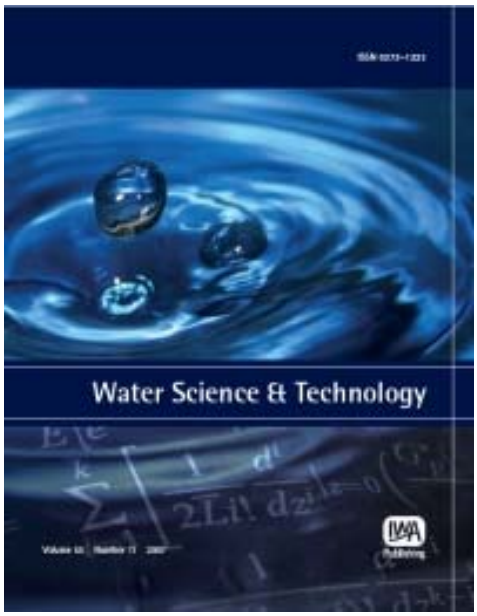

Water treatment plant sludge disposal into stabilization ponds

Sidney Seckler Ferreira Filho, Roque Passos Piveli, Silvana Audrá Cutolo and Alexandre Alves de Oliveira

ABSTRACT

Researchers have paid particular attention to the disposal of sludge produced in water treatment plants (WTPs) into wastewater treatment plants (WWTPs) for further processing, mainly because it is considered an attractive alternative for the treatment of waste generated in water production processes. This study evaluated the effects of flow equalization and disposal of sludge, from a conventional WTP, into a WWTP system that includes an anaerobic stabilization pond followed by a facultative pond. During the period of sludge discharge from the WTP into the wastewater system, the influent to the WWTP presented an increase of 17% (from 171 to 200 mg L^{-1}) of total suspended solids (TSS) and a 7.0% flow rate increase, without showing adverse effects on the organic load, TSS and nutrients removal. The most significant impact observed in the WWTP was the increase of solids accumulation rate in the anaerobic pond, with a value of 141 mm/year during the sludge discharge period. The operating time, before the dredging and desludging cycles required for this specific anaerobic pond, decreased from 12.7 to 10.4 years, which is consistent with previous studies in literature. Thus, based on the observed parameters of this study, it is viable to release solids from a WTP effluent into a WWTP that includes anaerobic stabilization ponds followed by a facultative pond. Indeed, this process scheme becomes a viable technical, environmental, and economical alternative for small to medium WWTPs.

Key words | sludge, stabilization pond, wastewater treatment, water treatment

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INTRODUCTION

Conventional water treatment plants (WTPs) are typically designed with main process units such as coagulation, flocculation, sedimentation, filtration, and disinfection. The coagulation process generates sludge which tends to separate into different fragments in the sedimentation (sludge from the settling tanks) and filtration units (spent filter backwash water). In addition, the sludge presents different physicochemical characteristics associated with its total suspended solids (TSS) concentration and its volumetric flow rates. So, these factors spur the need to treat the sludge properly for final disposal and minimize the environmental impacts associated with this disposal (ASCE *et al.* 1996).

Thickening and dewatering units allow the production of a dewatered sludge with approximate solids concentration of 20–30%. So these units are typically used to treat the sludge generated in WTPs, because they provide a solution for sludge handling and subsequent final disposal (Kawamura 2000). WTPs are now required to treat their final waste for disposal, due to restrictions imposed by environmental agencies. However, the employment of sludge treatment units is often hampered by the unavailability of land near the WTP. In addition, the implementation of sludge treatment units in WTPs is limited because of the high equipment, operating, and maintenance costs involved. Thus, in order to minimize the environmental impacts, the need to provide low-cost alternatives for sludge treatment is rapidly growing.

Among the low-cost alternatives, the release of sludge into the wastewater collection system has become attractive. The sludge can undergo further treatment in the wastewater treatment plant (WWTP), using only one physical structure to treat sludge from both the WTP and the WWTP, which provides significant savings in operational costs (Miyanoshita *et al.* 2009).

