Comparison between polishing (maturation) ponds and subsurface flow constructed wetlands (planted and unplanted) for the post-treatment of the effluent from UASB reactors

M. von Sperling*, F.L. Dornelas, F.A.L. Assunção, A.C. de Paoli, M. O. A. Mabub

Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais; Av. Contorno 842 – 7th floor; 30110-060 - Belo Horizonte – Brazil.
(*) Corresponding author: Tel.:+55 31 3409-1935; e-mail: marcos@desa.ufmg.br

Abstract: This paper presents the results of a comparison of the performance of two treatment systems operating in parallel, with the same influent wastewater. The investigated systems are (i) UASB + three polishing ponds in series + coarse filter (200 population equivalents) and (ii) UASB + subsurface flow constructed wetlands (50 population equivalents). Two wetland units, operating in parallel, were analysed, being one planted (*Typha latifolia*) and the other unplanted. The systems were located in Belo Horizonte, Brazil. The wetland systems showed to be more efficient in the removal of organic matter and suspended solids, leading to good effluent BOD and COD concentrations and excellent SS concentrations. The planted wetland performed better than the unplanted unit, but the latter was also able to provide a good effluent quality. The polishing pond system was more efficient in the removal of nitrogen (ammonia) and coliforms (*E. coli*). Land requirements and cost considerations are presented.
Keywords: Constructed wetlands, polishing ponds, UASB reactors, urban wastewater

INTRODUCTION

In warm-climate regions, anaerobic reactors are being applied for the treatment of urban wastewater, mainly because of their low operational costs (no energy consumption, low sludge production) and conceptual simplicity (no need for separate sludge thickeners and digesters). The main configuration is that of UASB (Upflow Anaerobic Sludge Blanket) reactors. UASB reactors contribute with the removal of organic matter and suspended solids, but the effluent quality requires, in most cases, a post-treatment step to further reduce BOD and suspended solids, in order to allow compliance with most water quality legislations. Additionally, nutrient (N and P) and coliform removal efficiencies in UASB reactors are very low, and in case it is necessary to produce an effluent with low concentrations of these constituents, specific post-treatment options need to be implemented (von Sperling and Chernicharo, 2005). Natural wastewater treatment processes, such as ponds and wetlands, are important post-treatment options, because they preserve the conceptual simplicity and low operational costs, and are able to remove some constituents that are little affected in the anaerobic step.

Polishing ponds are designed as maturation ponds, but have been so termed because they provide a further improvement in the effluent quality of anaerobic reactors. As most maturation ponds, their main objective is the removal of pathogenic organisms, such that the effluent can be safely discharged into a water body or used for irrigation. A certain ammonia removal is also expected, due to the increase in pH brought about by the intense photosynthetic activity. However, the presence of algae may increase the effluent concentration in terms of suspended solids and particulate BOD and COD. A simple and effective means of providing some solids removal may be accomplished by coarse rock filters as the last treatment step.

Subsurface-flow constructed wetlands are another simple natural wastewater treatment process that may be potentially used for the post-treatment of anaerobic effluents. Wetlands are usually planted with macrophytes, but there is a controversy in the literature regarding the real contribution of the plants in the overall removal efficiencies (Mara, 2004). Organic matter and suspended solids removal are usually very good in wetland systems, whereas nutrient removal is reported as being variable (USEPA, 2000), and coliform removal takes place, but is usually insufficient for direct applications such as agricultural reuse.

The choice of which system to apply depends, not only on the effluent quality produced, but also on land and cost requirements. Mara (2006) states that ponds are more viable in terms of land and cost requirements than wetlands when effluents with similar characteristics are aimed at.

This paper aims at investigating the comparative performance and land requirements of ponds in series and subsurface-flow constructed wetlands for the post-treatment of effluents from UASB reactors treating urban wastewater, a subject that still needs to be more covered in the literature. Additionally, the comparison between planted and unplanted wetlands is undertaken. All systems treat the wastewater from the city of Belo Horizonte, Brazil, and are situated in the same experimental area, thus receiving the same wastewater. Monitoring was undertaken in the same period, comprising one year of investigation.

