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Performance comparison and economics analysis of waste stabilization ponds and horizontal subsurface flow constructed wetlands treating domestic wastewater: A case study of the Juja sewage treatment works

Njenga Mburu [a,b,*], Sylvie M. Tebitendwa [a], Johan J.A. van Bruggen [a], Diederik P.L. Rousseau [c,d], Piet N.L. Lens [a]

[a] UNESCO-IHE Institute for Water Education, P.O. Box 3015, 2601 DA Delft, The Netherlands
[b] Department of Civil and Structural Engineering, Masinde Muliro University of Science and Technology, P.O. Box 190, 50100 Kakamega, Kenya
[c] University College West Flanders, EnBiChem Research Group, Graaf Karel de Goedelaan 5, 8500 Kortrijk, Belgium
[d] Laboratory of Analytical Chemistry and Applied Ecochemistry, Ghent University, Coupure Links 653, 9000 Gent, Belgium

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ABSTRACT

The performance, effluent quality, land area requirement, investment and operation costs of a full-scale waste stabilization pond (WSP) and a pilot scale horizontal subsurface flow constructed wetland (HSSF-CW) at Jomo Kenyatta University of Agriculture and Technology (JKUAT) were investigated between November 2010 to January 2011. Both systems gave comparable medium to high levels of organic matter and suspended solids removal. However, the WSP showed a better removal for Total Phosphorus (TP) and Ammonium (NH_4^+–N). Based on the population equivalent calculations, the land area requirement per person equivalent of the WSP system was 3 times the area that would be required for the HSSF-CW to treat the same amount of wastewater. The total annual cost estimates consisting of capital, operation and maintenance (O&M) costs were comparable for both systems. However, the evaluation of the capital cost of either system showed that it is largely influenced by the size of the population served, local cost of land and the construction materials involved. Hence, one can select either system in terms of treatment efficiency. When land is available other factor including the volume of wastewater or the investment, and O&M costs determine the technology selection.

1. Introduction

Conventional treatment plants are widely used for the treatment of domestic and industrial wastewater in developed countries. Even though very efficient, they are expensive to construct, intensive to maintain and require skilled personnel for their operation. In developing countries, very few well working conventional treatment plants can be found (Diaz and Barkdoll, 2006). Possible alternatives are those systems that provide a cheap, effective, reliable and sustainable way of treating wastewater. This includes the waste stabilization ponds (Babu, 2011) and constructed wetlands (Mburu et al., 2013). Both are well-established methods for wastewater treatment in tropical and subtropical climates (Machibya and Mwanuzi, 2006). Some of the advantages of these natural treatment systems over conventional wastewater treatment plants include: no need for skilled labour and therefore low operation and maintenance costs (Kayombo et al., 2000). Additionally, their zero-energy demand for the removal of organics and pathogenic organisms is contributing as a valuable tool for sustainable development (Thurston et al., 2001; Mashauri and Kayombo, 2002). It is particularly the case when topography allows gravity feeding. However, one of the disadvantages of these natural systems is their space requirement (Bastos et al., 2010).

The main expenses related to sewage services are capital cost, operation and maintenance (O&M) costs and the procurement of land (Tsagarakis et al., 2003). These are thus important parameters for selecting an appropriate treatment system (Tsagarakis et al., 2003; Sato et al., 2007; Rousseau et al., 2008). In this sense, appropriate technology should be affordable (capital cost), have a low operation and maintenance cost (sustainability), be effective in

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* Corresponding author. Department of Civil and Structural Engineering, Masinde Muliro University of Science and Technology, P.O. Box 190, 50100 Kakamega, Kenya. Tel.: +254 728777573.
E-mail addresses: njmburu2002@yahoo.com, n.mburu@unesco-ihe.org (N. Mburu).

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meeting the discharge standards (efficiency), give the least nuisance (public acceptability) and be environmentally friendly (Mara, 2004; Mara et al., 2007). Thus natural wastewater treatment processes (i.e., non-electromechanical, using physical and biological processes) that are simple, low-cost and low-maintenance are preferred as appropriate alternatives for conventional wastewater treatment by any country, but especially in developing countries in the tropical areas (Mara, 2006; Sato et al., 2007).

Waste stabilization ponds (WSPs) and horizontal subsurface flow constructed wetlands (HSSF-CWs) are not equally applied in hot climates, as the latter technology has been recently embraced in the developing countries (Kivaisi, 2001; Mara, 2004; Li et al., 2007). Comparing land area requirements and costs to achieve a required effluent quality can be useful in deciding whether to use a HSSF-CW or a WSP (Mara, 2006). The aim of this paper is to compare the two technologies in terms of pollutant removal efficiency, land area requirement, as well as investment, operation and maintenance costs. Such a comparison based on available data and facilities could offer technical and economic insights that would simplify technology selection processes. This deserves consideration and is especially relevant to small communities where the need for a reliable treatment of wastewater not only integrates with the selection of an economically and environmentally viable wastewater treatment technology, but also with social attributes such as workforce education level and available land. In this study, domestic wastewater was send to a pre-existing treatment system consisting of three interconnected waste stabilization ponds – a primary facultative and secondary facultative pond, followed by a maturation pond. An experimental pilot scale HSSF-CW was introduced and fed from the outflow of the primary facultative pond.

