Assessment of decentralized wastewater treatment systems in the rural area of Cuenca, Ecuador.

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Abstract

The rapid urbanization of Cuenca, Ecuador, during the last decades have oriented some efforts to build and operate some decentralized treatment systems for domestic effluents in its periurban and rural areas. However, some of these systems are facing a reduction in their treatment efficiency and others are currently out of operation. ETAPA (municipal institution in charge of water supply and sanitation), however, is working in a full evaluation of these systems to identify common difficulties in the operation and maintenance and also some deficiencies in the design and construction processes. The manuscript presents an overall evaluation of the physical infrastructure and the characterization of the treatment processes performed historically in the systems. The ultimate objective of this assessment is to improve the technical deficiencies and to adopt a long-term sustainable plan for O&M.

Keywords
periurban; domestic; treatment; decentralized; wastewater

INTRODUCTION

There is certainly a global trend which shows an annual increase of the percentage of world population with access to improved sanitation. However, the world has missed the Millennium Development Goals (MDGs) for basic sanitation set for 2015 (WHO/UNICEF, 2015), in contrast to the target for drinking water that was accomplished by 2010. While Latin America was just short to reach the MDG for sanitation, Ecuador met the target by 2015. Nevertheless, in the rural area of Ecuador, 25% of the population is still missing access to improved sanitation facilities. Considering the limited financial resources available in developing countries, there is an increasing demand for environmentally and economically sustainable wastewater treatment systems. From an economic perspective, the differentiation in centralized and decentralized systems is highly relevant (Singh et al., 2015). Moreover, a decentralized approach for wastewater treatment offers many other advantages related to public health, and brings a feasible opportunity for resources recovery from wastewater and also for water recycling for selected purposes such as agricultural and industrial activities (Nansubuga et al., 2016; Tchobanogious et al., 2004; Verstraete et al., 2009), decreasing the demand of fresh water (Bakir, 2001).

Cuenca, the third largest city of Ecuador, is certainly the leader in sanitation services in the country, operating the biggest wastewater treatment facility (Ucubamba waste stabilization pond system, 1.8 m^3/s – 90% of urban area coverage). Nevertheless, during the last 2 decades, the city experimented a massive expansion to the peri-urban areas, representing a serious challenge for ETAPA (Municipal institution in charge of water supply, sanitation and telecommunication services) to keep the high standards in water supply, sewerage and water treatment by increasing the areas served. Besides, the rural settlements surrounding the city (also served by ETAPA) are facing a similar behavior of rapid demographic growth and urbanization. Knowing the challenges to increase the sewerage network, which could take up between 80 and 90 % of the capital costs in a centralized treatment approach (Bakir, 2001), ETAPA decided to build 32 small decentralized wastewater treatment (DWWT) facilities. The many technological options available were balanced and analysed in terms of treatment objectives, cost, energy demand, Operation and Management (O&M) costs, etc., and finally, ETAPA selected anaerobic and natural systems looking for the sustainability of the systems in the long term. These systems experienced many difficulties from the beginning of the operation, especially with high overflows and clogging of the primary treatment units. However, most of the DWWT systems are still in operation. It was acknowledged by ETAPA the decrease in the efficiency of the systems and some assessments of the plants have been performed. From the experience of the managers and the results of the evaluations, some constraints have been identified as the main factors influencing the decline in the efficiency in some of the systems as follows: 1) the rapid population growth in the areas served by the systems, increasing considerably the fluxes and causing a dramatic reduction of the hydraulic retention times and organic overloads in the systems. 2) the limited economical resources and together to the low organization capacity of users to provide maintenance to the systems, even contributing to its deterioration; 3) in some cases, the adoption of standard solutions applied successfully in other countries, were not appropriate for the particular environmental conditions of a specific site. In these perspectives, this article presents a global evaluation of the systems with the objective to discuss the technical deficiencies and to recommend a long-term sustainable options for improving their efficiency and O&M.