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Stabilization ponds represent another viable low-cost alternative for wastewater treatment of small to medium towns. This process involves the adoption of primary facultative ponds or anaerobic ponds followed by facultative ponds. The use of stabilization ponds in wastewater treatment has been widely used in countries with temperate and tropical climates. This practice improves the quality of the treated effluent, not only allowing its release into receiving bodies but also providing an alternative for water reuse (Oakley *et al.* 2000; Kouraa *et al.* 2002; Muga & Mihelcic 2008; Mara 2009).

Since small to medium cities tend to have difficulties with the adoption of sludge treatment systems in WTPs, the use of WWTPs for sludge processing appears a feasible alternative, particularly because WWTPs already present stabilization ponds. The release of sludge in the wastewater collection system for further processing in stabilization ponds allows its effective treatment with the existing equipment in the WWTP. That is, stabilization ponds in WWTP achieve an effective treatment of sludge because their high hydraulic residence times allow an efficient separation of the TSS from the liquid phase.

Although some studies presented in the literature indicate the technical viability of water treatment sludge processing in WWTPs (Hsu & Pipes 1973; Asada *et al.* 2010), some topics remain unclear when considering stabilization ponds as an alternative for sludge treatment. Such is the case of the final effluent quality, the increase in sludge production, and the sludge accumulation rates in treatment units. Thus, this study aims to evaluate the release of sludge from WTPs into the sewer systems for further processing in stabilization ponds. Specifically, the present work focuses on the treated effluent quality impact, the increase of sludge production rate, and the sludge discharge pattern in stabilization ponds.

MATERIALS AND METHODS

Description of the stabilization ponds and monitoring program

The experimental study was conducted in real scale by evaluating the behavior of a wastewater treatment system composed of an anaerobic pond followed by a facultative pond. The WWTP is subjected to a load increment of TSS coming from a WTP in São Lourenço da Serra, 60 km from São Paulo (Brazil) – (23° 51.420'S 46° 57.313'W). The main physical characteristics of the stabilization ponds are shown in Table 1.

The monitoring of stabilization ponds was divided into two phases. The first phase (Phase 1 – 9 months) operated without the discharge of sludge from the WTP into the wastewater collection system. Subsequently, the second phase involved the monitoring of the WWTP (Phase 2 – 6 months) with the addition of sludge generated in the WTP (sludge from settling tanks plus the spent filter backwash water), with flow equalization, and released continuously in the wastewater collection system before being routed to the WWTP.

During the monitoring period, samples were collected biweekly (Phase 1) and weekly (Phase 2) at the entrance of the WWTP (Point 1), the effluent from the anaerobic pond (Point 2), and the effluent from the facultative pond (Point 3). The monitored physicochemical parameters were the biochemical oxygen demand (BOD), the concentration of total and volatile suspended solids (TSS and VSS), the total Kjeldahl nitrogen concentration (TKN), the ammonia (NH_3) concentration, and the total phosphorus concentration. Additional parameters measured at each sample point included the liquid phase pH and the temperatures of air and water. Immediately after the collection of the samples, these were stored, refrigerated at 4 °C, and taken to the laboratory for physicochemical characterization. All the analytical methods employed were done according to APHA (2005).

Water treatment plant description

The WTP where the sludge originated is a conventional plant that includes the processes of coagulation, flocculation, sedimentation, filtration, and disinfection. These processes are operated during Phase 2 with an average flow of 22 L/s (1,901 m³/d), with aluminum sulfate as its coagulant. The sludge (from settling tanks plus the spent

Table 1 | Characteristics of the WWTP composed of an anaerobic pond followed by a facultative pond

Pond type	Pre-treatment	Average influent flow (L/s)	Pond depth (m)	Surface area (m^2)	Total volume (m^3)
Anaerobic	Grit chamber	8.0	3.5	2,044 (36.5 m × 56.0 m)	5,116
Facultative	–	8.0	2.0	10,240 (64.0 m × 160.0 m)	18,731

filter backwash water), discharged every day, was sent to a flow equalization tank with a total volume of 50 m^3. The volume of sludge discharged daily from the WTP was about 48 m^3, which corresponds to a volumetric flow increase in the wastewater collection system of about 0.56 L/s. The sludge's average volumetric flow entering the WWTP during Phase 1 was 8.0 L/s, which corresponds to a 7.0% increase of flow.