MATERIAL AND METHODS

Monitoring

The investigation was carried out at the Experimental Wastewater Treatment Plant UFMG/Copasa, located at the Arrudas wastewater treatment plant (WWTP), in Belo Horizonte, Brazil, coordinates 19°53’42” S and 43°52’42” W. The experimental WWTP receives preliminary treated effluent (coarse and medium screens plus grit removal). The effluent is directed to two independent systems (Figure 1): (i) System 1: UASB reactor 1, three polishing ponds in series and a coarse rock filter; (ii) System 2: UASB reactor 2 and two subsurface-flow wetlands in parallel, one planted and the other unplanted.

The monitoring period was the same for both systems, comprising a full year (20/09/07 to 20/09/08). The monitored constituents were: (i) weekly frequency: pH, temperature, COD, N-ammonia, N-organic, N-nitrate, N-total, P-phosphate and P-total; (ii) two-weekly: BOD and SS. Analytical procedures were according to the Standard Methods for the Examination of Water and Wastewater.

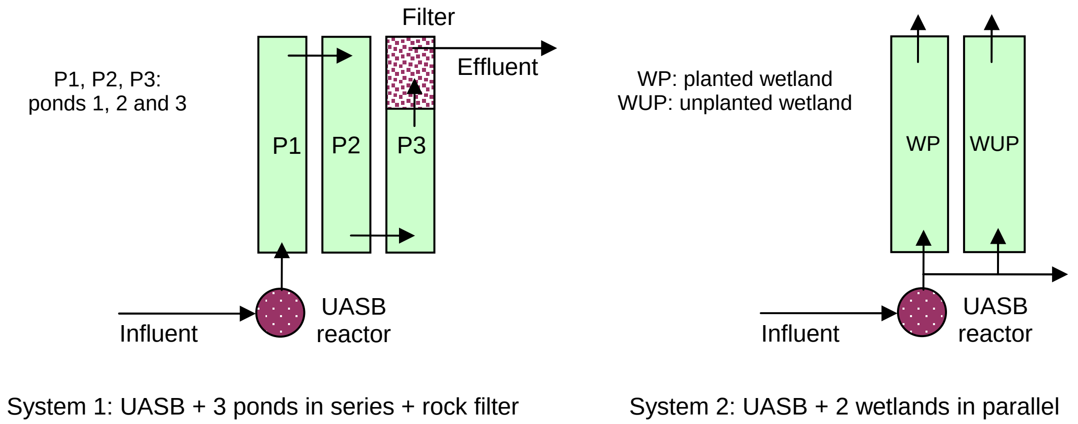

Fig. 1. Flowsheet of the two independent treatment systems investigated

Description of System 1: UASB – ponds – rock filter

The UASB reactor was cylindrical, made of ferrous cement. The ponds were rectangular, with a length-to-width ratio around 5. The rock filter was inserted inside the last polishing pond, and was made of commercial crushed stone (diameters from 3 to 8 cm). The population equivalent of the system was around 200 inhabitants. Table 1 shows the main characteristics of the system.

Table 1 Physical and operating characteristics of System 1

Unit	Volume (m^3)	Area at surface (m^2)	Dimensions	Hydraulic retention time (V/Q)
UASB reactor	14	3	H = 4.5 m; D = 2.0 m	0.5 days
Polishing pond 1	125	182	L = 25.00 m; B = 5.25 m; H = 0.80 m	4.3 days
Polishing pond 2	125	182	L = 25.00 m; B = 5.25 m; H = 0.80 m	4.3 days
Polishing pond 3	60	110	L = 16.56 m; B = 5.25 m; H = 0.60 m	2,1 days
Coarse rock filter	30	55	L = 8.44 m; B = 5.25 m; H = 0.60 m	1.0 days

L = length at bottom; B = width at bottom; H = height; D = diameter; Mean flow: 29 m^3/d

Description of System 2: UASB – wetlands in parallel

System 2 is composed of a carbon-steel UASB reactor with dimensions 1.20m x 1.20m x 5.00m (width; length; height). This unit operated with a flow of 30 m^3/d and a hydraulic retention time around 6 hours. Part of the effluent flow from the UASB reactor was directed to the two wetland units in parallel, each receiving a flow of 7.5 m^3/d (population equivalent around 50 inhabitants). One unit was planted with *Typha latifolia* and the other unit acted as an unplanted control. The support media in both units was steel slag with grain sizes mostly between 20 and 40 mm (d_{10} = 19 mm, d_{60}/d_{10}=1.2). The main characteristics are presented in Table 2.