MATERIAL AND METHODS

A critical recompilation of the several evaluations conducted of the 32 DWWT systems was made. The evaluations and characterizations performed historically and, particularly in the last 3 years were highlighted in order to give an objective overview of the current state of the systems. The recent evaluations have focused in few systems with different technological approaches. Very important information from 2 overall evaluations is also analysed. These evaluations were performed in 2005 (6 systems) (Neira, 2005) and in 2008-2009 (31 systems) (Ordóñez, 2009). The evaluation was different in every case, however, all of them (past and recent) have verified the current state of the structure and in many cases characterised the influent/effluent wastewater. Besides, several interviews with ETAPA staff (directives and system operators) and users of the systems were performed. Based on those quantitative and qualitative data, an overall discussion is presented, focusing in the technological aspects of the systems, the removal efficiency of the main quality parameters, the objectives of the treatment and the problems faced regarding the operation and maintenance. The discussion is extended to the problems present in the sewerage network which seriously influence the systems operation.

RESULTS AND DISCUSSION

Infrastructure, technology and systems configuration

In Figure 1 is depicted the systems location in a schematic but scaled map. The limits of the consolidated urban area of the city of Cuenca (450 000 inhabitants) is highlighted in gray, showing the spread of the systems within the rural area of Cuenca canton. There are 6 systems (black circles) located in the lowlands of Cuenca canton domain (around 30 m a.s.l). Those WWTPs are around 150 km distant (2 hours away by car) from ETAPA headquarters in Cuenca. The remaining 26 systems (blue triangles) are located in highlands between 1700 and 2900 m a.s.l., within a distance of 50 km of Cuenca.

In Table 1, are summarised the systems technology and highlighted some relevant information of them. As observed in the same table, all the systems except one, have a septic tank (ST) as primary treatment unit and 20 out of 32 systems are composed totally by anaerobic units. The combination of ST and anaerobic filter with vertical flow (AF/VF) and ST and constructed wetland (CW) are the favourite technologies used, despite of the climatic characteristics of the different sites. It is supposed that the construction and the low O&M costs were relevant factors for the selection of these technologies. In Table 1 are also presented the altitude and average temperatures of the DWWTs sites which vary from 11 to 18 °C in the highlands systems and around 22 °C in the lowland systems. It is observed in Table 1, that some systems have higher temperatures at higher altitudes; this is explained by the microclimates present in the valleys of the systems. The areas served by the systems differ significantly for each system. Despite of these essential varying factors, there are very close similarities in the dimensions and configuration of the main structures. This fact could suggest some deficiencies in the design process (i.e. the strict application of design-type guidelines without considering the characteristics of the wastewater and the climatic conditions) or in some cases, the existing systems were used as a model for new systems.

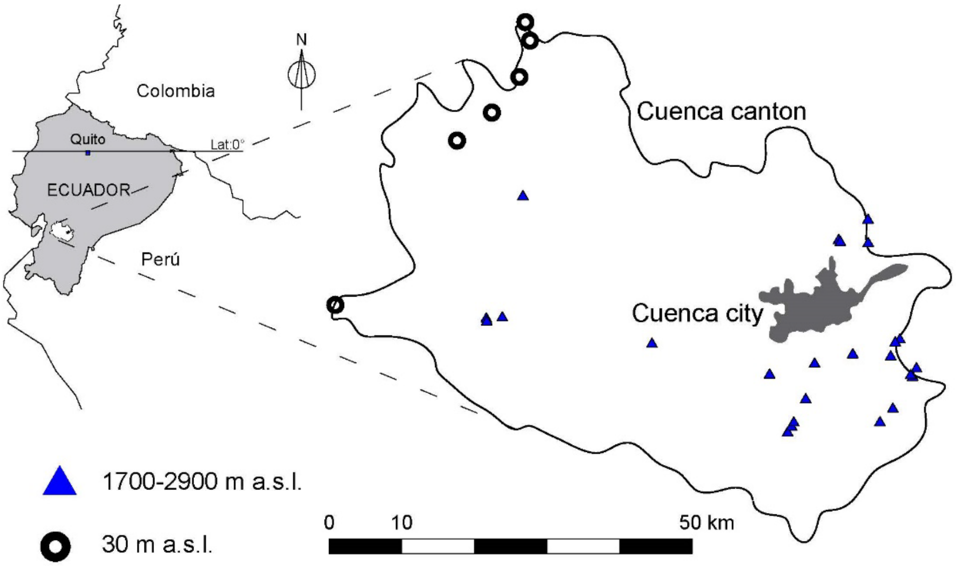

Figure 1. Location of the decentralized wastewater treatment facilities in the Cuenca canton.

