Journal of Environmental Management 114 (2013) 423–432

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Identifying sustainable rehabilitation strategies for urban wastewater systems: A retrospective and interdisciplinary approach. Case study of Coronel Oviedo, Paraguay

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ARTICLE INFO

Article history:
Received 17 August 2011
Received in revised form
16 July 2012
Accepted 19 October 2012
Available online 28 November 2012

Keywords:
Urban wastewater system
Rehabilitation
Sustainable sanitation
Retrospective
Interdisciplinary
Paraguay

ABSTRACT

Many wastewater managers in developing countries struggle with the daily operation of urban wastewater systems. Technically well-designed wastewater collection and treatments are often degraded and/or not properly functioning. In this paper, a realistic rehabilitation strategy is developed for the urban wastewater system of Coronel Oviedo (Paraguay), in which the actual performance is unsatisfactory, as revealed by a detailed technical assessment, including water quantity and quality monitoring data. Understanding the history, starting from the initial planning and design process, allows to explain the current failing status of the urban wastewater system of Coronel Oviedo. The key information for the specific local rehabilitation strategy was extracted from an interdisciplinary assessment of shortcomings of urban wastewater systems in Paraguay which were revealed by a survey of all existing wastewater systems. Opting for a stepwise rehabilitation strategy allows the wastewater manager to gradually improve the performance of the wastewater system. Reusing the wastewater in agriculture and recovering the energy of methane gas are possible advantageous options for attracting external financial resources. Finally, the crucial role that the wastewater manager must play for sustainable wastewater management to become effective in practice is discussed, and recommendations are provided on how decision makers, researchers and consultants can contribute by anticipating the challenging circumstances inherent to developing countries.

1. Introduction

Despite the urgent need for a widespread implementation of wastewater infrastructure in developing countries, the reality is that conventional approaches to the planning and design of sanitation seem to fail (IWA, 2006). The traditional design process focuses primarily on the technology itself, and too little emphasis is put on the process of solution identification, technology transfer and capacity building mechanisms that are crucial for the long-term success of sanitation infrastructure (Murphy et al., 2009).

Decision makers in many countries choose to apply the conventional wastewater treatment techniques that are widely utilised in developed countries while ignoring the local contextual conditions and constraints (Massoud et al., 2009; Singhirunnusorn and Stenstrom, 2009). Experiences in, e.g., Brazil also show that when technologies with proven efficiency in developing countries are selected, there is still no guarantee of a satisfying performance of wastewater treatment plants in practice (Von Sperling and Oliveira, 2009). The observed poor performance of treatment facilities cannot be attributed to the treatment processes *per se* but rather to design, operational and maintenance problems (Oliveira and Von Sperling, 2008).

To provide sustainable sanitation within the framework of the Millennium Development Goals (MDG), there is a focus on constructing wastewater collection, treatment and reuse. However, too little attention is given to why already existing wastewater treatment facilities are not performing well. The stories behind these poorly functioning wastewater systems hardly reach the decision makers, researchers and consultants involved in sanitation. There are, however, valuable lessons to be learned from these failing wastewater systems.

Meanwhile, many wastewater managers struggle with the daily operation of degraded or not properly functioning wastewater systems. Given the severe limitations in financial and human resources that characterise developing countries, the activities of

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http://dx.doi.org/10.1016/j.jenvman.2012.10.040

the wastewater manager are often limited to solving acute operational problems, such as pump failures and sewer blockages. As such, the actual failing performance of the wastewater system appears to the wastewater manager as one without solution.

We argue, however, that wastewater managers must opt for a strategy that entails a gradual improvement in system performance. A *retrospective* and *interdisciplinary* approach is proposed to identify sustainable rehabilitation strategies. The retrospective approach aims to look back at the history of the wastewater system, including the initial planning and design process, to understand its current failing status. The interdisciplinary approach reflects the necessity of understanding the influences of cultural, social, political, economic and demographic factors (Tiberghien et al., 2011).

In this paper, a rehabilitation strategy is developed for the urban wastewater system of Coronel Oviedo (Paraguay). Although collection and treatment technologies with proven efficiency in developing countries were selected during design, the actual performance is far from satisfactory. Firstly, the general shortcomings of urban wastewater systems in view of sustainability are discussed at the national level based on an assessment of all existing systems in Paraguay. Afterwards, the retrospective approach is applied specifically to the urban wastewater system of Coronel Oviedo, for which detailed technical information was collected.

The overall aim is to elucidate the crucial role that the wastewater manager plays for sustainable wastewater management to be *effective* in practice and to provide recommendations on how decision makers, researchers and consultants can contribute by anticipating the challenging circumstances inherent to developing countries.

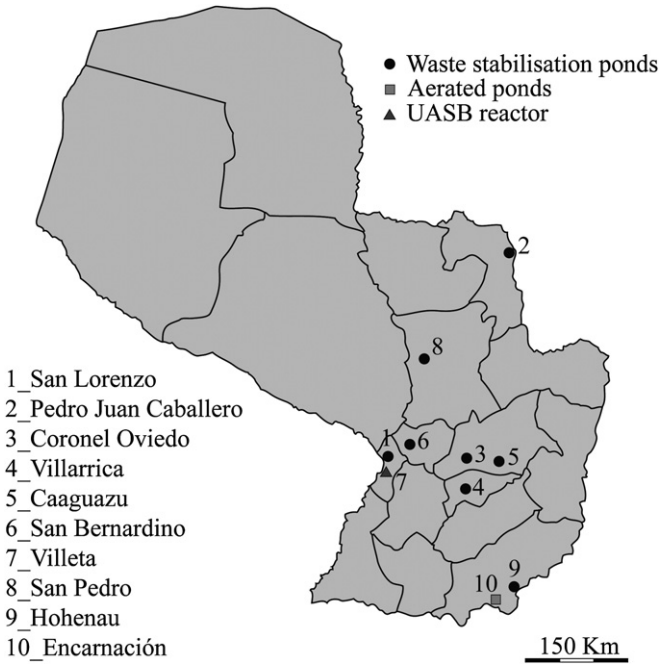

Fig. 1. Overview of the locations of the urban wastewater systems in Paraguay.

