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Management challenges for a more decentralized treatment and reuse of domestic wastewater in metropolitan areas

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ABSTRACT

In a case study located in suburban sectors of the metropolitan area of the Lerma Valley (Valle de Lerma), in the province of Salta (Argentina), 24 informal decentralized wastewater treatment systems (DWWTS) were evaluated. The analyzed systems had three general configurations: A, septic tank; B, septic tank combined with upflow anaerobic sludge blanket (UASB) reactor; C, septic tank combined with UASB and a final filtration step. Statistically significant differences ($p < 0.05$) were observed in effluent quality, measured as total coliforms, thermotolerant coliforms, and chemical oxygen demand (COD). Treatment A was the most inefficient, and was statistically different from B and C; there were no significant differences between the latter two. Thermotolerant coliform concentrations were high in all analyzed systems and did not comply with local discharge standards in soakaway pits or in the ground. The lack of a final disinfection step in these systems is thus a weakness that needs to be addressed. The formal inclusion of DWWTS in urban planning could reduce overall investment costs, as long as the best technologies are selected for each case. Incorporation of DWWTS in formal urban planning requires an open debate in which the social perspectives of all relevant users need to be considered.

Key words | decentralized sanitation, decentralized wastewater treatment systems, domestic wastewater, metropolitan areas, Salta, wastewater reuse

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INTRODUCTION

On a global level, billions of people are suffering from health and environmental problems due to inappropriate sanitation and wastewater treatment. This situation is particularly serious in developing countries, in peripheric slums, and suburban areas without sewer networks (Singh *et al.* 2015). Suburban areas are defined as a mixture of land uses associated with a range of urban and rural livelihoods (Parkinson & Tayler 2003). Suburban areas increase the vulnerability of metropolitan sectors to social and environmental changes. In some developing countries, urbanization is increasing faster than formal urban planning, with profound consequences on the availability of basic sanitation services. Overcoming this scenario demands rethinking current paradigms about domestic wastewater treatment services (Chirisa *et al.* 2017).

Sanitation policies exclusively focusing on centralized systems are unfeasible for many regions around the world (Allen *et al.* 2006). The utilization of decentralized wastewater treatment systems (DWWTS) has become a focus of interest in places lacking sanitation services (Yates 1985;

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Otterpohl *et al.* 1997; Zeeman & Lettinga 1999; Bradley *et al.* 2002; Chung *et al.* 2008; Massoud *et al.* 2009; Guo *et al.* 2014). DWWTS include a wide range of technological options providing treatment near the place of generation, minimizing transport and therefore costs (Wilderer & Schreff 2000). The decentralization level of domestic wastewater treatment has several scales: from individual, on-site systems (fully decentralized), to semi-centralized plants treating the effluents of isolated neighborhoods (Libralato *et al.* 2012; van Afferden *et al.* 2015). The combination of different technologies in complex decentralized treatment systems is also a focus of current research (Steer *et al.* 2002; El-Khateeb & El-Gohary 2003; Sabry 2010; Starkl *et al.* 2013; Singh *et al.* 2015). Although the discussion as to when the systems are no longer decentralized remains open, in many countries some of these technologies are not yet formally accepted or included in environmental legislation, and there is a lack of suitable institutional arrangements and legal framework for the promotion and incorporation of DWWTS in formal urban planning (Parkinson & Tayler 2003; de Graaf *et al.* 2011; Arora *et al.* 2016; Chirisa *et al.* 2017).