Table 2. Physical and operating characteristics of each wetland unit

Parameter	Value	Parameter	Value
Bed height (m)	0.4	Wet volume (m^3)	7.5
Liquid height (m)	0.3	Flow (m^3/d)	0.1
Length (m)	24.1	Surface hydraulic loading rate (m^3/m^2.d)	1.2
Width (m)	3.0	Hydraulic retention time (V.porosity/Q) (d)	
Surface area (m^2)	72.3		

RESULTS AND DISCUSSION

Overall results

Table 3 presents the mean values of the monitored constituents along the one-year experimental period, while Table 4 presents the overall (from raw sewage to final effluent) mean removal efficiencies for selected constituents. The number of data is approximately 50 for the weekly samples and 25 for the two-weekly samples. Mean liquid temperature was 23^{o}C. It is seen that both UASB reactors had different performances, causing different input concentrations to the post-treatment systems, especially in terms of COD and SS. However, the discussion on the performance of the UASB reactors is beyond the scope of this paper. Data variability and evolution of concentrations along the treatment system can be observed in the box-and-whisker plots in the subsequent sections, together with the interpretation of the results.

Organic matter

Figures 2 and 3 present the box plot of the BOD and COD concentrations along both treatment systems. From the tables and figures, it is clearly seen that the wetland systems are capable of providing a much better effluent quality in terms of organic matter (BOD and COD) compared with the ponds system. This is already expected, because the ponds produce algae, which constitute particulate organic matter in the effluent. The wetland systems, on the other hand, are composed by a medium with small grain size, which contributes with the removal of solids and particulate matter. In the ponds system, it is seen that, after the UASB reactor, there is not much improvement in terms of organic matter removal. At the end, the coarse filter is able to give a further reduction, giving a good effluent quality (all BOD values are below 60 mg/L). The effluent BOD and COD concentrations from the wetland systems are very good, with most BOD values below 20 mg/L. The planted unit was only marginally better than the unplanted unit in terms of BOD concentration, but was significantly better (Wilcoxon-matched pairs test, 5% significance level) in terms of COD.

Table 3. Mean concentrations of the monitored constituents in both treatment systems

Constituent	Raw sewage	UASB – ponds - filter					UASB - wetlands		
		UASB	Pond 1	Pond 2	Pond 3	Filter	UASB	Planted	Unplanted
BOD	175	53	36	37	39	29	43	16	18
COD	391	207	163	160	182	139	148	43	74
TSS	181	86	56	48	84	51	39	5	4
VSS	146	61	46	39	66	42	29	3	3
N-ammonia	28	32	27	18	13	14	34	28	31
N-organic	8	7	8	6	5	5	5	4	5
Nitrate	0.00	0.00	0.11	0.31	0.28	0.15	0.06	0.38	0.31
N-total	36	39	33	24	18	17	37	31	36
$P\text{-}PO_4$	0.80	0.92	0.95	0.90	0.79	0.87	1.36	0.64	0.55
P-total	1.70	1.68	1.66	1.72	1.78	1.80	-	2.19	2.10
pH	7.1	-	7.5	7.9	8.3	7.7	-	8.2	8.3
E. coli	1.2E+8	-	5.6E+5	9.2E+4	4.0E+4	-	-	1.3E+5	4.3E+5

Units: mg/L, except pH (dimensionless) and *E. coli* (MPN/100mL); Shaded cells: final effluent

Table 4. Mean overall removal efficiency in both treatment systems (%)

Constituent	UASB – ponds - filter	UASB – planted wetland	UASB – unplanted wetland
BOD	83	91	90
COD	64	89	81
SS	72	97	98
N-total	53	14	1
E. coli	99.97	99.89	99.64

Note: Removal efficiency calculated based on mean influent and mean effluent concentrations