In the rural area of Ecuador and especially in the south Andean region, the main objective of any sanitation program is still to prevent the spread of diseases, which means that a wastewater treatment facility must effectively decrease the pathogen organisms in the effluent. However, as widely addressed, small and compact anaerobic reactors are not efficient removing pathogenic organisms (Chernicharo et al., 2015). Table 1 shows that not post-treatment is included in any of the full anaerobic systems, which implies that at least the disinfection objective was never met in any of those systems as analysed further in this document.

Table 1 highlight as well, the presence or absence of preliminary treatment in the systems. In most cases, an overflow structure, coarse screening and a small grit chamber are included in the configuration. Similar to the dimensions of the reactors, the preliminary units are almost identical in size and configuration in all the systems analysed. Finally, it is noticed that nearly 65 % of the systems include a dry bed for the excess sludge. However, none is currently operating, and only few hardly operated during a small period after the start of the systems (Ordóñez, 2009). In few cases the dry beds are being used with minimal efficiency as filtration chambers for polishing the effluent.

Table 1. Infrastructure and Technology of the Decentralized Wastewater Systems

Nº	System Name (Location)	In Operation	Access Roads	Served Area	Altitude	T	O&M Plan	Preliminary Treatment			Primary Treatment			Secondary Treatment			Sludge drying bed	Final Disposal
				ha	m a.s.l	°C		By-Pass	Screen	Grit Chamber	Type	Chamber	L;W;D [m]	Type-number	Filter Media	L;W;D [m]		
1	Ricaurte (Flor de Camino)	---	---	N/D														
2	Molleturo (Luz y Guía)	---	---	N/D														
3	Abdón Calderón (Molleturo)	✓	✓	72.2	30	22	✓	OS	✓	---	ST	2	N/D	FWSW-2	---	N/D	✓	Stream
4	Estero Piedra (Molleturo)	✓	✓	N/D	30	22	✓	OS	✓	✓	ST	2	N/D	FWSW-2	---	N/D	✓	TL
5	Flor y Selva (Molleturo)	✓	✓	55.8	30	22	✓	OS	✓	---	ST	2	N/D	FWSW-2	---	N/D	✓	TL
6	Jesús del Gran Poder (Molleturo)	✓	✓	417.5	30	22	✓	OS	✓	---	ST	2	N/D	FWSW-1	---	N/D	✓	Infil
7	La Suya (Molleturo)	✓	✓	43.5	30	22	✓	OS	✓	---	ST	2	N/D	HF/AF	Gravel	---	✓	TL
8	Tamarindo (Molleturo)	✓	✓	N/D	30	22	✓	OS	✓	---	ST	2	N/D	FWSW-1	---	N/D	✓	Stream
9	San Antonio (Chaucha)	✓	---	N/D	1700	18	✓	---	✓	---	ST	2	N/D	VF/AF	Gravel	---	---	Stream
10	San Gabriel - Parte Baja (Chaucha)	✓	---	N/D	1700	18	✓	N/D			ST	N/D		HF/AF	N/D	---	---	N/D
11	San Gabriel (Chaucha)	✓	---	75.2	1700	18	✓	N/D			ST	N/D		HF/AF	N/D	---	---	N/D
12	Cruz Verde (Chiquintad)	✓	---	75.2	2440	17	---	OS	---	---	ST	2	N/D	---	---	---	---	Stream