During Phase 2, the data collection included the quality of raw water influent to the WTP, as well as the dosages of chemicals employed in the coagulation process. Table 2 shows the average raw water quality characteristics and coagulant dosages evaluated during Phase 2.

From the data in Table 2, it was possible to determine the WTP's sludge production and the TSS increase in the wastewater collection system, which was eventually routed to the WWTP.

Evaluation of the sludge production rate and its accumulation in the anaerobic pond

The evaluation of the sludge production rate and its accumulation in the anaerobic pond was done during the period of sludge discharge from the WTP into the wastewater collection system. The quantification of the sludge production rate was done by bathymetric tests realized at the beginning and at the end of Phase 2. These tests were performed at nine sampling points along the anaerobic pond, distributed over its surface area. That is, three points were located near the pond entrance, three in the middle of the pond, and three in near the end. All the bathymetric sections were accessed by boat, and for each one of the nine sampling points the sludge layer height was measured employing the 'white towel test' (Papadopoulos *et al.* 2003).

Table 2 | Operational characteristics of the water treatment plant monitored during the sludge discharge period into the wastewater collection system – Phase 2

Parameter	Value
Average flow (L/s)	22.0
Number of working hours per day	15 h a day
Coagulant	Aluminum sulfate
Minimum, average, and maximum coagulant dosages (mg $Al_2(SO_4)_3.14H_2O$/L)	10.2; 15.0; and 22.6
Minimum, average, and maximum raw water turbidity (NTU)	5.0; 16.8; and 25.4

RESULTS AND DISCUSSION

Water treatment sludge production and its impact on wastewater treatment plant

Based on average values of the raw water turbidity, coagulant dosage, and average flow rate, the sludge produced in the WTP and released into the WWTP can be calculated according to the following expression:

$$P_s = Q.(K.T + (0,236.C).10^{-3} \quad (1)$$

where P_s is the sludge production in kg/d, Q is the average flow rate in m^3/d, T is the average turbidity of the raw water in NTU, K is the ratio of TSS concentration to raw water turbidity, and C is the coagulant dosage expressed in milligrams $Al_2(SO_4)_3.14H_2O$/L.

The sludge production values calculated from Equation (1) assumes two major contributing components. The first factor involves the TSS present in the raw water and retained in the WTP. Because it is not common to quantify the TSS concentration in raw water influent to WTP, it is reasonable to assume a linear relationship with the turbidity parameter. The value of K can vary from 1.0 to 2.0 (Pavanelli & Bigi 2005; Chanson *et al.* 2008; Cornwell & Roth 2011). The second component includes the coagulant precipitation added in the form of aluminum sulfate as aluminum hydroxide. That is, according to the stoichiometric relationship, it is assumed that for every mole of aluminum added one mole aluminum hydroxide precipitates. Assuming an average K value of 1.5, it is possible to calculate the daily sludge production in the WTP.

The calculated results show that the sludge production ranged from 11.6 to 40.4 kg/d. These variations originate from the different operational conditions in the WTP imposed by fluctuations in the raw water quality and the coagulant dosages used in the treatment process.

The average monthly influent flow rate to the WWTP during Phase 2 was constant at approximately 8.5 L/s. Assuming an inlet solids loading rate increase, from 11.6 to 40.4 kg/d, the theoretical increase in the TSS concentration can be estimated as varying from 16 to 55 mg L^{-1}. Figure 1 presents the median, as well as the 25 and 75 percentile values of TSS entering the WWTP (Point 1), exiting the anaerobic pond (Point 2), and exiting the facultative pond (Point 3) during Phases 1 and 2.