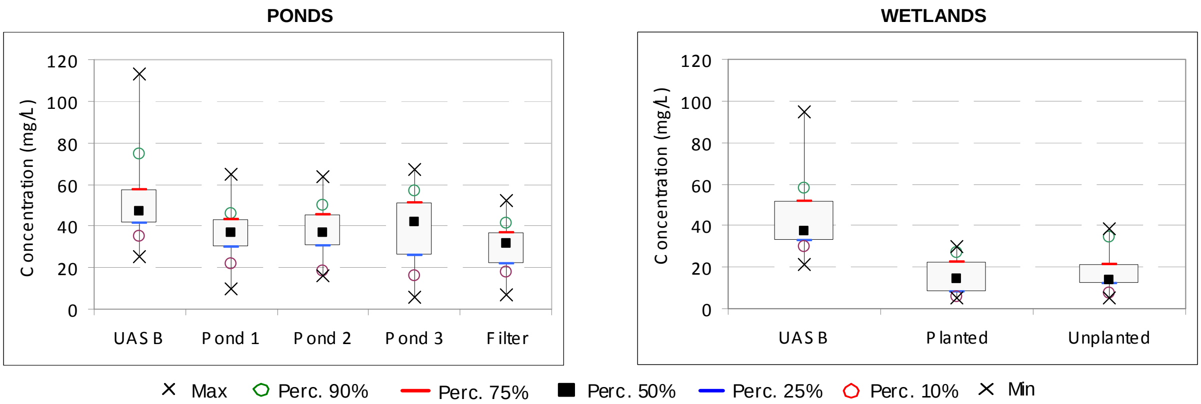

Fig. 2. Box plot of the BOD concentrations along the treatment systems

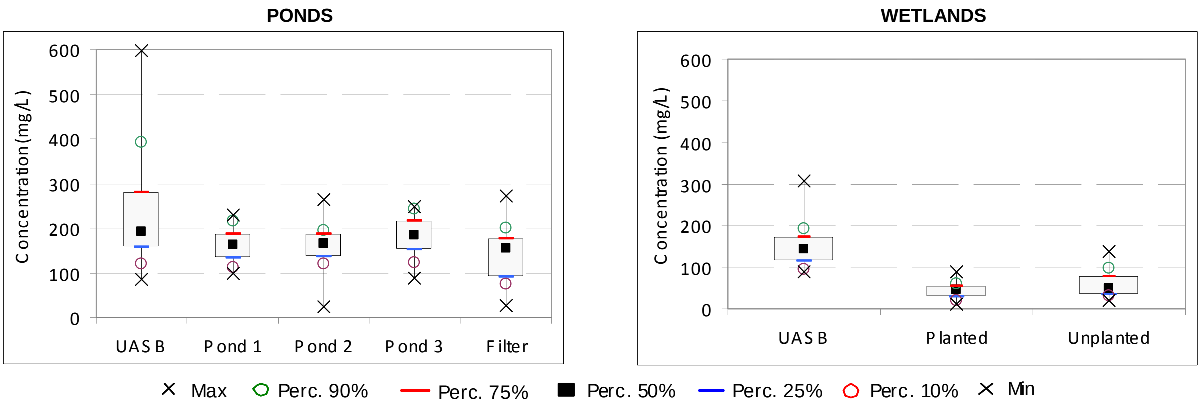

Fig. 3. Box plot of the COD concentrations along the treatment systems

Suspended solids

Figure 4 presents the box plot of the SS concentrations along both systems. Similar comments to organic matter can be made: better performance of the wetland systems, increase of SS concentrations in the ponds (algae production) and good contribution of the coarse filter. However, it is important to emphasize the excellent quality of the planted and unplanted wetlands, producing average SS concentrations of 5 and 4 mg/L, respectively (no significant differences in the Wilcoxon test), values that are comparable to those of sophisticated secondary treatment processes. The average removal efficiencies of the planted and unplanted wetland systems are excellent (97 and 98%, respectively), and this is probably the most remarkable aspect in these systems. The VSS/SS ratio in both systems is around 75%, indicating that most of the suspended solids are of organic nature.