13	La Isla (Chiquintad)	✓	---	54.3	2440	17	✓	N/D			ST	N/D		AF/--	N/D	---	---	N/D
14	Churuguzo (Victoria del Portete)	✓	✓	226.5	2500	11	✓	---	✓	✓	ST	2	11,9;3,4;2,5	FWSW-2	---	34,5;20,2;1,8	✓	Stream
15	Escaleras (Victoria del Portete)	✓	✓	49.3	2500	11	---	OS	✓	✓	ST	2	N/D	VF/AF	Brick	---	✓	Stream
16	Cumbe (Victoria del Portete)	✓	✓	40.3	2500	11	---	---	✓	---	ST	2	N/D	VF/AF	Gravel	---	✓	Stream
17	Quillopungo (El Valle)	✓	✓	150.8	2520	15	✓	OS	✓	---	UASB	3	N/D	HF/AF	Gravel	---	✓	Stream
18	Soldados (San Joaquín)	✓	---	N/D	2550	17	✓	OS	✓	---	ST	3	7,3;3,0;2,9	FWSW-1	---	31,7;18,7;2,5	✓	Stream
19	Acchayacu (Tarqui)	✓	✓	129.4	2582	14	✓	---	✓	---	ST	2	N/D	VF/AF	Brick	---	---	Stream
20	Tutupali (Tarqui)	✓	✓	41.5	2582	14	✓	OS	✓	---	ST	2	N/D	VF/AF	Brick	---	✓	Stream
21	El Chorro (Santa Ana)	✓	---	47.9	2600	17	✓	---	---	✓	ST	2	N/D	VF/AF	Brick	---	---	Stream
22	Guabo (Sidcay)	✓	✓	25.4	2600	14	✓	OS	---	---	ST	2	9,4;3,1;1,5	VF/AF	Brick	---	✓	Stream
23	Santa Ana Laureles (Santa Ana)	✓	---	24.4	2600	17	---	OS	✓	---	ST	2	9,4;3,0;1,5	VF/AF	Gravel	---	---	Stream
24	San Pedro (Santa Ana)	✓	✓	71.0	2600	17	✓	OS	✓	---	ST	2	11,1;4,3;2,7	VF/AF	Brick	2,5 Di 3,3 D	✓	Stream
25	Santa Ana Cementerio (Santa Ana)	✓	✓	32.9	2600	17	✓	OS	✓	✓	ST	2	9,4;3,1;1,5	VF/AF	Brick	---	✓	Stream
26	Santa Bárbara (Santa Ana)	✓	---	8.6	2600	17	---	---	---	---	ST	2	N/D	HF/AF	Gravel	---	---	Stream
27	Macas de Quingeo (Quingeo)	✓	✓	11.1	2792	15	---	---	---	---	ST	2	7,6;2,9;2,9	HF/AF	Gravel	7,6;2,9;2,9	---	Stream
28	Quingeo Centro (Quingeo)	✓	✓	103.6	2792	15	---	---	✓	---	ST	2	N/D	VF/AF	Gravel	---	✓	Stream
29	Octavio Cordero Palacios	✓	---	38.4	2820	17	✓	N/D			ST	4	4,8;4,7;1,5	---	---	---	---	Stream
30	Tarqui Centro (Victoria del Portete)	✓	✓	605.1	2852	11	✓	OS	✓	---	ST	2	11,0;3,9;2,8	FWSW-2	---	N/D	✓	N/D
31	Bella Unión (Santa Ana)	✓	✓	76.5	2900	12	✓	OS	✓	---	ST	4	N/D	VF/AF	Brick	---	✓	Stream
32	Pueblo Nuevo (Molleturo)	✓	✓	55.8	3500	5	✓	---	---	---	ST	1	N/D	HF/AF	Gravel	---	✓	Stream

Legend:

T	Temperature	OS	Overflow Structure	VF/AF	Vertical Flow Anaerobic Filter	TL	Tideland
L;W;D	Length;Width;Depth	ST	Septic Tank	HF/AF	Horizontal Flow Anaerobic Filter	Infil	Soil Infiltration
m a.s.l.	Meters above sea level	UASB	Upflow anaerobic sludge blanket reactor	Di	Diameter	✓	Available
O&M	Operation and Maintenance	FWSW	Free Water Surface Wetland	N/D	Not Data	---	Not available

Technological and physical evaluation

Sewerage network. All the DWWT systems are connected to a sanitary system, serving an average of 200 people (Neira, 2005). The network underlies public and private lands, which makes it vulnerable to connect illicit discharges into the pipes and the manholes.