2. Materials and methods

2.1. Survey of urban wastewater systems in Paraguay

In 2008, all cities in Paraguay with an urban wastewater system were visited, including each time (*i*) an inspection of the wastewater treatment system (WWTS) and (*ii*) an interview with the local wastewater manager about the history of the wastewater system and the encountered operational problems. The visited cities are indicated on the map in Fig. 1, while the main design characteristics of the WWTS are presented in Table 1.

2.2. Description of the study area Coronel Oviedo

Coronel Oviedo is a small city in Paraguay (±52 000 inhabitants) located 130 km east of the capital Asunción. The locations of the sanitary sewer system and the WWTS are indicated on the map in Fig. 2. The sanitary sewer system is composed of sub-catchments I and II, which cover 25% and 75% of the urban area, respectively. The wastewater produced in sub-catchment I is collected in pumping station PS1, where it is transported through a pressurised sewer pipe to sub-catchment II. At the outlet of sub-catchment II is pumping station PS2, which transports the wastewater towards the WWTS at a distance of 5.4 km.

The flow at the outlet of the sanitary sewer system has been continuously measured during the period from 23 February 2009 to 22 February 2011 based on the monitoring of the on and off switching of the different pumps in PS2. A continuous measurement of rainfall intensity was performed by a tipping bucket rain gauge (TB1) for the period from 26 February 2009 to 22 February 2011. Water quality data, such as chemical oxygen demand (COD), were collected at the outlet of the sewer system during 3 periods (according to the Standard Methods (APHA, 1998)): 1 during dry weather (22 February 2010) and 2 during rainy weather (Rain event 1: 13–14 March 2010 with 54 mm; Rain event 2: 21–23 April 2010 with 107 mm).

Substantial time was invested in field reconnaissance and stakeholder consultation, including an extended period of residence in Coronel Oviedo. The field reconnaissance took place during periods of extreme rain/drought and operational accidents (e.g., sewer blockages, pump failure and sanitary sewage overflow (SSO) events). Being present during several heavy storm events gave insight in the behaviour of the sanitary sewer system. Stakeholder consultation

Table 1
Design characteristics of the WWTS in the urban areas of Paraguay (IE: inhabitant equivalent; FP: facultative pond; MP: maturation pond; UASB: upstream anaerobic sludge blanket; NA: not available).

	City	Year	Treatment units	Operation	IE	Flow (l/s)
1	San Lorenzo	1972	2 FP + 1 MP	Series	5000	9.26
2	P. J. Caballero	1979	2 FP + 2 MP	Series	NA	NA
3	Coronel Oviedo	1999	2 FP + 2 MP	Parallel	57 352	82.84
4	Villarrica	1999	1 FP + 1 MP	Series	25 114	43.44
5	Caaguazú	2001	2 FP + 1 MP	Parallel	39 483	64.43
6	San Bernardino	2001	1 FP + 2 MP	Series	12 000	12.02
7	Villeta	2005	UASB reactor	–	NA	NA
8	San Pedro	2005	2 FP + 2 MP	Parallel	16 070	NA
9	Hohenau	2008	1 FP + 2 MP	Series	NA	NA
10	Encarnacion	2008	2 Aerated Ponds + 3 Sedimentation Ponds	Parallel	101 725	228

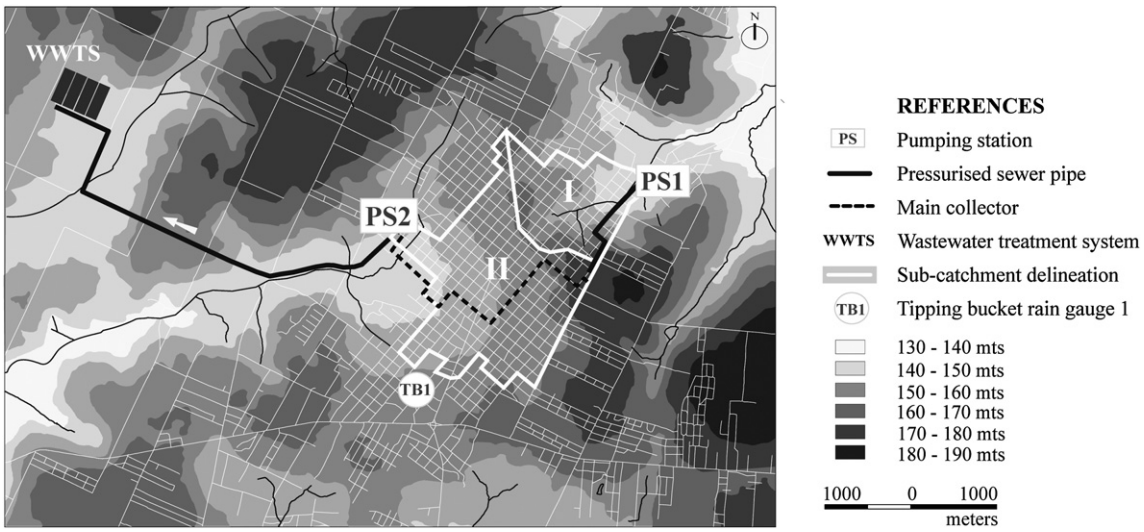

Fig. 2. Map with location of the wastewater infrastructure in Coronel Oviedo.

revealed the available *local* knowledge of the wastewater system. In practice, this consultation was performed by maintaining close contact with the operational team and attending to daily tasks, such as the realisation of household connections and the maintenance of the WWTS. In addition, the local population was consulted about their experiences with the urban wastewater system.