Urban sprawl has come to characterize some metropolitan areas of Argentina, a country where only 52% of houses are connected to a formal sewer network. In the Lerma Valley in northern Argentina (province of Salta), water and sanitation management faces new challenges due to urban growth and mounting pressure on drinking water sources (Iribarnegaray *et al.* 2012; Iribarnegaray *et al.* 2015). One of the most important environmental problems is the discharge of raw or partially treated sewage into rivers, water bodies, and the soil. Despite the long-term use of several types of DWWTS (usually septic tanks), there is little information about the performance, institutional control, and social perspectives with respect to them. This contrasts with growing knowledge related to the technical characteristics of more advanced configurations of DWWTS, especially among some local specialists (Seghezzo *et al.* 2003). However, the performance and the potential health and environmental risks of DWWTS have not yet been thoroughly studied at the local level. In unplanned settlements and slums, septic tanks are used as ‘transitory’ DWWTS, generally with final disposal in soakaway pits. Such settlements are not provided with formal, centralized wastewater services for varying periods of time (usually years or decades). The diffuse pollution produced, exacerbated by housing density, is a serious health and environmental risk which is not adequately addressed by local institutions. In suburban sectors located far away from sewer networks and wastewater treatment plants, DWWTS are often the only viable treatment option. These sectors with incipient urbanization and diverse socio-economic conditions are in constant development throughout the metropolitan area.

In this paper, we present an evaluation of effluents from several DWWTS treating domestic wastewater in the metropolitan area of the Lerma Valley (Salta, Argentina). The evaluated systems are currently used in: (a) unplanned settlements within or on the perimeter of consolidated urban centers; (b) dispersed urban sectors throughout suburban areas of the Lerma Valley; and (c) gated communities and private urban development projects. This study was not meant to assess the removal efficiency of different treatment systems, but rather to compare the ability of these systems to comply with local discharge standards. We assess the problems associated with the final disposal or reuse of these effluents, estimate possible impacts on local urban planning, and discuss future challenges for decentralized wastewater treatment systems in the region.

METHODS

The case study

The Lerma Valley occupies an area of 600 km^2 and is located at about 1,200 m.a.s.l. Total population in the valley amounts to 620,000 inhabitants, distributed in numerous urban conglomerates and rural areas (Figure 1). While more than 530,000 inhabitants are concentrated in the provincial capital, the city of Salta, the population living in the metropolitan area of the Lerma Valley represents more than 50% of the population of the entire province. In the last ten years, the population of the metropolitan area has increased 28.8%, while Salta city has increased 13.2% (INDEC 2010). The climate in this valley is subtropical with a dry season (from April to November). Rainfall varies between