2. Experimental set-up

2.1. Study area

The pilot scale HSSF-CW and the WSP were located within the premises of the Jomo Kenyatta University of Agriculture and Technology (JKUAT) sewage works, in Juja town, Kenya. The sewage works are at a global position of 1°05′49.28″S 37°01′21.91″E and an altitude of 1463 m, some 40 km North East of Nairobi City. JKUAT sewage works treats the university campus' domestic wastewater of about 5000 inhabitants by a set of 5 stabilization ponds. The final effluent is discharged to a near-by river via a natural waterway (Fig. 1).

2.2. Description of the systems

The system described has an operational WSP and an experimental pilot scale HSSF-CW. The WSP system designed for a 2700 population equivalent, consisted of 2 primary facultative ponds (PFP), 2 secondary facultative ponds (SFP) and a maturation pond

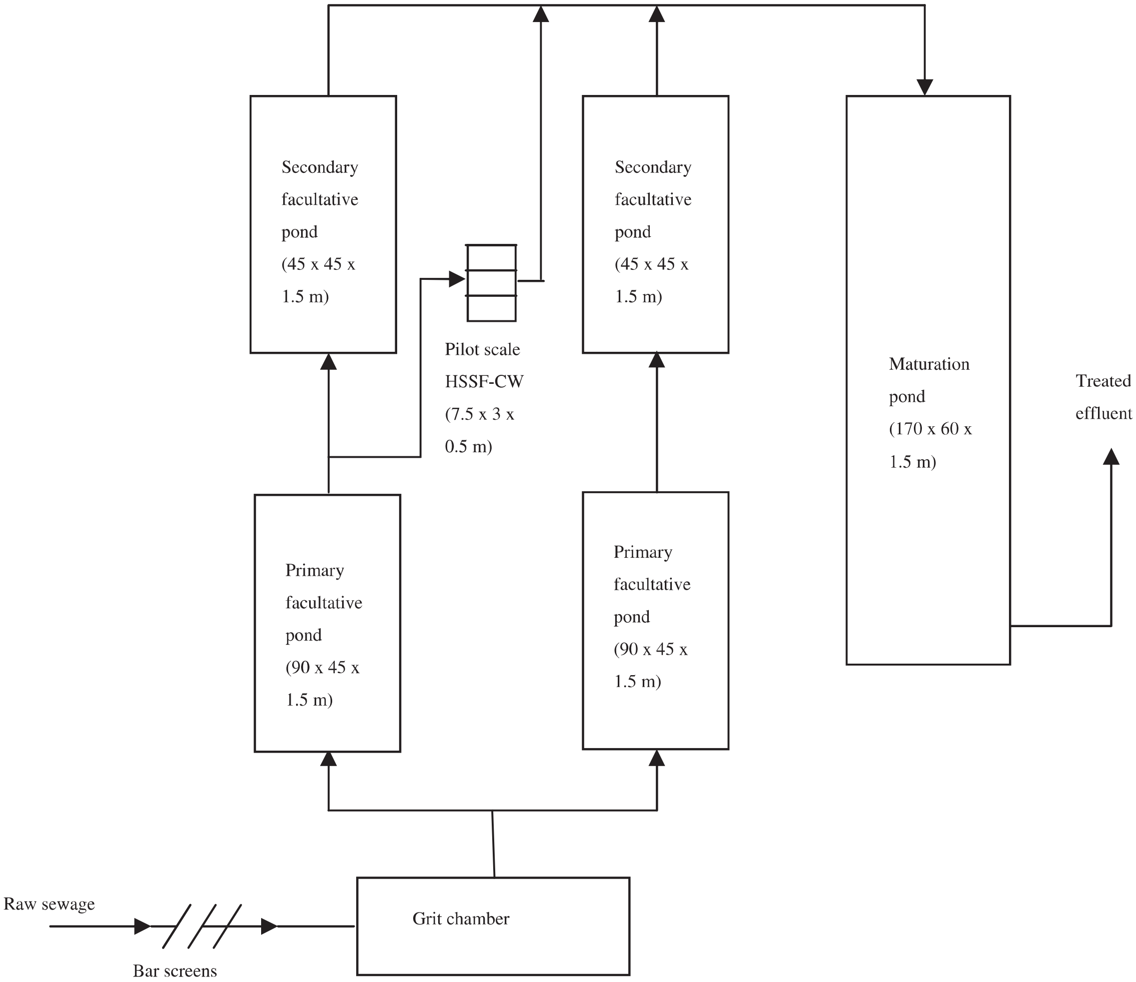

Fig. 1. Waste stabilization ponds and the pilot scale horizontal subsurface flow constructed wetland schematic layout at the JKUAT sewage treatment works.