2.3. Stepwise assessment

A four-step approach for the assessment and subsequent rehabilitation of existing wastewater systems is proposed.

Step 1: analysis of human factors influencing wastewater management in Paraguay.

First, the general shortcomings of the urban wastewater systems in view of sustainability are identified based on the survey of existing systems in Paraguay. The influences on the observed shortcomings of relevant human factors (i.e., economic, migration, institutional, political and cultural aspects) are discussed. The aim is to explain from a broader perspective the shortcomings of urban wastewater management in Paraguay.

Step 2: detailed technical assessment of the wastewater system of Coronel Oviedo.

The projected status of the wastewater system according to its design is described. A schematic overview of the wastewater system is presented together with a discussion of the main design parameters and assumptions. Then, the actual performance of the wastewater system is assessed based on (*i*) the analysis of the monitoring data and (*ii*) the interpretation of field reconnaissance and stakeholder consultation. The problems actually encountered for the wastewater system are discussed from a merely technical point of view. The aim is to pinpoint where and how the actual system fails to comply with the expectations from design.

Step 3: SWOT analysis.

The strengths, weaknesses, opportunities and threats for obtaining sustainable wastewater management in Coronel Oviedo are formulated.

Step 4: proposal of a rehabilitation strategy.

Practical measures are proposed, including structural adaptations and management practices, which allow the wastewater manager to gradually improve the performance of the wastewater system.

3. Interdisciplinary assessment of the shortcomings of urban wastewater systems in Paraguay

3.1. Identification of the general shortcomings of urban wastewater systems

- Severe degradation of sanitation infrastructure

The waste stabilisation pond (WSP) of P.J. Caballero is currently functioning as a wetland. The ponds were gradually filled up by sediments, water plants and trees. At the WSP of San Bernardino, reed has started to invade the ponds. The actual status of the WSP of San Lorenzo is, however, the most disconcerting because all ponds operate anaerobically due to high organic and hydraulic loading. Structural degradation was already present in 1985, as documented in the Master Plan for Sewerage in Asunción (Halcrow, 1985). Halcrow observed the accumulation of sediments at the entrance, dubious structural integrity, losses due to bad embankments and erosion of the embankments. Similar shortcomings are present at the WSPs of Villarrica and Coronel Oviedo, where the concrete slabs of the inner embankments have collapsed. Limited information is available about the status of the sewer systems. It is worth mentioning that an audit revealed that several structural deficiencies were already present for the sewer system of Villeta right after commissioning (Contraloría General de la Republica Paraguay, 2005).

- Underloading of the WWTS

The majority of the WWTSs are hydraulically underloaded, with the exception of the WSP of San Lorenzo. The numbers of household connections are far below those projected. In addition, most of the WWTSs receive diluted wastewater due to groundwater infiltration. Consequently, the actual organic loadings are far below those assumed during design.

- Discharge of harmful effluents

In Villarrica, Caaguazú, Coronel Oviedo, San Lorenzo and Villeta, the final effluent is discharged into a stream with a dilution capacity that is too little, resulting in high concentrations of algae and nutrients. The heavily overloaded WSP of San Lorenzo delivers, in addition, an effluent with unacceptably high concentrations of faecal coliform (FC; i.e., 10^8/100 mL).

- Excessive stormwater inflow and infiltration (I/I)

The consulted wastewater managers are aware of I/I occurring in their sewer systems. However, they do not have a quantitative conception of the problem because no flow monitoring is performed. Related operational problems are sewer blockages and the lifting of manhole covers. The occurrence of I/I is not limited to the older systems built with ceramic pipes. The more recently constructed condominial sewer systems of Villeta and San Pedro already collapsed due to excessive I/I within less than one year after being commissioned (Contraloría General de la Republica Paraguay, 2005).

- High operation cost

Due to (*i*) heavy opposition of the local population and (*ii*) related difficulties of acquiring suitable and affordable terrains, most WWTSs have had to be constructed at a great distance from the urban area. In San Bernardino, the wastewater must be pumped over a distance of approximately 10 km to reach the WSP; for Coronel Oviedo, it is 5.4 km. These distances result in high operation costs due to electricity consumption and expenses for the maintenance of the pumping station.

3.2. Analysis of the human factors influencing wastewater management

- Economic

From an economic perspective, Paraguay lags behind the rest of Latin America in many respects: it is one of the poorest countries and has a very unequal income distribution (Ferrario, 2006). The latest survey indicates that 35.1% of the population lives in poverty and 19% in extreme poverty (DGEEC, 2009). The economic reality of Paraguay highlights that a large fraction of the population, in particular the people residing in the rural area, is unable to pay for basic services like water provision and sanitation. There is a severe lack of state revenue, which is, however, necessary for the proper operation and maintenance of the sanitation infrastructure.

- Migration

The International Organisation for Migration (IOM) estimated that at the beginning of 2010 there were ±770 000 Paraguayan emigrants, representing almost 12% of the total estimated population (IOM, 2012). Within the country, there is a strong migration from rural to urban areas. A major driver of this movement is the arrival of foreign, large-scale agricultural producers (European Commission, 2007), which are favoured by low land costs and high land availability (Nickson, 2010). Immigrant farmers buy up the land from smaller, often impoverished Paraguayan farmers (Nickson, 2010), who consequently are forced to move to urban areas. The rural people moving to the urban areas have limited resources, and they end up in informal settlements at the outskirts of the urban area rather than in the centre, where the sewer systems were constructed.