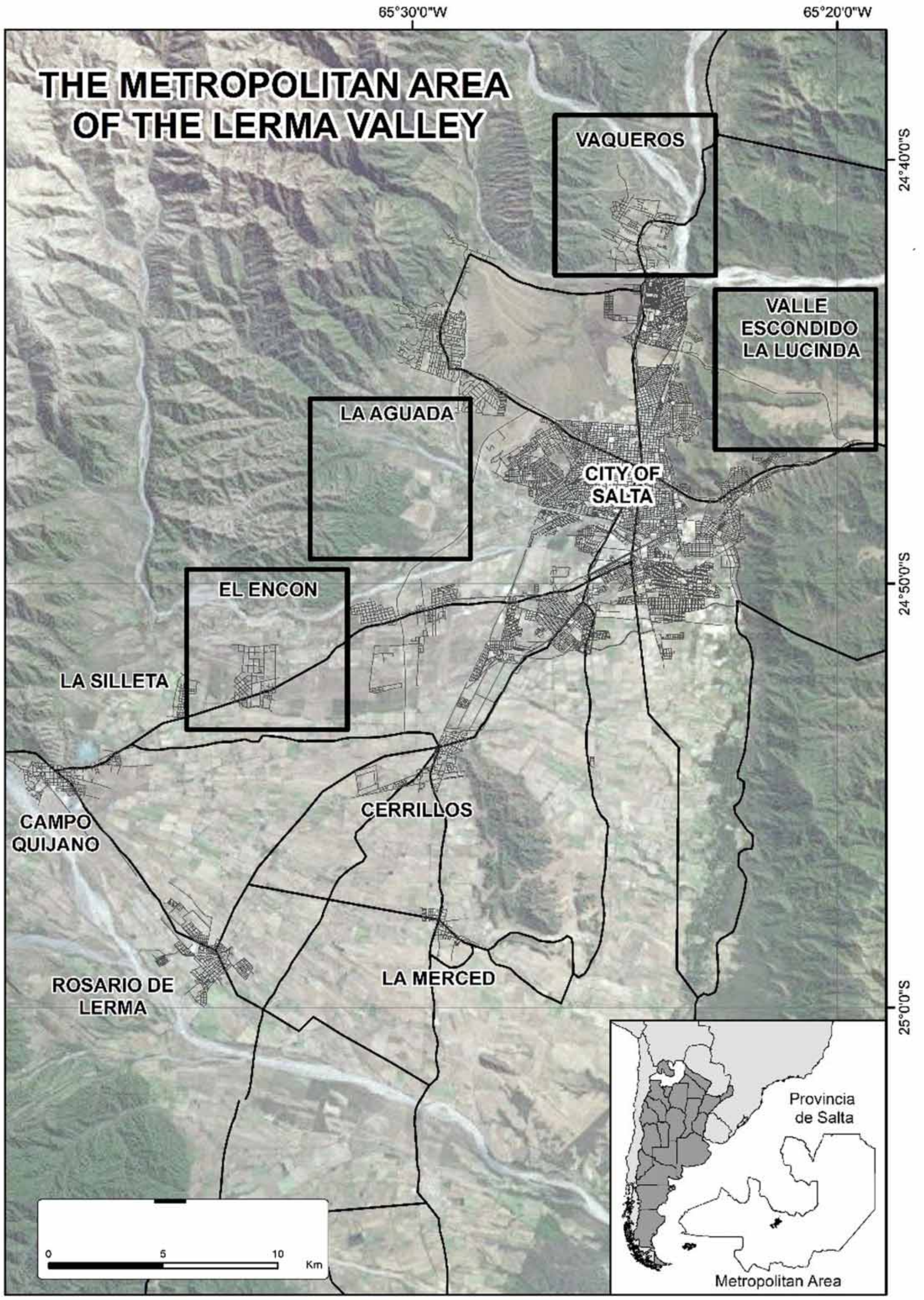

Figure 1 | Metropolitan area of the Lerma Valley, in the province of Salta (northern Argentina). The rectangles indicate the sectors where DWWTS were sampled.

700 mm in the south to more than 1,500 mm on the hillsides of the north. The average temperature of the city is 16.5°C.

Although the coverage of the sewage network in the city of Salta is relatively high (over 80%), there are important sectors without service availability. In addition to the city of Salta, the study area included seven satellite towns with strong interactivity: La Caldera, Vaqueros, Campo Quijano, Rosario de Lerma, Cerrillos, La Merced, and San Lorenzo. Centralized wastewater infrastructure in these urban centers is very limited or non-existent. The rapid growth of urban centers and the progressive urbanization of interurban spaces call for urgent investments in sanitation infrastructure. High investment costs involved in centralized systems favored the development of several types of DWWTS. In areas where these systems are currently in use, no formal monitoring system has been set in place by water companies or the government. The simplest and most widely used DWWTS configuration is a septic tank usually followed by some type of soakaway pit. Potentially high environmental impacts of the massive use of septic tanks in inadequate areas is apparently an 'invisible' problem for local institutions and urban developers (Yates 1985). The discharge of high concentrations of organic matter and pathogens in the ground (via soakaway pits) is risky in places where aquifers are vulnerable or are being used as a source of drinking water (Naughton & Hynds 2014). With the aim to complement the limited treatment efficiency of septic tanks, more complex configurations of DWWTS have been adopted. Improvements include additional biological treatment steps and a final filtering unit, with variations and adaptations on a case-by-case basis. The technological alternative of treating domestic wastewater using an upflow anaerobic sludge blanket (UASB) reactor has been extensively evaluated (Bogte *et al.* 1993; Abdel-Shafy *et al.* 2015). Research on anaerobic wastewater treatment systems in Salta began in 1995, when the first pilot-scale UASB reactor for sewage treatment was started up. Since then, many years of research have demonstrated the feasibility of this technology for the treatment of both raw and pre-settled sewage under local environmental conditions (Seghezzo *et al.* 2003). A spin-off of this research was the popularization of a type of DWWTS locally known as STAR system, an acronym for 'wastewater treatment system' in Spanish (Sistema de Tratamiento de Aguas Residuales). This system has been widely used in gated communities and private residential areas, where internal regulations and the need for irrigation water favored its dissemination.

