the high relevance to bring the system to a community, together to information and education about the benefits of treat the wastewater for the public and environmental health. When the community served links their health problems with the contact to their own fecal wastes, the education process and the further enrolment of the people in O&M task could be fast and effective. Many studies acknowledge and stress this fact: Sundaravadivel and Vigneswaran (2001) analyses the management of DWWT systems in peri-urban areas in India, emphasizing the relevance of the information about health and the importance to run surveys among the users. Van Dijk et al., (2014) also stress the importance of conduct qualitative and quantitative surveys to take the right decisions for the O&M of the systems. Kema et al. (2012) focuses into the education and training, recommending to involve youth people in the process. The importance to stablish solid links between the government and the community served has been highlighted by many authors (Heymans et al., 2004; Kamal et al., 2008; Sara and Graham, 2014) in numerous studies in the southeast of Asia. Beausejour and Nguyen (2007) explains the importance of the hygiene education at home and the relevance to involve the users from the beginnings of the sanitation programs; e.g. in the decision-making process of technology selection and the maintenance of the systems later on.

Ecuador has some government agencies in charge of the environmental sanitation at different levels. These include the National Secretariat of Planning and Development (SENPLADES), Information Systems for Autonomous Governments (SIGAD), the National Water Secretariat (SENAGUA) and the Decentralized Local Governments (GADs). In the last years, the progress in sanitation coverage has been evident both in the urban and rural areas of the country. Ecuador met the Millennium Development Goal (MDG) for basic sanitation in 2014 (WHO/UNICEF, 2015). However, for the treatment of domestic effluents, there is an important gap especially in the O&M of the DWWT located in the rural areas. Despite of the important efforts of the different agencies, an effective connection between the actions of these agencies and the organizational and management competences of the communities served is still needed. The environmental and health education in the rural areas should be reinforced in the institutional agendas. In addition, the engineers in the public institutions must have the competences for chose the most suitable option for a particular place and to design properly the systems together to an O&M plan.

In rural areas of the southern Andean region of Ecuador, there are, unfortunately many examples of DWWT systems that have completely lost their functionality due to the lack of O&M. This can be associated directly with intermittent or no involvement of the served population and the scarcity of resources of the public agencies. Decentralized management does not mean inefficiency or abandon and is independent of socioeconomic level of the population. Fam et al. (2014) and Viet Anh et al. (2004) reports good examples of well-organized communities in Melbourne (Australia) and Hanoi (Vietnam) respectively which were supported by volunteers and education workshops about the benefits of the wastewater treatment and the saving of water resources. Meleg (2012), instead, presents a similar study in three low-income communities in Brazil. Here, the Integrated Rural Sanitation System (SISAR) model was stablished. The SISAR model comprises a community organization in small clusters with a cross-subsidy scheme. Thus, the income of big systems, compensates the costs of O&M of small systems, providing also support in technical, social and administrative matters. The success of SISAR model was built on the integration and responsibility of all the inhabitants of a particular area, improving the overall quality of life.

CONCLUSIONS AND RECOMMENDATIONS

The decentralized systems offer a smart and sustainable solution for DWWT in rural and peri-urban areas in the southeast Andean region of Ecuador. The technological offer of DWWT is wide and in constant development around the world; however, there is a preference towards the anaerobic systems mainly because of the low O&M costs. The temperature is undoubtedly a determinant factor when considering the technical feasibility of the systems; nevertheless, even at low temperatures, the anaerobic processes in combination with aerobic or anaerobic systems could be an efficient alternative to remove DBO and pathogenic organisms. Considering the environmental conditions of the Andean subtropical regions analyzed, the anaerobic systems are a convenient technological alternative, particularly in individual septic tank units or in more advanced units such as UASB reactors. A combination of septic tanks followed by an anaerobic filter or constructed wetlands are also good alternatives for DBO and pathogen removal. On the other hand, at the mountain region with lower temperatures, there are still various viable alternatives; among them, the anaerobic filters followed by a hybrid anaerobic reactor; or, a combination of a UASB reactor or a septic tank with an anaerobic filter. Nevertheless, it is also feasible to improve the environmental sustainability of these systems including sludge dehydration and disinfection for reuse in soil application.

However, these technological alternatives require a validation by pilot experiences under different environmental conditions before their implementation. In addition, it is necessary that the governmental organizations encourage that the design processes must consider sound characterizations of the effluents, and the analysis of the receive water bodies and their self-purification capacities. Furthermore, the actual organizational strength of the community served should be considered on beforehand for planning the O&M activities. The level of success of the decentralized system is directly proportional to the level of community involvement. In order to achieve the fundamental objective of any treatment system, it is strongly suggested to first convince the system users about the necessity of domestic effluent treatment to preserve both the public health and the environment. The community organizational capacities could be noticeably improved with the involvement of community leaders in the O&M responsibilities reinforcing at the same time the environmental education, among children, teenagers and young adults.

Consequently, it is crucial, to reinforce the administrative and organizational capacities of the communities which could be extended to other productive local schemes. In Ecuador, finally, it is necessary to reinforce scientific research towards decentralized WWT technologies and to strengthen the capabilities of the engineers in the whole process of technology selection, design, and operation and maintenance of decentralized DWWT systems.

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