Preliminary treatment. The overflows to the systems are controlled with a bypass structure, which is composed by a manhole with a small baffle/weir inside in which the excess wastewater surpassing the baffle are evacuated directly into the receiving water body through a bypassing pipe. This network configuration, unfortunately does not guarantee the entrance of particulate material to the system. Additionally, after the first global evaluations, screen bars and settlers were built in many systems before the STs, which, nonetheless are not sufficient to prevent the clogging of the STs when large rainfall events occur.

Septic Tanks (ST). The STs analysed are commonly composed by a two chambers reactor of around 80 to 100 m^3 (3,0 m depth and a relation L/B around 2,5). The STs are in good structural conditions after 10 to 15 years of construction and all of them contain ventilation pipes, inspection manholes and inlet/outlet baffles as recommended for a good performance (Mara, 1996).

Constructed Wetlands (CW). CWs are present as secondary treatment in the 25% of the systems analysed. All of the CWs are Free Water Surface Wetland (FWSW) configuration with inlet/outlet structures composed by perforated pipes to distribute and collect the influent/effluent from the reactor. The 8 secondary FWSWs use water hyacinths (*Eichhornia crassipes*) as the main aquatic plant species.

Vertical Flow Anaerobic Filter (VF/AF). Used as secondary treatment for the effluents of the ST. All of them are composed by circular covered chamber with granular media (brick pieces and/or gravel) along the 70% of the reactor depth. There are not structures for biogas recovery. The influent/effluent consist to a perforated pipes located at bottom and top of the upflow configuration reactor. There is one exception (Bella Unión) where the VF/AF consist in a rectangular shaped open reactor. Despite of the expected acidity environment inside, VF/AF reactors are in good structural conditions.

Horizontal Flow Anaerobic Filter (HF/AF). Used also as secondary treatment for the STs. The easier and economical construction in comparison to VF/AF, make this technology attractive for some sites. In this configuration, the ST and the HF/AF are constructed in a single enclosed chamber with a dividing wall for the two stages (monoblock). The media used is gravel and typically cover the 50% of the total reactor depth. A perforated wall distribute the influent in the filter. The physical infrastructure are in good conditions in the systems visited. However, a considerable clogging was observed in the perforated walls and the media surface.

Upflow Anaerobic Sludge Blanket (UASB). Only one system (Quillopungo) out of 32 is composed by an UASB reactor as primary treatment. In the main reactors (3) of this system, the influent is discharged at the bottom of the reactor by a single pipe and the effluent is collected by a perforated pipe with no biogas collection system. The three phase separator (De Lemos Chernicharo, 2007) was not working properly during the several visits to this system, there were no baffles to prevent biogas in the sedimentation chamber having as a consequence high concentration of suspended solids in the effluent. This WWTP is the only one with a designed stage for disinfection (chlorine contact chamber), but, this chamber was never used as such.