During the first phase, the median TSS concentration entering the WWTP was 171 mg L^{-1}, whereas the values

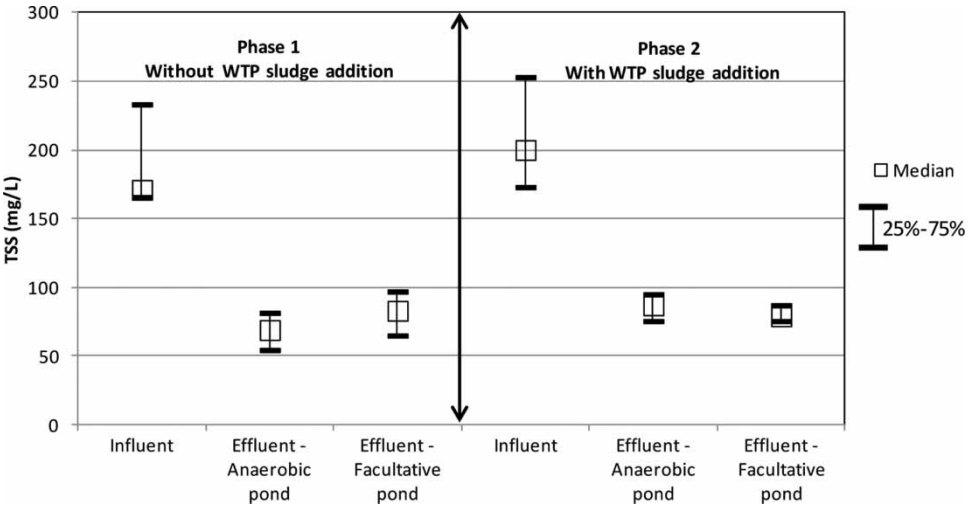

Figure 1 | Box plot diagrams of influent and effluent TSS concentrations in WWTP for Phases 1 and 2.

for the second phase show a median value of 200 mg L^{-1}. The increase in the median TSS concentration in Phase 2 (from 171 to 200 mg L^{-1}) is due to sludge release from the WTP in the wastewater collection system. This increase of 29 mg L^{-1} is within the range of values previously calculated (Equation (1)) between 16 and 55 mg L^{-1}. Based on the average sludge volumetric flow rates entering the WWTP in both Phase 1 and 2 (Phase 1: 8.0 L/s – Phase 2: 8.5 L/s) and their respective TSS concentrations (Phase 1: 171 mg L^{-1} – Phase 2: 200 mg L^{-1}), there was an increase in the influent's solids load of about 28.7 kg/d. This value is also consistent with the WTP solids load estimated from Equation (1).

Although the TSS concentration entering the WWTP increased about 17%, the quality of the treated effluent did not worsen since the final effluent TSS concentrations from the facultative pond (Point 3) were between 83 mg L^{-1} for Phase 1 and 79 mg L^{-1} for Phase 2. These values are similar to those expected for WWTP composed of an anaerobic pond followed by a facultative pond (USEPA 2011). Statistical analysis was completed for the effluent TSS concentration from the facultative pond during both Phase 1 and 2. The analysis, done with the Mann–Whitney test and a confidence level of 5%, showed that the concentrations for both phases were statistically similar.

During Phase 1, the median concentration value of TSS in the effluent from the anaerobic pond that entered the facultative pond was 69 mg L^{-1}. During Phase 2, the median value was equal to 87 mg L^{-1}, which corresponds to a removal efficiency of 60% in Phase 1 and 57% in Phase 2 for the anaerobic pond. Even though the addition of sludge from WTPs could be beneficial to the TSS separation in WWTPs (Guan *et al.* 2005), its concentration in the anaerobic pond effluent during Phase 2 showed an increase of 18 mg L^{-1}. However, it is important to point out that during the day the sludge is released from the WTP into the wastewater collection system with flow equalization. Thus, the impact of TSS load from the WTP into the WWTP was significantly reduced by the flow equalization, which may explain the lack of negative effects related to solids separation.

The average hydraulic residence time in the anaerobic ponds were determined as 7.4 and 6.9 d for Phases 1 and 2, respectively, taking as their basis the influent average flow rates to the WWTP (Phase 1: 8.0 L/s – Phase 2: 8.5 L/s). The high hydraulic residence time values indicate that the higher removal of TSS entering the WWTP occurred in the anaerobic pond. Therefore, the highest rates of sludge accumulation were observed in this unit.