- Institutional

The Paraguayan public sector suffers from a high level of politicisation and endemic corruption, thus operating at an extremely low level of effectiveness (Ferrario, 2006; Nickson, 2010; Nickson and Lambert, 2002). For the sanitation sector, these characteristics prevent the elaboration of a long-term vision. The investments for preventing the degradation of the sanitation infrastructure are not being made. The typical problems arising during the implementation of WWTSs, i.e., the opposition of the local population and the lack of affordable land, have not been adequately anticipated. These problems have resulted in delays of up to several years before the sanitation infrastructure becomes operational. In two cases, i.e., the cities of Luque and Caacupe, the construction of the WWTS was cancelled, even though financing was available (Diaz, 2008).

Public institutions in Paraguay are characterised by a high degree of centralisation (Ferrario, 2006; Nickson and Lambert, 2002). The local wastewater managers in the interior of the country do not receive sufficient financial resources for adequate operation and maintenance. Institutions lack the capacity to enforce existing regulations (Gacitúa Marió et al., 2004). Consequently, it is no surprise that, till date, no legal actions have been undertaken to solve the problem of illegal connections of roofs and squares to the sanitary sewer system or that the Ministry of Environment did not enforce measures to prevent the discharge of SSO into the receiving water. Diaz (2008) argues that the lack of evaluation at the institutional level facilitated corruption during the construction of the sanitation infrastructure, contributing to the poor structural quality of the wastewater systems.

- Political

For most of its existence, Paraguay has embodied a form of political authoritarianism best described as a *predatory state*, as argued by Richards (2008) and Nickson (2010). Here, leadership is exercised not in the best interests of society-at-large but rather in the interests of the ruling clique (Richards, 2008). This situation is reflected in the lack of political will to provide resources for preventing the degradation of the sanitation infrastructure.

In Paraguay, political parties are highly fragmented into competing factions (Nickson, 2010). This fragmentation results in ministries being divided among the factions of the winning parties and each ministry having its own often political agenda. The level of inter-ministerial coordination is extremely underdeveloped (Nickson, 2010). For instance, the National Secretariat for Habitat and Housing (SENAVITAT) provides free housing for landless farmers in the peri-urban areas. However, no consideration is given to urban planning or environmental protection. A growing number of people are living in irregular settlements located at the outskirts of the traditional urban centre, with inadequate infrastructure, inaccessibility to services and poor environmental conditions.

- Cultural

The lack of public awareness of the importance of sanitation for environmental protection and public health is reflected in the recurring strong opposition during the implementation of wastewater systems. As mentioned before, this lack of awareness has even resulted in the cancelation of sanitation projects. The most remarkable case is the city Caacupe, where the sewer system had already been finalised when the construction of the WSP was cancelled due to protest of the *beneficiated* communities. Household connections to the sewer system were, however, realised, and

ever since, the collected wastewater has been discharged without any form of treatment into a nearby stream.

A culture of non-payment has arisen among certain marginalised communities in Paraguay (Nickson, 2010) who expect the state authorities to provide them with free electricity and water, in particular in the slums near the urban centres. In addition, many illegal connections exist to the water distribution network, mainly by individual households but also by smaller private water companies. Even if hard evidence of private water companies tapping water is available, prosecution hardly ever follows because the owners often benefit from protection by political powers. These types of practices heavily fall on the management budget.

4. Technical assessment of the urban wastewater system of Coronel Oviedo

4.1. Design

In 1999, the city of Coronel Oviedo was provided with a sewer system covering an area of approximately 2.4 km^2. A schematic overview of the urban wastewater system is given in Fig. 3.

The WWTS is a WSP consisting of 2 parallel series of 2 ponds, more specifically, a facultative pond followed by a maturation pond. The effluent of the WSP is discharged into a nearby stream. According to the original design calculation, the population to be served by 2006 was 57 352 (Stage 1). Further expansion of the sanitary sewer system would be necessary, together with the addition of a pond to the existing WSP, to increase the capacity and serve 66 576 inhabitants by 2016 (Stage 2). The main design parameters for both stages are presented in Table 2.

The collection system was designed as a separate sewer system under the assumption that only municipal wastewater is transported. The design of the WSP was accomplished according to the procedure of Sáenz (1985) with the objective being the discharge of a hygienically safe effluent. The facultative ponds are designed for biochemical oxygen demand (BOD_5) removal based on their surface organic loading, a term referring to the quantity of organic matter and expressed in kilograms of BOD_5 per day applied to each hectare of pond surface area (Peña and Mara, 2004). The maturation ponds receive the effluent from the facultative ponds, and their size and number depend on the required bacteriological quality of the final effluent (Peña and Mara, 2004), i.e., an FC concentration below 5×10^3/100 mL for the WSP of Coronel Oviedo. The design resulted in all four ponds having identical dimensions, with a length of 360 m, a width of 100 m and a depth of 1.9 m, corresponding to a retention time of 9.6 days for each reservoir provided the flow is concentrated to one reservoir. As such, the overall theoretical retention time of the WSP based on the volume is approximately almost 40 days. The design, however, assumed that the actual hydraulic retention time is only half of the volumetric one. The design retention time is, therefore, 20 days.

Table 2
Main design parameters for the wastewater system of Coronel Oviedo for Stage 1 (2006) and Stage 2 (2016).