Systems

Effluents from 24 informal DWWTS were sampled before final disposal (Table 1). Three system configurations were evaluated (Figure 2(a)–2(c)): A, septic tank; B, septic tank combined with a UASB reactor; and C, septic tank with UASB reactor and a filter as final treatment step (STAR system). The septic tank is the simplest arrangement and is often combined with soakaway pits. Septic tanks evaluated were either made of concrete or plastic (polyester reinforced with glass fiber). In configurations B and C, the UASB reactor constitutes the biological step (Figure 2(b)). In UASB reactors, treatment is carried out in an upflow tank by a sludge blanket that is formed at the base of the reactor, which consumes the organic fraction in a metabolic process that develops in the absence of oxygen (Seghezzo *et al.* 1998). In two type B systems, the UASB was replaced with a biodigester available in the local market with comparable operating conditions. In the third configuration, a final filtering device was added (Figure 2(c)). Filtering materials vary, with the most used being coarse sand and gravel. In this unit, the liquid goes through a bed of gravel of varying size in which a biofilm of bacteria is generated. This unit is intended to remove remnant suspended solids coming from the UASB reactor. Some systems included a fat trap. None of the systems included separation of black and gray water. Hydraulic retention time in UASB reactors and anaerobic filters varied between 6 to 12 and 2 to 4 hours, respectively (Seghezzo *et al.* 2003). Retention time in septic tanks is highly variable. Single-family UASB reactors assessed were in the range of 0.5 to 0.7 m^3, considering a water consumption around 250 L/person·d.

Samples, laboratory techniques, and local legislation

Samples were taken by personnel of the Laboratory of Environmental Studies (LEA) at the National University of Salta (UNSa). Samples were kept at 4°C until analyzed. pH was measured at the moment of sampling. Organic matter, as total chemical oxygen demand (COD) was determined. Settleable solids at 10 min and 2 hr were determined in Imhoff cones. Analyses were performed according to *Standard Methods for the Examination of Water and Wastewater for Surface Waters* (Eaton *et al.* 2005) or using HACH® micro methods. Bacteriological variables determined were total coliforms (TC) and thermotolerant coliforms (FC), using the technique of fermentation in multiple tubes and successive dilutions using MacConkey broth (Britania Lab Argentina) and

Table 1 | Detailed configuration, materials, location, and final disposal of evaluated systems

System	Persons	Type	Configuration	Material	Location	Final disposal
S1	3	A	ST	Concrete	Vaqueros	Soakaway pit
S2	3	A	ST	Polyester	El Encón	Sub. drainage
S3	4	A	ST	Concrete	Vaqueros	Soakaway pit
S4	3	A	ST	Concrete	Vaqueros	Soakaway pit
S5	1	A	ST	Polyester	El Encón	Soakaway pit
S6	4	B	ST + UASB	Concrete	Vaqueros	Soakaway pit
S7	3	B	ST + UASB	Concrete + PFG	Vaqueros	Soakaway pit
S8	2	B	ST + BR	Concrete + P	Valle Escondido	Native forest
S9	5	B	ST + UASB	Concrete + PFG	Vaqueros	Soakaway pit
S10	4	B	ST + UASB	Concrete + PFG	Vaqueros	Soakaway pit
S11	4	B	ST + UASB	Concrete	La Lucinda	Sub. drainage
S12	3	B	ST + UASB	Concrete	La Lucinda	Sub. drainage
S13	2	B	ST + BR	Concrete + P	La Lucinda	Irrigation
S14	2	C	ST + UASB + F	Concrete	La Lucinda	Irrigation
S15	5	C	ST + UASB + F	Concrete	La Aguada	Soakaway pit
S16	5	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation
S17	4	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation
S18	4	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation
S19	3	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation
S20	4	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation
S21	3	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation
S22	2	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation
S23	4	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation
S24	5	C	ST + UASB + F	Concrete	Valle Escondido	Irrigation