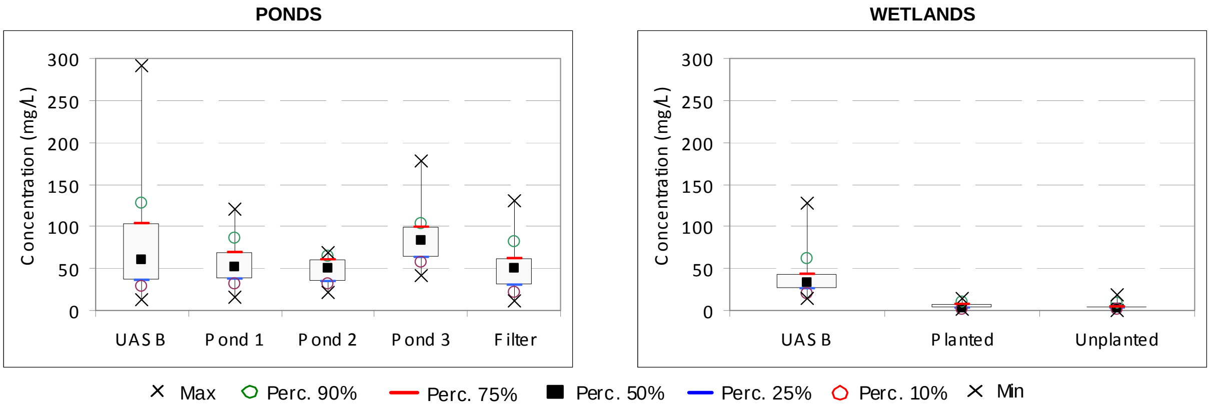

Fig. 4. Box plot of the SS concentrations along the treatment systems

Nutrients

As shown in Figure 5, in the ponds system total nitrogen concentrations decrease systematically from pond to pond. The effluent concentrations are higher than those obtainable in sophisticated biological nutrient removal plants using the activated sludge process, but are lower than those obtainable by most other treatment processes. Most of the removal is of the ammonia nitrogen, one of the reasons being probably linked to free ammonia desorption through the ponds surface due to the high pH (Pano and Middlebrooks, 1982). However this mechanism needs yet to be confirmed, since it is controversial in the literature (Camargo and Mara, 2006). Regarding both wetland systems, nitrogen removal was poor and much lower than in the pond system. Low nitrogen removal efficiencies in planted constructed wetlands have been observed in many installations (USEPA, 2000), but it should be remembered that the efficiency is dependent upon the plant species and the harvesting strategies implemented. Thus, the results obtained in this particular research with *Typha latifolia* cannot be extended to other systems with different conditions. As depicted in Figure 6, most of the nitrogen in all post-treatment systems is present in the ammonia form, followed by organic nitrogen, with only insignificant concentrations of the oxidized forms (nitrite and nitrate).

Phosphorus removal in the ponds and wetland systems was very poor. In the ponds system, consistently higher pH values would be required to sustain a partial phosphate precipitation. In the wetlands system, plant absorption and reactions with the iron-containing steel-slag used as media showed to be not important.