Design	Unit	2006	2016
Served population	Inhabitants	57 352	66 576
Daily wastewater production	L/d/Inhabitant	124.8	132.8
Flow	L/s	82.8	102.3
BOD_{in}	mg/L	400	377
FC_{in}	units/100 mL	4×10^8	4×10^8
FC_{out}	units/100 mL	5×10^3	5×10^3

4.2. Actual status

As of 2011, the expansion of the wastewater system as foreseen for the start of Stage 2 has not taken place. The number of households connected to the sanitary sewer system is extremely low compared with the design projection. Flow monitoring data have revealed a daily wastewater production of approximately 1360 m^3, which represents only 19% of the projected volume of wastewater production for Stage 1 (2006). During dry weather, a large volume of infiltration water enters the sanitary sewer system. The average daily infiltration is approximately 2750 m^3, which is approximately double the wastewater production. The result is a very diluted inflow to the WSP, with an average COD concentration of approximately 230 mg/L. During design, a BOD_5 concentration of 400 mg/L was used. Assuming a $BOD_5/COD \cong 0.44$ for weak wastewater (Metcalf and Eddy, 2003), the actual organic loading on the WSP is only approximately 15% of the organic loading used during the design.

During storms, the sanitary sewer system suffers from excessive I/I. The amount of stormwater entering the sewer pipes is so high that the conveyance capacity is quickly exceeded, resulting in a mixture of stormwater and wastewater bubbling up from the manholes into the street. In the design there was no provision for overflow. In addition to the illegal connections of roofs, it is believed that many interconnections between the sanitary sewer system and the stormwater drainage system exist. In Fig. 4, the hourly flow at the outlet of the sanitary sewer system is given for a 28-day period together with the hourly rain. At the start of a rain event, the flow increases to 3–4 times the flow value during dry weather, resulting in a further dilution of the wastewater. Notice that for the larger storms, the flow remains high until long after the rain ends.

Pump failures are most likely to occur during heavy storms. The occurrence of excessive I/I results in the extended continuous functioning of pumps with consequent overheating. During a day without the influence of rain, such as 6 January 2010, a pumping cycle during peak flow consists typically of 7–8 min of pumping followed by 8–9 min of filling the pumping chamber. In contrast, the 2-year flow monitoring data revealed that on 8 occasions a single pump in PS2 had been functioning continuously for more

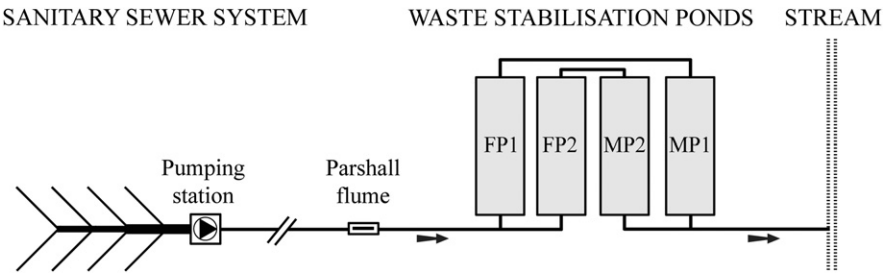

Fig. 3. Schematic overview of the urban wastewater system of Coronel Oviedo.

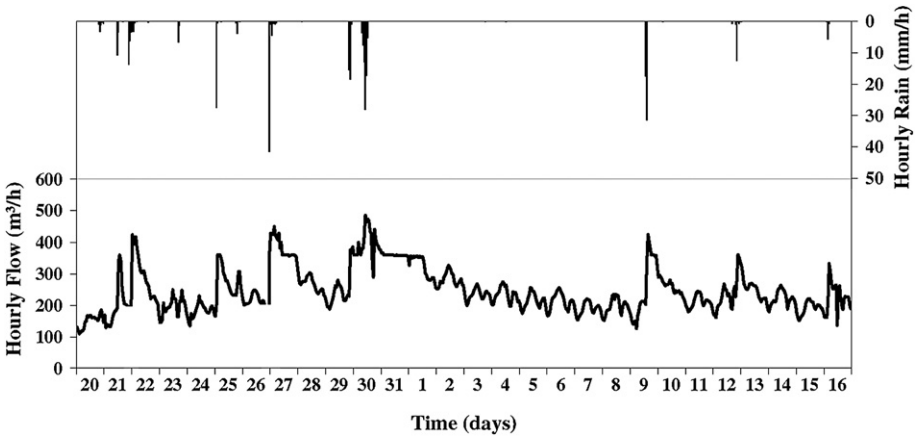

Fig. 4. Hourly flow and rain at the outlet of the sanitary sewer system of Coronel Oviedo for the period from 20 December 2009 to 16 January 2010.

than 1 day due to I/I. The most extreme case was a pump working for 2 days and 8 h due to a storm with a total precipitation amount of 129 mm on 22–23 June 2009.

A second cause of pump failure is the entrance of objects, such as garbage and stones, in the suction inlet. No adequate grit removal is available at the pumping station, and the accumulated sand has not been emptied for several years. The failure of the pumps results in the occurrence of SSO upstream of the pumping station, representing severe environmental pollution of the receiving water. For instance, a pump failure on 21 October 2009 resulted in an interruption of pumping for more than 10 days. During this period, all of the wastewater was flowing through an improvised SSO structure into a nearby stream. The high content of pathogens represents a severe threat to the health of communities located downstream.

The commonly observed interruption of electrical power supply during heavy storms is also a cause of SSO. During the monitoring period, more than 10 SSO events were identified as the consequence of power supply interruption. An important issue is that these interruptions occur most often during the first hour(s) of a storm. Water quality monitoring during storm events revealed that the system of Coronel Oviedo is characterised by a strong first-flush, with COD concentrations reaching up to 1900 mg/L (Cuppens et al., 2012). Hence, the SSO events caused by power supply interruption are most critical for the receiving water because they contain the solids and organic matter accumulated in the sewer system during the preceding dry weather period.