ST: septic tank; BR: bioreactor; UASB: upflow anaerobic sludge blanket reactor; P: polyester; PFG: polyester reinforced with glass fiber.

incubating at 37°C ± 0.5°C for 48 hours for TC and 44.5°C ± 0.5°C for 24 hours for FC. Bacterial concentration was expressed in MPN (most probable number)/100 mL. Local regulations were used to evaluate effluent standards (Ordinance 10438/00, Municipality of Salta, and Resolution 011/01, provincial Ministry of Environment and Sustainable Development (Table 2).

Data analysis was performed using INFOSTAT software (Di Rienzo *et al.* 2015). A variance analysis was used to compare different DWWTSs when data were normally distributed (checked with the Q-Q-Plot graphical method) and variances were homogenous (checked with the Levene test). If this was not the case, non-parametric statistics were used (Kruskal–Wallis). After variance analysis, post-hoc comparisons were made to detect differences between groups using the procedure described in Conover (1999).

RESULTS AND DISCUSSION

As seen in Table 3, some of the variables analyzed exceeded the limits set by local legislation. pH values were all in the acceptable range. Only one sample from a system B exceeded discharge standards for settleable solids (2 hours), but only 35% of the samples complied with both legislation limits for settleable solids (10 minutes). Similarly, less than half of the samples (47%) complied simultaneously for COD discharge standards. Samples that complied with both legislations corresponded to system types B and C.