Table 2. Characterization inventory of the Decentralized Wastewater Systems

Nº	System Name (Location)	Date	Discharge	BOD_5		COD		TKN		TP		TSS		TS		TC		ThC		pH
			m^3/day	mg / L												MPN / 100 mL				-
				Inf	Rem	Inf	Rem	Inf	Rem	Inf	Rem	Inf	Rem	Inf	Rem	Inf	Eff	Inf	Eff	Inf
1	Ricaurte (Flor de Camino)	Feb, 2009	---	155	60%	347	47%	13.5	N/D	5.7	N/D	222	N/D	821	N/D	2.4E+07	2.4E+07	2.4E+07	2.4E+07	7.6
2	Molleturo (Luz y Guía)	Sep, 2009	---	58	81%	24	-11%	N/D		N/D		23	35%	154	12%	2.2E+05	1.2E+04	N/D		6.7
14	Churuguzo (Victoria del Portete)	June, 2014	---	30	60%	174	59%	6.0	-25%	1.4	22%	74	88%	268	20%	1.1E+06	1.6E+06	1.1E+06	1.6E+06	6.7
		Feb, 2016		170	90%	603	85%	12.5	52%	3.2	67%	496	98%	776	72%	4.90E+06	1.70E+06	4.9E+06	4.6E+05	6.8
15	Escaleras (Victoria del Portete)	Feb, 2016	---	420	89%	1744	95%	83	54%	4.6	13%	1636	98%	1984	79%	1.4E+06	3.5E+07	1.4E+06	1.7E+07	6.7
17	Quillopungo (El Valle)	Dec, 2015	---	100	60%	279	61%	53	41%	3.9	23%	156	85%	518	37%	7.0E+06	2.0E+06	7.0E+06	1.1E+06	7.2
		May, 2016	126	47	79%	218	64%	23	35%	1.8	16%	114	95%	506	16%	1.7E+06	4.9E+05	1.7E+06	3.3E+05	7.0
18	Soldados (San Joaquín)	June, 2014	---	33	70%	149	77%	3	32%	1.5	64%	53	45%	162	44%	7.9E+05	7.9E+04	2.7E+05	1.7E+04	7.0
22	Guabo (Sidcay)	2015	20	49	67%	113	53%	N/D		3.3	48%	21	48%	169	8%	5.2E+07	1.3E+07	8.4E+06	4.9E+06	---
		Apr, 2016	---	245	90%	977	97%	44	49%	3.4	28%	1550	99%	1842	87%	1.7E+06	7.9E+06	1.7E+06	4.9E+06	6.7
23	Santa Ana Laureles (Santa Ana)	Oct, 2015	33	365	86%	839	70%	134	14%	7.5	0.2	436	95%	1134	47%	1.30E+07	3.30E+06	1.30E+07	1.70E+06	7.3
		Feb, 2016		170	48%	413	15%	51	-67%	4.4	-0.8	26	-177%	557	-2%	2.40E+07	2.30E+04	2.40E+07	2.30E+04	7.6
24	San Pedro (Santa Ana)	June, 2014	---	580	96%	2038	94%	229	98%	N/D		229	91%	1236	69%	1.6E+12	2.8E+07	3.5E+11	1.7E+07	9.2
25	Santa Ana Cementerio (Santa Ana)	Dec, 2015	20	265	71%	684	62%	122	23%	11.9	23%	161	70%	815	37%	1.7E+07	1.7E+07	1.7E+07	1.7E+07	7.4
		May, 2016		375	86%	818	77%	74	34%	7.0	41%	210	86%	930	46%	2.3E+07	4.9E+06	1.3E+07	4.9E+06	7.3
27	Macas de Quingeo (Quingeo)	Oct, 2015	---	223	92%	440	85%	53	72%	3.1	58%	72	93%	593	65%	4.9E+06	5.4E+06	4.9E+06	7.9E+05	7.1
		Mar, 2016	---	58	60%	142	68%	26	5%	3.3	34%	69	88%	298	24%	4.90E+06	4.9E+06	4.9E+06	3.3E+06	6.8
28	Quingeo Centro (Quingeo)	Jan, 2009	---	10	-150%	32	-128%	1.3	-122%	N/D		43	23%	283	-46%	7.9E+05	2.4E+06	2.2E+05	1.3E+06	7.0
		Feb, 2015	---	46	59%	147	66%	26	-5%	1.7	-0.1	62	81%	344	19%	2.20E+06	9.40E+05	1.40E+06	9.40E+05	7.1
29	Octavio Cordero Palacios	2015	24	63	-27%	142	-29%	---	---	3.9	15%	62	-85%	601	-36%	1.3E+08	3.4E+07	7.7E+07	1.3E+07	---
30	Tarqui Centro (Victoria del Portete)	Sep, 2010	---	133	81%	313	70%	N/D		7.4	25%	95	80%	407	-42%	7.7E+07	3.7E+07	3.4E+07	2.4E+07	7.3
		May, 2016		225	76%	841	70%	21.4	56%	18.9	92%	840	73%	1376	56%	1.30E+06	2.30E+06	1.30E+06	2.30E+06	6.3
31	Bella Unión (Santa Ana)	Mar, 2016	---	620	95%	2488	94%	238	77%	22.4	75%	2412	99%	2742	86%	4.9E+07	7.9E+06	1.40E+07	4.90E+06	6.7
32	Pueblo Nuevo (Molleturo)	---	---	---	---	---	---	---	---	---	---	62	-85%	---	---	---	---	---	---	---