Water treatment sludge addition and its effects on final effluent quality

One of the major issues regarding the release of sludge from the WTP into the WWTP is the possible effect on the treated effluent quality. Figure 2 shows the median, as well as the 25 and 75 percentile values of BOD concentration in the influent to the WWTP (Point 1), the effluent from the anaerobic pond (Point 2), and the effluent from the facultative pond (Point 3) for both Phase 1 and 2.

The median influent BOD concentration to the WWTP was equal to 235 mg L^{-1} (Phase 1) and 301 mg L^{-1} (Phase 2). Although there was an increase of approximately 17% in the influent TSS concentration to the anaerobic pond,

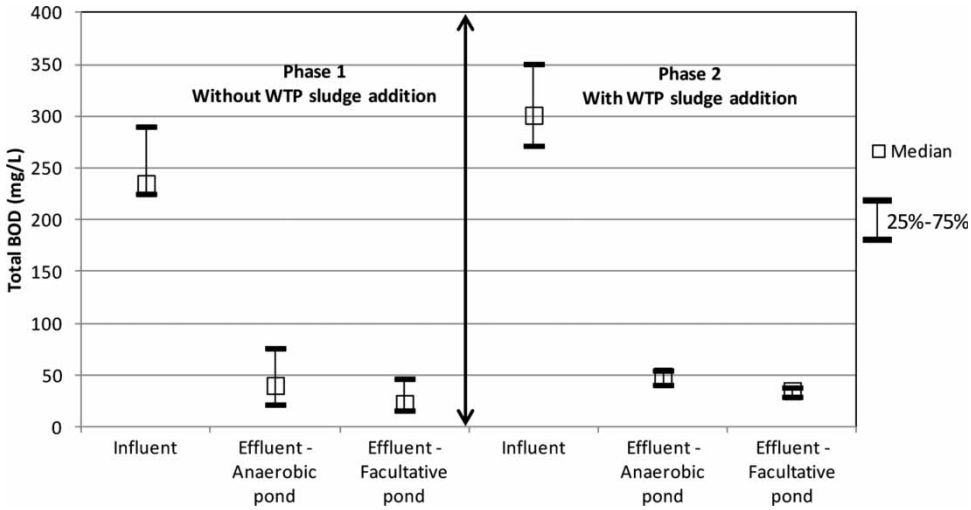

Figure 2 | Box plot diagrams of influent and effluent BOD concentrations in WWTP for Phases 1 and 2.

an increase of organic load in the influent to the WWTP due to TSS from the WTP is not expected. This is because the sludge from the WTP is formed mainly by solids from inorganic compounds and inert material (Verrelli *et al.* 2010), so the organic load is not affected.

During Phase 1, the median BOD concentration in the effluent from the anaerobic pond was 40 mg L^{-1}, which corresponds to an organic load removal efficiency of 83%. In regard to the second phase, the median BOD concentration in the effluent from the anaerobic pond was 49 mg L^{-1}, which corresponds to an organic load removal efficiency of 84%. The Mann–Whitney test was applied for BOD variables in the effluent from the anaerobic pond for Phases 1 and 2. For a confidence level of 5%, this test showed that both values were statistically equivalent. Thus, it can be concluded that the increase in the TSS concentration entering the anaerobic pond did not impair the organic load removal, since its values for both Phase 1 (83%) and 2 (84%) were very close.

It is worth discussing the high values of organic load removal observed in the anaerobic pond. Based on the average flow rate and organic load at the inlet to the anaerobic pond, the values of the volumetric organic load are estimated as 0.039 and 0.044 kg/m³ d for Phases 1 and 2, respectively. Typical volumetric organic load values used in the design of anaerobic ponds in tropical countries are approximately between 0.1 and 0.4 kg/m³ d. The organic load removal values expected for these loads are around 50–60%. Since the volumetric organic load applied to the facultative pond was between 0.039 and 0.044 kg/m³ d for both Phase 1 and 2, which are both lower than the recommended values, the high organic load removal values are acceptable (Türker *et al.* 2009).