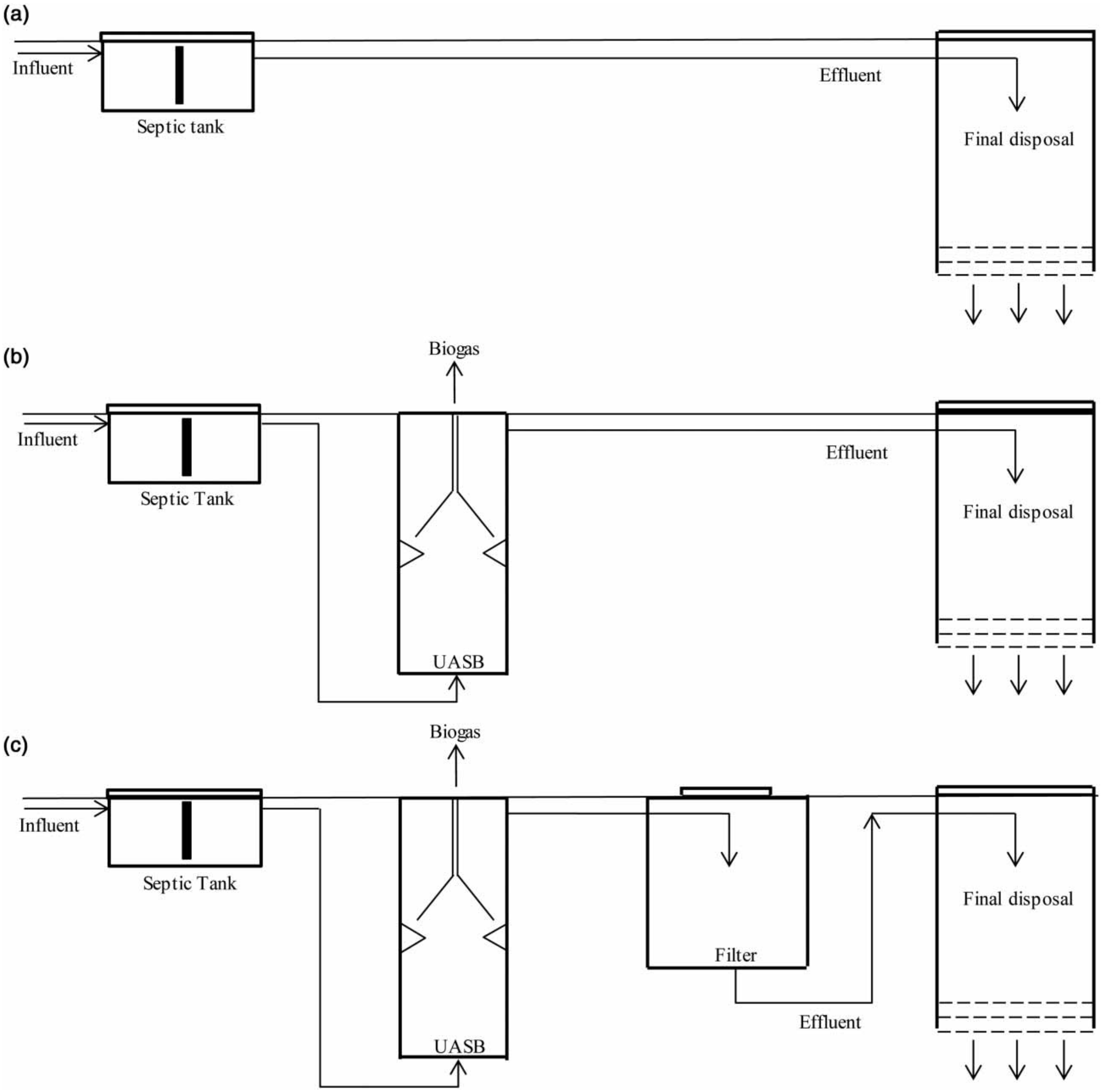

Figure 2 | Types of decentralized wastewater treatment systems (DWWTS) assessed. Drawings not to scale. (a) septic tank; (b) septic tank combined with a UASB reactor; and (c) septic tank with UASB reactor and a filter as final treatment step (STAR system).

None of the samples complied with standards for FC. Statistically significant differences were observed in effluent quality, expressed as COD, TC, and FC among the different treatments (Table 3). If we also consider the mean, minimum, and maximum values of COD, TC, and FC, it appears that treatment A is the most inefficient. Treatment C would be the most efficient, while intermediate efficiencies were obtained for treatment B, although the latter two treatments did not show statistically significant differences. No significant differences were observed between treatments regarding pH and settleable solids. A disinfection step was supposedly present in some type B systems, but this did not clearly reflect on effluent quality.

Although the addition of UASB reactors have improved the quality of the final effluent, low efficiency in terms of pathogenic organisms is a problem that demands immediate action, particularly in cases where effluents are used for irrigation. The improvement of wastewater treatment could have a significant impact on the environmental risks of final disposal (with reuse or not), but a lesser impact on

Table 2 | Local discharge standards for final disposal in soakaway pits

		Discharge standards	
Parameters	**Units**	**Ordinance 10438/00**	**Resolution 011/01**
pH		5.5–10	6.5–10
Settleable solids (10 minutes)	mL/L	0.5	Absent
Settleable solids (2 hours)	mL/L	5.0	≤5.0
COD	mg/L	200	≤500
FC	MPN/100 mL	2,000	≤2,000

COD: chemical oxygen demand; FC: thermotolerant coliforms; MPN: most probable number.

the minimization of health risks (Maimon *et al.* 2010). The use of chlorine tablets as a method of disinfection appears to be ineffective, possibly due to lack of monitoring and design flaws. Subsurface drainage is the most recommended practice for final disposal, as it avoids direct human contact, prevents unpleasant odors and proliferation of biological vectors, improves irrigation efficiency, and prevents aquifer pollution (Jeppesen 1996; Naughton & Hynds 2014).