Legend**:**

Inf	Influent	COD	Chemical Oxygen Demand	TS	Total Solids	---	Not available
Eff	Effluent	TKN	Total Kjeldahl Nitrogen	TC	Total Coliforms		
Rem	Removal	TP	Total Phosphorus	ThC	Total Thermotolerant Coliforms		
BOD	Biochemical Oxygen Demand	TSS	Total Suspended Solids	N/D	Not data		

Treatment processes evaluation

In Table 2 is presented the main figures of the characterization of the systems. It is noticeable the very low concentration of the organic matter and other constituents in the influent of some systems, which denotes the very high diluted wastewater entering the systems despite of the sanitary sewerage network present in all the served areas. This problem has been acknowledged by ETAPA and the presence of recurrent illicit waters entering the network was identified. The illicit discharges have produced recurrent overflows in the systems, consequently, bypassing flows are often present in the receiving water bodies. The illicit discharges have several sources, the main ones detected are as follows: i) Drainage of field crops and irrigation water excesses, which could enclose high concentrations of pesticides and other farming products that could be toxic for some anaerobic biomass, inhibiting the biological processes (Crites and Tchobanoglous, 1998; Von Sperling and de Lemos Chernicharo, 2005). ii) Runoff from roofs, courtyards, terraces, etc., and other effluents from households, in which there is a high risk to allow in the system uncontrolled particulate material and very high punctual discharges during rainfalls; and, iii) runoff from roads and other public spaces, which normally enter into the sewerage network through the manholes. There are recurrent incidents reported to ETAPA in which the manholes have been opened to allow stagnant flows be evacuated easily and fast from no-pavement roads, causing vast amounts of sand, clays and other particulate material to clogging the preliminary treatment and even the STs during and after high rainfall events. There are serious difficulties to solve these problems for several factors described in the O&M section of this document.

Table 3. Summary of the global efficiencies and main problems for each technology used

Technology	# of systems	Removal min; mean; max	recurrent problems observed
ST + HF/AF	7	COD: 61; 75; 85% (2); TC: <0; <1; 2 log (2)	Clogging of ST and AFs
ST + VF/AF	12	COD: -118; 54; 97% (7); TC: <0; <1; 5 log (7)	Clogging of ST and AFs; organic overload;
ST + FWSW	8	COD:59; 73; 85% (3); TC: <0; <1; 1 log (3)	Clogging of ST; Clogging of ST; short circuiting in FWSW
ST + FWSW + Infil	1	-	-
UASB + HF/AF	1	COD: 62% (1); TC: <1 log (1)	Organic overload; clogging of AFs
Only ST	2	COD: -28% (1); TC: <1 log (1)	Clogging of ST

COD: Chemical Oxygen demand; TC: Total coliforms; (N) Number of systems characterised; ST: Septic Tank; AF: Anaerobic Filter; HF: Horizontal Flow; VF: Vertical Flow; FWSW: Free Water Surface Wetland; Infil: Soil Infiltration; UASB: Upflow anaerobic sludge blanket; OUT: Currently out of operation.

In Table 2 and Table 3 is shown the efficiencies in the organic removal in some of the systems. These data correspond in some cases to only one characterization performed normally few weeks after an integral maintenance of the systems. A maintenance implies, a complete cleaning of the STs, and the removal, clean and relocation of the media filter in the anaerobic reactors, replacing the media filter, in some cases. In this way, after a maintenance, it is expected that an important percentage of the particulate organic matter is retained in the STs and media filter during the first days/weeks of operation. Therefore, some removal efficiencies shown in the Table 2 (see characterizations performed in 2016) should be analysed carefully, since they may not be reflecting the quality of the bioprocesses in the reactors. It is also highlighted in Table 2 the almost negligible removal of pathogenic organisms in the fully anaerobic systems. As stated before, this fact was expected due to the typical low efficiency of the anaerobic processes in this regard. It is emphasised that none of the systems characterised in terms of FC, are achieving the Ecuadorian standards for neither discharging in fresh water bodies nor for water reuse in crop irrigation (<1000 MPN/100mL) (Ministerio del Ambiente del Ecuador, 2015); therefore, these effluents would need obligatory disinfection for any practical use downstream. Table 2 is also depicting the very high variability in the organic loads to the systems, despite of the similarities in the systems size and population served. This could be also explained by the presence of illicit discharges in the sanitary sewerage.