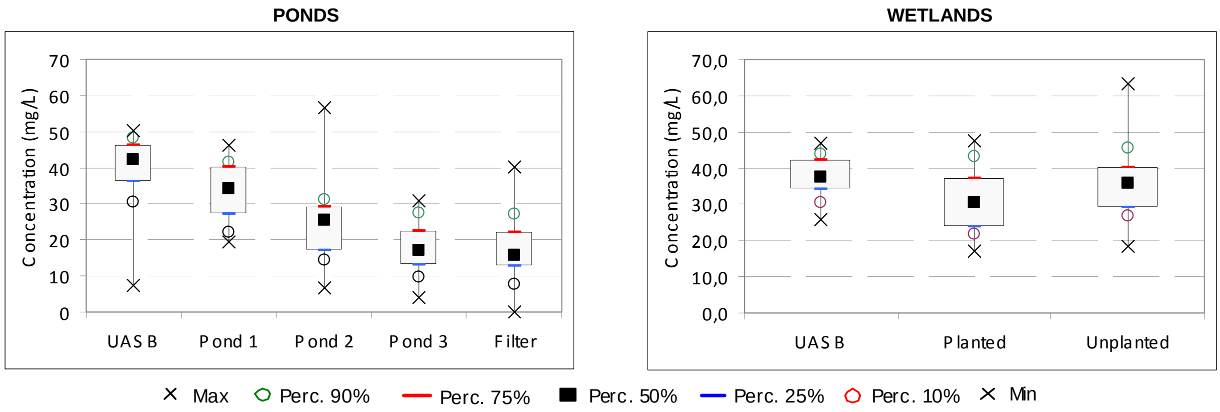

Fig. 5. Box plot of the total N concentrations along the treatment systems

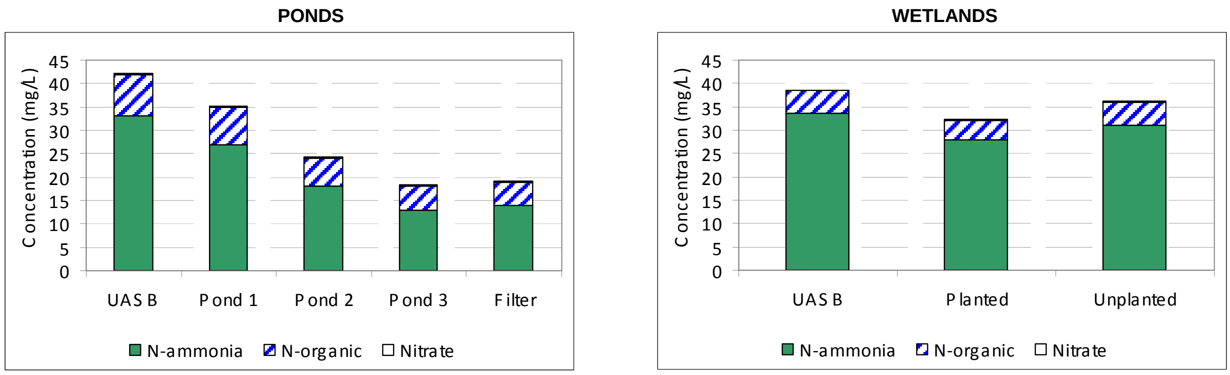

Fig. 6. Distribution of the main forms of nitrogen along the treatment systems (mean values)

Coliforms

As expected, *E. coli* removal was substantially better in the ponds system, compared with the wetlands (see Figure 7). As a matter of fact, polishing ponds are designed as maturation ponds, and have as primary roles the removal of pathogenic organisms. The results show that the decay of *E. coli* takes place systematically in all ponds. In the present case the ponds effluent cannot be used for unrestricted irrigation (geometric means > 10^3 MPN/100mL), but an even better effluent quality can be achieved by the incorporation of one or more units in series, or through the adoption of shallower ponds. Experiments previously conducted in the same plant, with four ponds in series with lower depths (total hydraulic retention time of only 7.4 days), led to 6.4 log units removal, and mean effluent concentrations of 3.8×10^2 MPN/100mL (von Sperling and Mascarenhas, 2005). Research on several polishing pond systems in Brazil indicated that average helminth eggs concentrations are usually lower than 1 egg/L, limit value of the WHO guidelines for restricted and unrestricted irrigation. Helminth eggs were not monitored in this experimental period, but previous results are in accordance with the above statements (von Sperling et al, 2005). Regarding the wetlands, effluent *E. coli* concentrations were similar to those obtained in the effluents from ponds 1 and 2.

Planted versus unplanted wetlands

When comparing the planted and unplanted units, even though the performance of the planted one was better for most constituents (some of them with statistical significance by the Wilcoxon matched pairs test at 5% significance level), it is always a matter of careful consideration as to the real need of planting. Based on the results obtained, it is seen that there is no general answer to this question. Although the performance of the unplanted wetland was inferior, it was still very good for organic matter and solids removal, and its higher conceptual simplicity may indicate its application whenever a compatible effluent quality is required.