Nonetheless, local conditions should also be carefully considered. The soil could become the last treatment step only if certain conditions are met, such as a low aquifer vulnerability, an acceptable distance to water sources, and an adequate soil texture, among other factors (Maimon *et al.* 2014). The separation of black and gray water, although not yet a widespread practice in the region, could improve the safety of water reuse for irrigation, due to the relatively low concentration of pathogenic organisms in gray water. In some medium- to high-income areas, which are not served with a formal sewer network, wastewater reuse also caused some problems such as odor nuisance and accumulation of treated wastewater on the ground (in clay-predominant soils). Sprinklers used for irrigation are also a health risk if humans come into direct contact with the wastewater. Under similar environmental conditions, other gated communities in the region opted for semi-decentralized options with an internal sewer network and an isolated wastewater treatment plant. Artificial wetlands for subsurface treatment could be a promising alternative where sufficient space is available (Steer *et al.* 2002; El-Khateeb & El-Gohary 2003).

Table 3 | Summary of the results obtained and statistical analysis

Variable	**DS (1)**	**DS (2)**	**S**	**N**	**μ**	**SD**	**Minimum**	**Maximum**	**C**
pH	5.5–10	6.5–10	A	5	7.75	0.56	7.32	8.53	●
			B	8	7.58	0.33	7.05	8.18	●
			C	11	7.45	0.34	7.00	8.00	●
COD (mg/L)	200	≤ 500	A	5	521.6	280.0	208.0	814.0	○
			B	8	227.0	151.8	48.0	446.0	●
			C	11	188.7	98.6	55.0	392.0	●
Settleable solids 10 minutes (mL/L)	0.5	Absent	A	5	1.70	1.57	0.00	4.00	●
			B	7	0.51	0.65	0.00	1.60	●
			C	10	1.43	4.42	0.00	14.00	●
Settleable solids 2 hours (mL/L)	5.0	≤ 5.0	A	5	1.80	1.52	0.00	4.00	●
			B	6	0.95	1.05	0.00	2.50	●
			C	10	1.60	4.71	0.00	15.00	●
TC (MPN/100 mL)	–	–	A	4	5.08×10^8	4.07×10^8	2.40×10^8	1.10×10^9	○
			B	8	1.01×10^8	9.39×10^7	1.10×10^7	2.40×10^8	●
			C	9	9.60×10^7	1.32×10^8	2.90×10^5	3.90×10^8	●
FC (MPN/100 mL)	2,000	≤ 2,000	A	4	5.08×10^8	4.07×10^8	2.40×10^8	1.10×10^9	○
			B	8	8.72×10^7	9.99×10^7	2.80×10^6	2.40×10^8	●
			C	9	8.90×10^7	1.36×10^8	3.50×10^4	3.90×10^8	●

DS: discharge standards; (1): Ordinance 10438/00; (2): Resolution 011/01; S: system; N: number of systems assessed; μ: mean; SD: standard deviation; C: contrasts. Means with the same symbol (● or ○) are not significantly different from each other ($p > 0.05$).