Operation and Maintenance evaluation

ETAPA, which has permanent and well trained personnel for the operation of Ucubamba WSP, has evolved along the time to the needs in operation and maintenance of the decentralized systems. Initially, around 20 years ago, the activities for maintenance of the WWTPs were in charge of the same maintenance unit in charge of the sewerage system. The specific needs for personnel trained in wastewater treatment, obliged to ETAPA to create new maintenance teams exclusively for the O&M of the WWTPs. This personnel obviously implies permanent human and economic resources that is demanding great efforts since the 32 systems are localized in remote areas as shown in the Figure 1.

A recurrent problem for the O&M of the systems, as detailed in previous section is the uncontrolled particulate material entering the systems during rainfall events. The clogging of the preliminary treatment units has been already reported during the past evaluations and is still present nowadays. The location and extension of the sewerage network made almost impossible for ETAPA to prevent the illicit discharges despite of the continuous monitoring. The vast amounts of particulate material will be continuously entering the sewerage if the community served do not take care of the sewerage infrastructure, especially the manholes. The unpaved roads in conjunction to the natural steep slopes will affect the performance of the systems for many years to come, therefore, the efforts should be oriented also to the education of population served about the direct benefits to their public health if the wastewater is treated before discharging in the streams.

It is also noticed in Table 1 that 12 systems do not have access roads. This fact is definitely hindering a proper maintenance and is demanding more human and economic resources in the long run. It is not surprising to find in Table 1 that half of the systems without a maintenance plan correspond to systems without car access. The land and economical resources availability in the Andean region of Ecuador is certainly an important factor limiting the location of the WWTPs; nevertheless, for the systems with remote location, it is emphasized the need to build capacities in local organizations to get involved in the O&M and therefore in the advantages to have sustainable wastewater treatment for their effluents

CONCLUSIONS

The conclusions can be summarised as follows:

- Despite of having separate sanitary systems, there are significant amounts of particulate material entering the WWTPs during rainfall events causing the collapse of the pre-treatment structures and occasionally clogging the primary STs. Unfortunately, in some cases, the population served by the system is contributing to this problem opening the manholes to evacuate stagnant waters from roads and public spaces.
- In some cases, when a partial or full clogging of some units need an urgent intervention, the remote location of some systems together to the inaccessibility by car in some DWWT sites, are directly contributing to the lack of maintenance of the systems, because only manual cleaning

and minor activities can be performed at the sites. Unfortunately, in some cases, this fact has directly contributed to decrease the efficiency of the system and in some cases, the abandon of the systems.

- The community served by the DWWT systems has never been involved in the O&M of the systems, giving the full responsibility to ETAPA. From the assessment of these and many other decentralized systems in developing countries, it is strongly recommended to create real capacities and compromises in the local communities with regard to the O&M of the systems by means of education about the benefits of the wastewater treatment.
- The pathogen concentration in the effluents of the systems is currently restrictive for productive uses downstream. The anaerobic treatments are very inefficient for removing pathogen organisms; and, despite of some minor removal in the CW systems, the concentration of FC is still very high in the systems analysed. There is room for improvement in this regard, by means of adding disinfection units, although, this action should be carefully analysed since the high concentration of suspended solids in the effluents may hinder the disinfection processes.
- The frequent (and needed) cleaning up of the systems is causing the wash out of the biomass that hardly grew up on those operation conditions. In this way, there is low biological activity in the reactors, while the physical processes (sedimentation and filtration) are almost the only mechanism of BOD removal in many systems analysed. It is strongly recommended to the operators of the systems to sustain the conditions for a real grow of anaerobic biomass, which can take up to several months at the temperatures of the Andean region and to perform characterizations of the biomass activity for longer periods during the regular operation of the systems.

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