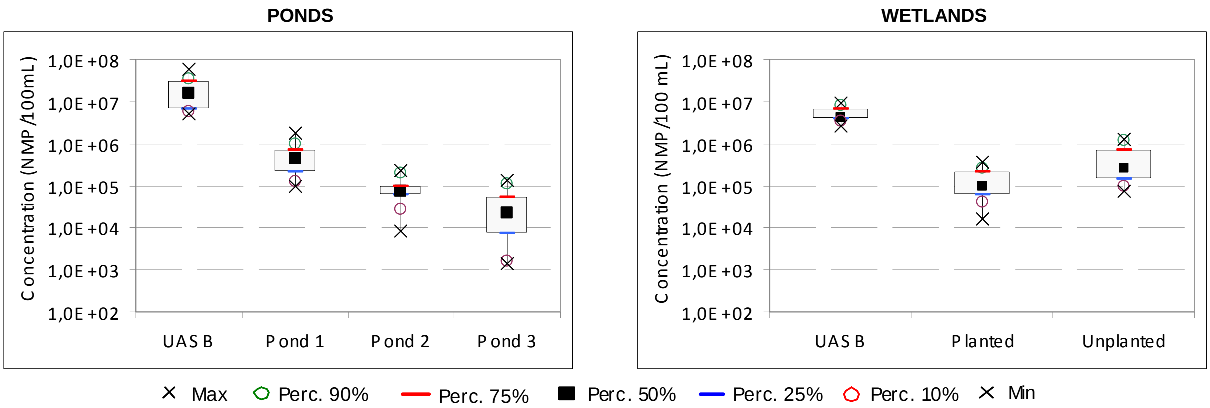

Fig. 7. Box plot of the *E. coli* concentrations along the treatment systems

Hydraulic headloss

An important operational aspect is that no appreciable head loss has been observed in the coarse rock filter inserted in the last pond, after more than three years of operation. This is due to the large grain size of the crushed stones. In the wetlands, due to the smaller grain size of the media, headloss in the first few meters is taking place after one year of operation, causing surface flow in the inlet area. The removal and cleaning of the media in the first meters will be necessary in the medium term. Although this will bring a demand in terms of maintenance labour, the undertaking of the task is simple and is expected not to pose a problem.

Land requirements and cost aspects

Taking into account only the net area occupied by the units (excluding dykes, internal roads, parking, laboratory etc), per capita land requirements can be calculated using the area values from tables 1 and 2, and considering that the ponds system serve a population of approximately 200 inhabitants and each wetland serves around 50 inhabitants. Neglecting the area occupied by the UASB reactors (which is proportionately very small), the following values are obtained for the investigated system (Table 5).

Table 5. Per capita net land requirements for the experimental systems investigated

Post-treatment system	Number of units	Net land requirement (m^2/inhabitant)
Pond system	1 pond	0.8
	2 ponds	1.6
	3 ponds	2.1
	3 ponds + coarse filter	2.4
Wetland system	Planted unit	1.4
	Unplanted unit	1.4

It is seen that the wetland systems investigated are comparable, in terms of land requirements, to a post-treatment system composed of two ponds. Such a pond system (two ponds) was able to produce similar effluent coliform concentrations, better nitrogen removal, but poorer solids and organic matter removal. For both systems, land requirements are obviously high, due to the fact that they are naturally-based processes.

No detailed cost values are available for the construction of both systems. The construction of the shallow ponds and the wetlands are somewhat similar, because they are both shallow units, with similar requirements for excavation, dykes and lining. A major difference is the filter media in the wetlands. In Belo Horizonte, approximate costs for the steel slag is around US$10/$m^3$. Each wetland used 30 m^3 of media, which, for the 50 inhabitants, results in approximately US$6/inhabitant. For ordinary crushed stones the values would be approximately the double, that is, US$12/inhabitant.

CONCLUDING REMARKS

When comparing the experimental systems investigated (UASB + three polishing ponds in series + coarse filter; UASB + planted wetland; UASB + unplanted wetland), it can be concluded that:

- The wetland systems were more efficient in the removal of organic matter and suspended solids, leading to good effluent BOD and COD concentrations and excellent SS concentrations.
- The planted wetland performed better than the unplanted unit, but the latter was also able to provide a good effluent quality.
- The polishing pond system was more efficient in the removal of nitrogen (ammonia) and coliforms (*E. coli*).
- The polishing pond system, if incorporating one more unit in the series, would be able to generate an effluent compliant with unrestricted irrigation quality requirements.
- Pond systems designed for effective coliform removal require substantial area, larger than 2.5 m^2/inhabitant (net area) under the climatic conditions of the experimental site.
- Hydraulic headloss in the wetland system was larger than in the ponds-coarse filter system.
- Construction costs are likely to be higher for wetland systems, compared to a system with two polishing ponds.

It is seen that there is no general conclusion of which system is better. The decision, as is always the case when selecting wastewater treatment processes, depends on the effluent quality requirements and on land availability and cost issues. The points commented in this paper are applicable to the systems investigated, and extrapolation of conclusions to other systems operating under different loadings and conditions needs to be done carefully.

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