In relation to the WSP, a severe degree of structural degradation is observed. The concrete slabs used for the embankment collapsed due to (*i*) severe wave action and (*ii*) cows entering the WSP for drinking. The outside embankments suffer from soil erosion. The water quality monitoring data of the WSP demonstrate that the FC concentrations in the effluent are approximately 10^3/100 mL. During the winter period, however, values close to 10^5/100 mL have been encountered. Given that the actual inflow to the WSP is only 57% of the design flow, the pathogen removal efficiency of the WSP is rather low, notwithstanding the favourable climate of Paraguay with its high temperatures. Baffles, which are considered indispensable for the good performance of maturation ponds, are not present. Because the WSP was built on a plateau without any protection from the wind, the problem of hydraulic short-circuiting is exacerbated.

The effluent of the WSP contains extremely high concentrations of algae and nutrients, resulting in the eutrophication of the receiving water. The latter is an extremely small stream for which the baseflow consists almost entirely of WSP effluent. Consequently, the stream has a green colour downstream of the discharge point due to the high concentration of algae. This visual pollution has led to protests from the communities located downstream.

5. SWOT analysis for sustainable wastewater management in Coronel Oviedo

5.1. Strengths

- The available wastewater infrastructure has considerable capacity remaining for the additional collection and treatment of municipal wastewater. The terrain next to the WSP, foreseen for the expansion during Stage 2, has already been acquired.
- No limitation in human resources exists for improving the service in water supply and sanitation. The bottleneck is the limitation of financial resources for tools and materials.

5.2. Weaknesses

- The benefits of the available sanitation infrastructure in the urban centre are partially lost because no adequate sanitation is provided to the surrounding informal settlements. The lack of territorial planning has resulted in settlements that have been founded in highly unsuitable locations (e.g., spring areas and flood plains). These dwellings have simple soak pits with high phreatic water levels. The contamination of both surface water and groundwater resources by pathogens prevails.
- The drinking water supply in Coronel Oviedo is very poor due to (*i*) insufficient surface water abstraction capacity and (*ii*) high losses in the water distribution system. Under the continuous pressure of complaints by the local population, the available human resources are allocated for fixing leaks in the distribution network at the expense of maintaining the sanitation infrastructure.
- The lack of awareness about the importance of adequate sanitation is great. In addition, a deep distrust in the local office exists due to the actual poor water supply services.

5.3. Opportunities

- Introducing the reuse of treated wastewater in agriculture would be highly beneficial. In addition to the general benefit of using the WSP effluent with high concentrations of nutrients as a cheap source of fertiliser (Muga and Mihelcic, 2008), the

reuse practice can solve the existing environmental and social problem. It is, however, of utmost importance to respect the guidelines of the World Health Organisation (WHO) for the safe reuse of wastewater in agriculture. The key objective for the WWTS is to reduce sufficiently the pathogen content of the effluent in order to avoid unacceptable health risks for the agricultural workers and consumers.
- The distance that the WWTS effluent needs to be transported for the wastewater reuse project is very small. Suitable terrain is available just besides the WWTS. As a consequence of the remote location of the WWTS from the urban centre (5.4 km), it is situated in agricultural land without competition of urbanisation or industry.

5.4. Threats

- No financial aid from the traditional development cooperation agencies is expected to be available in the short-term. According to official statistics, Coronel Oviedo is currently provided with *adequate* sanitation, and priority is given to the construction of new WWTSs due to the extremely low number of existing systems in Paraguay.
- It will take considerable time before a major attitude change can take place at all levels within the public institutions to combat the negative consequences of politicisation, centralisation, corruption and bureaucracy. Thus, there is little hope for the wastewater manager to see any changes in the short-term macro-context.

6. Proposal of a rehabilitation strategy for Coronel Oviedo

In this section, a stepwise rehabilitation strategy for Coronel Oviedo is proposed that first considers (cheap) technical adaptations for the immediate improvement of efficiency and then gradually moves to a long-term vision and realisation of sustainable sanitation.

6.1. Stage 1

The parallel operation mode of the WSP is changed to a series of 4 ponds. The actual low organic loading does not represent a risk for overloading of the first pond in the short-term. The aim is to improve the pathogen removal efficiency of the WSP by increasing the overall retention time. As such, the influent to the fourth pond is expected to comply with the hygienic standards for reuse in aquaculture, i.e., an FC concentration less than 10^4/100 mL (WHO, 2006). In addition, a low-cost irrigation scheme is implemented on the available terrain. A line of trees is planted at both ends of the WSP perpendicular to the main wind direction. These trees will help diminish the negative influences of wind.

For the sanitary sewer system, priority is given to the removal of accumulated sand and dirt in the pumping chambers and the proper working of the grit removal devices. In addition, the origin(s) of the large baseflow must be traced and, if straightforward to realise, removed. One must attempt to locate the contributing source(s) by visual inspection of the manholes during the night hours, when wastewater production is practically non-existent.

To meet all targets, a revision of task allocation must be elaborated in dialogue with the available staff. In doing so, it will be possible to restore their motivation, which is often lacking due to the non-participative attitude of the higher management. Although local staff members may have good proposals regarding management, their opinions are never heard.

After performing a comprehensive stakeholder analysis (Robinson et al., 2010), the wastewater manager must initiate a discussion platform about the existing situation of urban wastewater management. Specific targets of the wastewater manager are (*i*) introducing the concept of wastewater reuse in agriculture and explaining the associated benefits, and (*ii*) demonstrating the commitment of the local staff to rehabilitate the wastewater system with, however, the participation of the stakeholders. The wastewater manager must be open to all ideas and opinions. Field-visits and workshops are organised to familiarise the stakeholders with the pilot project of wastewater reuse.