The median BOD concentrations in the final effluent of the WWTP were 23 mg L^{-1} (Phase 1) and 35 mg L^{-1} (Phase 2), which indicates the BOD concentration values were fairly constant for the facultative pond effluent. Likewise, the Mann–Whitney test ($\alpha = 5\%$) was done for the BOD values in the effluent from the facultative pond during Phases 1 and 2. From this test, it can be concluded that both quantities were also statistically equivalent. Thus, considering the organic load removal, the release of sludge into the WWTP with the observed conditions did not cause any significant alterations in the final effluent quality. The observed BOD values in the final effluent of the facultative pond are also justified by its low organic load rates, since during both Phase 1 and 2 the organic load was 97 kg BOD/ha d. The secondary facultative stabilization ponds that operate in a tropical climate typically have organic load values up to 200 kg BOD/ha d, which enables the production of a final BOD effluent with values lower than 60 mg L^{-1} (Ellis & Rodrigues 1995; USEPA 2011).

Table 3 presents statistical values calculated for the additional physicochemical parameters analyzed during the monitoring of the WWTP during Phases 1 and 2.

During Phase 1, the removal of NKT, NH_3, and total phosphorus concentrations reached values of 36, 38, and 40%, respectively. In turn, for Phase 2 the removal values were 29, 36, and 53%, respectively. Thus, values for Phase 1 and Phase 2 were very similar to each other. The Mann–Whitney test ($\alpha = 5\%$) for NKT, NH_3, and total phosphorus concentrations in the effluent from the facultative pond

Table 3 | Results of water quality parameters evaluated at inlet (Point 1) and final effluent of WWTP (Point 3) in Phase 1 and Phase 2

		TKN		NH_3		Total phosphorus	
Sample		**Phase 1**	**Phase 2**	**Phase 1**	**Phase 2**	**Phase 1**	**Phase 2**
Inlet of WWTP (Point 1)	Number of data points	14	22	14	22	13	20
	Mean	47	55	28	35	6	6.4
	Standard deviation	17	22	6	9	2.7	1.4
	Median	42	52	29	36	5	6
	25% percentile	32	41	26	30	4	5.8
	75% percentile	56	60	30	41	8	6.9
Final effluent of WWTP (Point 3)	Number of data points	14	22	14	22	13	20
	Mean	27	37	18	23	3.5	3.3
	Standard deviation	11	19	7	9	2.0	1.4
	Median	27	37	18	23	3.0	2.8
	25% percentile	21	25	14	17	2.2	2.7
	75% percentile	34	44	21	27	3.9	3.5

All units in mg L^{-1}.

during both Phase 1 and 2, showed that these variables were statistically equivalent. Also, the addition of sludge from the WTP did not interfere in the nutrients' removal process.

According to several researchers, it is estimated that the removal of NH_3 in facultative stabilization ponds can occur by the combined mechanisms of air stripping, assimilation by cell biomass, or by nitrification and denitrification processes (Racault *et al.* 1995; Zimmo *et al.* 2004; Picot *et al.* 2005a). Since the TSS concentrations and particles that originated in the WTP's sludge tended to separate by gravitational sedimentation in the anaerobic pond, the TSS concentration in the facultative pond decreased enough not to inhibit the nutrients' removal process. The same argument applies to the phosphorus removal in stabilization ponds. This process may happen by the mechanisms of sedimentation of the nitrogen's particulate fraction, or incorporation by the cell biomass, or by chemical precipitation (Strang & Wareham 2006). Whichever the leading mechanism was, it was not favored or inhibited by the addition of sludge from the WTP into the WWTP.

Some researchers (Babatunde *et al.* 2009; Zhao & Yang 2010; Boyer *et al.* 2011) have observed that sludge formed from precipitated aluminum hydroxide has an adsorption capacity for soluble phosphorus present in the liquid phase. However, its adsorption capacity is rather small; around 0.1–25 mg P/g sludge. Since the maximum sludge concentration released in the wastewater treatment system was 16 to 55 mg L^{-1}, its adsorption capacity to remove soluble phosphorus tends to be rather small and does not justify the significant phosphorus removal difference between Phases 1 and 2.