Social perspectives and future challenges

Due to the lack of a coherent normative framework, most DWWTS users believe that a septic tank coupled at best with a simple soakaway pit is enough to fulfill their sewage treatment responsibility. At the same time, both the government and the water company believe that sewage treatment outside of the sewerage system is none of their business. This kind of 'social agreement' between users and local institutions is supported by the idea that at some point in the future, the entire area will be serviced by the formal centralized sewer collection and treatment system. Semi-rural areas relatively close to towns and cities are sought by middle- and high-income families looking to live a more rural lifestyle. Best DWWTS configurations for each case will strongly depend on factors such as type of soil, depth of the water table, income, available environmental information, personal environmental awareness, and national, municipal or even private regulations, among others (Massoud *et al.* 2009). An added value of DWWTS is their potential to promote water reuse (for irrigation, for instance). However, in our case study, lack of institutional commitment and unplanned urban development is missing this excellent opportunity to reduce water consumption and minimize surface water pollution. So far, the water company has been blaming consumers for the wastage of drinking water despite the fact that important leakages from the water distribution network have been accounted for (Iribarnegaray *et al.* 2014). The need of a responsible 'green' consumer is sometimes considered a pre-requisite for the adoption of more sustainable technologies. Yet treatment choices are currently driven mainly by the lack of a sewer network nearby. Criteria such as knowledge, simplicity, costs, and market availability also drive the selection of a certain technology. The lack of institutional accountability related to ill-designed and operated DWWTS also relates to the idea that centralized systems are desirable. Institutional recognition of the current unregulated and dangerous situation could constitute a window of opportunity to test the potential and advantages of technology diversification. End-users tend to stick to well-known alternatives to minimize the potential risks commonly associated with relatively unknown technologies. Technologies are not intrinsically sustainable if they are disconnected from users' perspectives and from the settings in which they are to be utilized. The fact that more sustainable technologies should be usable by all sectors of society alike is also a considerable challenge. The concept that there are (or should be) different technologies for different social groups is probably unsustainable in itself, and should be challenged on ethical grounds. Meanwhile, new urban developments continue to be built far from sewer networks, forcing owners to resort to whatever DWWTS is available to them. The management problem of household wastewater is only addressed in environmental impact studies (EIS) of private urban developments, which are characterized by weak institutional supervision and even weaker follow-up. EIS generally recommend that each house must have an efficient DWWTS, with few details regarding the proper configuration and infrequent evaluation of soil and groundwater characteristics or adequate follow-up measures, among other things. Social, political, and cultural aspects that influence the acceptability and proper use of DWWTS need to be considered in future research. The institutional acknowledgement of their responsibilities in the monitoring, management, and inclusion of technological diversity for domestic wastewater treatment is also a key issue. We believe that a careful combination of centralized and decentralized wastewater treatment systems is probably the most sustainable alternative for urban and suburban areas.

CONCLUSIONS

This study compared effluent quality from 24 decentralized wastewater treatment systems located in the metropolitan area of the city of Salta, Argentina. Three basic configurations were assessed, from simple septic tanks to more complex systems combining UASB reactors, anaerobic filters, and disinfection steps. Septic tanks usually discharge in soakaway pits. Results showed that the risk of polluting groundwater is high due to the poor quality of the effluents, which contain high concentrations of organic matter, suspended solids, and thermotolerant coliforms. The addition of a UASB reactor and a filter improved the quality of the effluent in terms of organic matter and suspended solids concentration. However, none of the systems complied with local discharge standards for pathogens. The alleged use of chlorine tablets in some of the systems does not seem to have a practical impact on the reduction of coliforms in the effluent. Under the current scenario of unregulated and uncontrolled use of decentralized wastewater treatment technologies, urgent action from local management institutions is needed to establish a basic set of best practices in this field. Adequately selected DWWTSs can reduce costs and minimize environmental risks only if formally included in urban planning strategies. Housing density and optimum plot size are also important variables that need to be incorporated in land use plans. The correct use of DWWTSs could also allow a more secure scenario for effluent reuse, saving drinking water currently used for garden irrigation. Even though decentralized treatment systems seem a valid technological option, their incorporation in urban planning is also dependent on users' perspectives. Social, cultural, and political aspects can influence the acceptability and effective use of DWWTSs and needs to be considered in future research on this issue.

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