6.2. Stage 2

In Stage 2, revenues that become available from agricultural production are utilised to finance low-cost structural adaptations to the wastewater system. A manifold inlet structure is provided at the front end of the first pond to avoid local overloading and odour problems (Shilton and Harrison, 2003). Self-made baffles (PVC sails) are installed in the second and third ponds to improve the hydrodynamic efficiency and, as such, contribute to improved conditions for pathogen removal. Materials and tools are acquired for repairing the (mostly obvious) interconnections between the stormwater drainage system and the sewer system.

The most important target is to increase revenues by outsourcing the wastewater reuse practice. A first option is selling the WSP effluent to nearby farms. A second option is the development of a social project that creates employment and business for the local communities. Sponsoring can be obtained from the government or NGOs, for whom poverty alleviation is a key goal. For Coronel Oviedo, water and labour intensive agricultural practices, such as tree nurseries and horticulture, are feasible options. This type of project would allow the negotiation of financial compensation for the delivered wastewater. Preference must be given to the second option because it has a more comprehensive impact on the human factor of local sustainable development (Flores et al., 2008).

The wastewater manager must motivate the stakeholders to take their responsibility (Robinson et al., 2010) and to participate in the rehabilitation of the urban wastewater system. For instance, they can assist in removing the connections of I/I or organise house-to-house visits to convince the wider public about not dumping their waste into the sewerage.

6.3. Stage 3

In Stage 3, an anaerobic pond is added in front of the first pond in the series. Due to its high solids and BOD_5/COD removal capacity, the anaerobic pond acts as a buffer against the overloading of the following facultative pond. As such, the stable and efficient operation of the WSP is guaranteed. A bypass mechanism towards the facultative pond is provided to avoid heavily diluted and oxygen-rich wastewater from entering the anaerobic pond during storms. Preferably, the financial assistance is acquired through economic incentives within the framework of the Clean Development Mechanism (CDM). The CDM enables industrialised countries to meet some of their obligations for reducing their carbon emissions through the purchasing of emissions reduction from projects in developing countries (World Bank, 2007). The CDM project proposed for the WSP of Coronel Oviedo involves the recovery of methane gas produced by the added anaerobic pond. The feasibility of this type of project has recently been demonstrated in Santa Cruz de la Sierra (Bolivia) with funding of the World Bank. A schematic overview of the rehabilitated urban wastewater system is presented in Fig. 5.

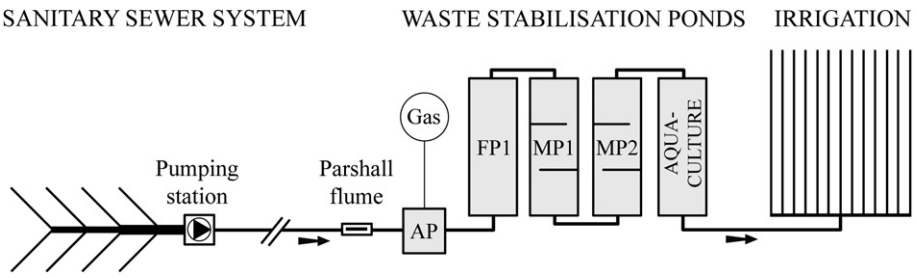

Fig. 5. Schematic overview of the rehabilitated urban wastewater system.

6.4. Stage 4

The local maintenance team together with hired specialists in detection techniques (e.g., smoke testing and closed circuit television inspection) must eliminate the remaining connections of I/I. A map is made of the houses actually connected and those still to be connected. This survey allows the determination of the extent to which the area served by the sewer system can be expanded. If additional collection capacity is still available, one can connect some of the surrounding informal settlements. For the remaining informal settlements, low-cost wastewater collection and treatment technologies are considered. Mara and Alabaster (2008) propose condominial sewerage for the more densely-populated peri-urban areas, while VIP latrines, pour-flush toilets and ecological sanitation toilets are options for the low-density areas. The condominial sewerage technology has been applied in Paraguay for the wastewater systems of San Pedro, Villeta and Hohenau. The key concept of this technology is the engagement of groups of households (blocks), who consequently plan, construct and maintain their branch of the condominial sewer system. External support is, however, necessary for financing. Options are the national government through loans of development agencies or the usual foreign donors, such as Taiwan and Japan (Nickson, 2010).

7. Discussion

- Why should the rehabilitation strategy work?

The main feature of the strategy is that measures are realised first, which require no or limited investment and which are straightforward to carry out by the in-house staff. In the meantime, initiatives are undertaken to (*i*) generate revenues for financing the pending rehabilitation activities and (*ii*) stimulate the active participation of the stakeholders. Reusing the wastewater and recovering the energy of methane gas are attractive activities to finance the operation and maintenance of sanitation schemes in developing countries (Murray and Ray, 2010). Wastewater managers can benefit from the financial support of the CDM (Neuhoff et al., 2009) and the increasing demand for water and nutrients to sustain agricultural production in the context of global food security (Cordell et al., 2009). It is, however, crucial that suitable terrain is available nearby the WWTS. This is explained by the economical viability of the reuse project being very much dependent on the transport cost of the WWTS effluent.

The major strength of the rehabilitation strategy is the integration of a detailed understanding of the local context with up-to-date scientific knowledge on environmentally sound technologies. Analyses of both human and technical factors are used, and recent innovations for sustainable sanitation are incorporated. Furthermore, the water quantity and quality monitoring data available for Coronel Oviedo allow appropriate decision making for effective management based on quantitative information (Huang and Xia, 2001).