Sludge accumulation in the anaerobic pond

Based on the bathymetric surveys performed in the anaerobic pond, it was possible to estimate the sludge accumulation rate for the period of sludge release from the WTP into the WWTP. The performed bathymetry result from the anaerobic pond at the end of Phase 2 is shown in Figure 3.

The pattern of sludge discharge in the anaerobic pond indicates a relatively homogeneous distribution along its surface area. This pattern showed the level of sludge slightly higher at the beginning of the structure (50–60 cm) and slightly lower towards the exit (30–40 cm). The relative homogeneous distribution can be explained by the low average hydraulic residence time, around 7 d, which allows the TSS to be carried and later deposited over the pond's entire surface area. The same homogeneous pattern of sludge discharge in anaerobic ponds was also observed in other studies (Paing *et al.* 2000; Nelson *et al.* 2004). The effect of hydrodynamic factors such as wind and the wind's longitudinal velocity profile explain the higher sludge discharge at the beginning of the pond and lower discharge towards the end.

Based on the bathymetric results obtained at the beginning and at the end of Phase 2, it was possible to estimate the sludge accumulation rate in the anaerobic pond, 141 mm/year. This value is similar to those expected for anaerobic ponds that operate in a tropical climate. Other studies have shown values of sludge accumulation rate in anaerobic ponds between 50 and 150 mm/year, varying according to meteorological conditions. Thus, it is expected to obtain accumulation rate values for ponds operating in a

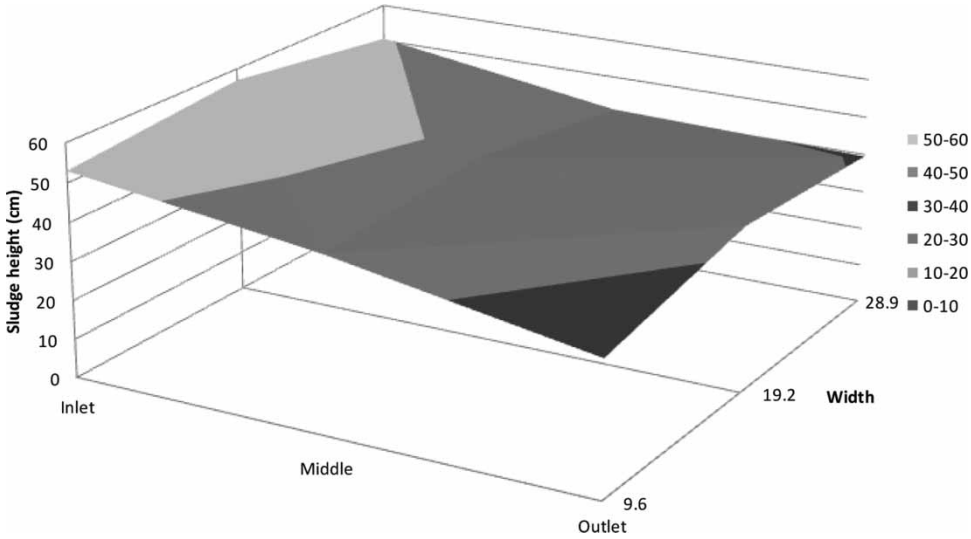

Figure 3 | Anaerobic pond bathymetry performed at the end of the sludge discharge period from the WTP into the WWTP.

temperate climate higher than those that operate in a tropical climate (Papadopoulos *et al.* 2003).

The sludge accumulation rate observed for the anaerobic pond can be compared with the calculated values, using the methodology proposed by Saqqar & Pescod (1995):

$$\frac{T_{sa} = K_{as}.(1.7\text{VSS} + 4.5\text{FSS} + \text{BOD}).1,000}{\rho.A_s} \quad (2)$$

where T_{sa} is the sludge accumulation rate in mm/year; K_{as} is the accumulated sludge coefficient; VSS is the volatile suspended solids load influent to the pond in kg/year; FSS is the fixed suspended solids load influent to the pond in kg/year; BOD is the organic load influent to the pond, expressed as $BOD_{5,20}$ in kg/year; ρ is the specific mass of water in kg/m³; and A_s is the average surface area of the pond in m².