It should be remarked that during the elaboration of the rehabilitation strategy for Coronel Oviedo information of the interdisciplinary assessment at the national level was used. We argue that the main driving factors for failing sanitation facilities in Paraguay are homogeneous as the survey of all wastewater systems demonstrated that the same problems are occurring at the different sites. This type of homogeneity at the national level will not necessarily hold true for other countries. For such cases, an interdisciplinary assessment at the local level is required as performed by Tiberghien et al. (2011).

- What lessons are to be learned by decision makers, researchers and consultants?

7.1. Decision makers

During the planning of new sanitation projects, decision makers should rigorously anticipate the problems associated with the local context. The lack of awareness by decision makers in this arena is illustrated by the fact that a number of the shortcomings for wastewater systems in Paraguay were already identified in 1985 (Halcrow, 1985). Looking today to the operational performance of wastewater systems constructed afterwards, one can only conclude that the processes of identifying the appropriate solutions and building capacity mechanisms did not take place. An emblematic example, with the experience of Coronel Oviedo in mind, is that 41 pumping stations are present in the recently constructed sewer system of Encarnacion, with the WWTS being located several km outside of the urban centre. Notwithstanding the difficult topographic conditions, would decentralised wastewater collection and treatment perhaps not have been a more sustainable option? The experience of Paraguay illustrates clearly that only accounting for technical and economical aspects leads to unsustainable wastewater systems in practice. Decision makers should always first gain the necessary understanding of the local context before dealing with the technical aspects of the sanitation project.

7.2. Researchers

Although, in reality, large shorter- and longer-term fluctuations in water quantity and quality occur at the entrance of the WWTS, and some incidents (e.g., failing power supply and pumps) are unavoidable, a *steady-state* mind-set still rules among researchers (Beck and Cummings, 1996). During the development of wastewater treatment technologies, their main goal is to increase the *average* pollutant removal efficiency while minimising the cost. The experience of Paraguay shows, however, that the largest challenge for a sustainable WWTS in practice lies in the capacity for coping with undesirable phenomena as I/I, feeding interruption and

changes in loading, which are inherent to the context of developing countries. Therefore, researchers should set their priorities on making the available wastewater treatment technologies more *resilient* rather than developing new treatment technologies, which have higher average performance under experimental conditions with steady-state flow and a high constant pollution load (Cuppens et al., 2012).

7.3. Consultants

During the design of the wastewater infrastructure, consultants give too little justification regarding the selected design methodology and assumptions with reference to the local context. Little forethought is given in their design to cope with unavoidable disturbances. They assume that when the wastewater system is put in place, it will behave according to plan (Beck, 1996).

For instance, in Coronel Oviedo, no SSO structure was foreseen for PS2 during design. The reason was that providing space for 2 spare pumps in the pumping chamber would suffice. When the failure of all pumps occurred, the wastewater was flowing out of a manhole located 300 m upstream of PS2, and the surrounding houses were flooded. The same scenario occurred at PS1, where an improvised overflow structure to the stormwater drainage channel was provided further upstream. During rain events, however, the stormwater in the drainage channel enters the sanitary sewer system because no non-return flap-valve was installed. The massive entrance of stormwater has lead to the frequent failure of the pumps in PS1. Then, wastewater was found to flow into the stormwater drainage channel during the dry weather period following the rain event until the pumps were eventually repaired. In addition to the high cost, the repair of a pump entails a huge burden on human resources, as the removal and installation in-situ has to be done manually. This example demonstrates how the lack of forethought during design jeopardises the sustainable operation of the wastewater system. Therefore, the consultants should consider a number of scenarios regarding the designed system with attention to robustness under a number of events and possible incidents.

8. Conclusion

The sustainability of technically well-designed and appropriate wastewater collection and treatment can easily be undermined by one or more human factors. Such problems have been demonstrated here in detail for the urban wastewater system of Coronel Oviedo in Paraguay, but similar experiences have been reported for sanitation infrastructure in other developing countries (Lasut et al., 2008; Tiberghien et al., 2011). In this paper, an interdisciplinary assessment was used to understand the influences that human factors have on wastewater management in Paraguay. The retrospective approach allowed to pinpoint where and how the actual urban wastewater system of Coronel Oviedo fails to comply with the expectations from design. It became evident that the solution to seemingly simple operational problems goes far beyond technical considerations.

For the rehabilitation of poorly performing wastewater infrastructure in developing countries, the attitude and capacity of the local wastewater manager will be a decisive factor. Opting for a stepwise rehabilitation strategy allows a gradual improvement of the performance of the wastewater system while in the meantime generating the necessary revenues by taking advantage of opportunities offered by the system itself (e.g., the reuse of wastewater in agriculture and CDM projects). In addition to initiating discussion among the stakeholders, the challenge is to stimulate their active participation during rehabilitation measures.

We argue that it is not merely the responsibility of the wastewater manager to ensure that wastewater management becomes (truly) sustainable in developing countries. Decision makers, researchers and consultants should thoroughly understand the challenging context inherent to developing countries. They must take other factors into consideration besides economical and technical. A key objective should be to develop and design more robust WWTSs that provide sufficient flexibility for the wastewater manager to cope with unavoidable disturbances.

More efforts must be made to collect water quantity and quality data for existing wastewater systems in developing countries. Quantitative monitoring data are indispensable for the daily operation of the wastewater system and for the elaboration of a long-term management strategy. In addition, quantitative information facilitates more realistic feedback to the decision makers on advances or shortcomings in providing adequate sanitation in the framework of the MDG.

Acknowledgements

This research was conducted within the framework of a Ph.D. study funded by the Flemish Interuniversity Council (VLIR). The authors would like to thank ESSAP and SENASA and the Junta de Saneamiento of Villeta, Hohenau and San Pedro for participating in the survey of the wastewater systems. The authors are especially grateful for the support received by the maintenance team of ESSAP of Coronel Oviedo during data collection.

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