The original K_{as} value proposed by Saqqar & Pescod (1995) is 0.6, which was obtained from anaerobic stabilization pond studies operating in a tropical climate. In contrast, ponds in a temperate climate had K_{as} values as high as 1.4 (Papadopoulos *et al.* 2003). As the anaerobic pond's monitoring period while receiving sludge from the WTP was less than a year, it is possible that part of the settled solids still present biodegradability. This behavior suggests the adoption of K_{as} values between 0.6 and 1.4. It is also suggested to use a K_{as} value of 1.0 to calculate the sludge accumulation rate in stabilization ponds for periods shorter than a year (Franci 1999). Therefore, the sludge accumulation rate obtained was 101 mm/year, based on a K_{as} value of 1.0 and, the influent fixed (46 mg L^{-1}) and VSSs (154 mg L^{-1}), and the organic load for Phase 2 (301 mg L^{-1}). Since the calculated accumulation rate (101 mm/year) was similar to the observed value (141 mm/year), Equation (2) is appropriate to estimate the sludge accumulation rate in stabilization ponds.

Equation (2) yields the sludge accumulation rate value for Phase 1 of 83 mm/year. Thus, there the sludge accumulation rate increased from 83 to 101 mm/year, during the period of sludge discharge from the WTP into the WWTP. Although the 21.7% increase is triggered from the sludge discharge from the WTP into the WWTP, the discharge does not impose greater limitations in the operation of sludge dredging, dewatering, and final disposal processes. Generally, anaerobic stabilization ponds are designed with consecutive desludging cycle times between 5 and 10 years. Assuming an anaerobic stabilization pond 3.5 m deep, a dredging requirement after filling 30% of its total volume (Picot *et al.* 2005b), and the sludge accumulation rates calculated for Phase 1 (83 mm/year) and Phase 2 (101 mm/year), the operating time between consecutive desludging periods would be 12.7 years without sludge addition from the WTP, and 10.4 years with sludge addition from the WTP. Although the operating time is shorter with sludge addition from the WTP, the estimated times are fairly close to each other and neither of them should impose further operational restrictions nor additional costs to the dredging, dewatering, and final disposal processes.

CONCLUSIONS

The treatment and disposal of sludge generated in conventional WTPs has been a major challenge in the environmental field, especially for small to medium-sized facilities. Considering that many municipalities have WWTPs with anaerobic stabilization ponds followed by a facultative pond, it becomes economically attractive to discharge sludge generated in the water treatment processes into WWTPs for subsequent disposal. This process scheme becomes viable due to the stabilization pond's high hydraulic residence time and its capability for TSS removal. In the present work, the estimated TSS concentration, after the addition of sludge from the WTP into the wastewater treatment process, varied between 16 and 55 mg L^{-1}. The experimental results showed that the addition of the WTP's sludge, with 24 h/d-flow-equalization, into the wastewater collection system did not hinder the treatment processes and the organic load and TSS removal remained constant throughout the sludge discharge. Since WWTPs with anaerobic stabilization ponds typically have high hydraulic residence times, the greatest TSS removal occurs in this unit. Therefore, the main impact to the treatment process was the sludge accumulation rate increase. The accumulation rate during the sludge discharge period was 141 mm/year, which is very similar to the calculated value using the model proposed by Saqqar & Pescod (1995) – 101 mm/year. Hence, the obtained sludge accumulation rate requires shorter dredging and desludging cycle times. The final effluent quality was not significantly affected by the discharge of sludge with TSS concentration of around 16–55 mg L^{-1}, with proper flow equalization, and suitable hydraulic conditions. The sludge discharge into the wastewater collection system presented in this study indicates the viability of this process scheme as an alternative for the treatment and disposal of WTP sludge in WWTPs with anaerobic ponds followed by a facultative pond.

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