(MP) that are aligned in series (Fig. 1). The primary facultative ponds also act as the sedimentation pond receiving raw wastewater from the septic tank effluent pump. The septic tank (located 600 m away from the waste stabilization ponds) receives wastewater from the students' hostels, staff quarters, cafeterias and laboratories at JKUAT. The ponds were periodically covered with duckweed (*Lemna* sp.) and Fern (*Azolla pinnata*) and attracted ducks and goose. The mean flow rate into the PFP and SFP was 349 m^3/d and that into the MP was 698 m^3/d, resulting into a hydraulic retention time (HRT) of 14.6, 6.9, and 19.5 days respectively, giving a total HRT of 41 days.

The constructed wetland system, described in details by Mburu et al. (2013), consisted of two pilot scale cells of HSSF-CW receiving primary effluent from the outflow of one of the PFP. In one of the HSSF-CW cells, the macrophyte *Cyperus papyrus* was planted (1 plant per m^2), while the second cell acted as a control. At the time of this study, *C. papyrus* had senescenced, but below-ground biomass was present. The mean flow rate for the control and planted cell was 3 m^3/d, resulting in a HRT of 1.5 days.

In WSP holding basins or lagoons, wastewater is stabilized in a confined environment. Area requirements are based on volumetric and surface organic loading rates (Mara, 2006). In the HSSF-CW, water flows through a porous medium such as gravel in which plants are rooted. The porous media provide anchorage for the emergent macrophyte and surface area for microbial growth which consequently enhances the transformation or removal of chemical and biological constituents in wastewater (García et al., 2010). Determination of area requirements for constructed wetlands is based on the rules of thumb or first order design equations (Kadlec and Wallace, 2009). The wastewater has to be pretreated prior to the HSSF-CW (a minimal acceptable level being equivalent to primary treatment), to reduce the risk of clogging from solids. The biological conditions in these systems are similar in certain aspects; water near the bottom is in an anoxic/anaerobic state, while a shallow zone near the water surface tends to be aerobic. The source of oxygen is atmospheric re-aeration, photosynthesis (in facultative pond) and root oxygen leaching (in wetlands). These natural treatment systems promote the development of microorganisms which are responsible for much of the biological treatment occurring in the systems. The operation of the two systems does not involve material input (chemicals) and energy consumption, as treatment mechanisms are natural and wastewater flow within the systems is entirely driven by gravity.

2.3. Analysis of the physico-chemical parameters

Physico-chemical variables were measured *in-situ*. pH, conductivity and total dissolved solids were measured with a HACH, ECO 40 multi-probe, whereas dissolved oxygen and temperature were measured with a dissolved oxygen meter (Model HACH, HQ40d multi-probe).

Wastewater samples were collected for analysis of ammonium-nitrogen (NH_4^+–N), total phosphorus (TP), chemical oxygen demand (COD), biological oxygen demand (BOD_5) and total suspended solids (TSS). All were analyzed using standard methods as described in APHA (1998). Mass removal efficiencies were calculated as a difference between input and output mass loading rates. Statistical analysis was performed using MINITAB 15 and Microsoft Excel 2007 software. Comparison of variables was performed using the analysis of variance technique (ANOVA) and the Tukey's multiple comparisons was used to test differences in the means.

2.4. Cost evaluation

The costs of the two systems were calculated based on land requirement, capital, operation and maintenance costs for the treatment of domestic wastewater at JKUAT sewage works, and expressed per population equivalent (PE). Comparative costing was based on undiscounted (and annualized) capital, O&M cost estimates at the time of the study, and ignoring the need for expenditures to earn a rate of return on the investment. Capital cost included the cost of land and the estimated construction cost for both the WSP (earthworks, lining the bottom and embankments, inlet and outlet structures) and the HSSF-CW (masonry and concrete works, plumbing, gravel media and establishing the macrophyte). O&M costs included those of personnel and maintenance (routine and arising repairs, inlet–outlet inspection, landscaping, desludging and macrophyte harvesting (for the HSSF-CW)). A design period of 20 years for the HSSF-CW and WSP systems was used. The initial cost calculation for the HSSF-CW is based on the pilot plant sizing of 12 PE, which is eventually extrapolated to a full size HSSF-CW for 2700 PE and with a corresponding area of the sedimentation pond included in the costing as well.

3. Results and discussion

3.1. Quality of influent and effluent

The main results for the water quality parameters (BOD_5, COD, TSS, NH_4^+–N, and TP) are given in Table 1 for the PFP, SFP, MP and the HSSF-CWs. The WSP removed almost or more than 90% of the BOD, COD and TSS, only 21% of the TP and 50% of the NH_4^+–N. The HSSF-CW removed more than 84% of BOD_5, COD and TSS. NH_4^+–N was not removed while, TP removal was 13% in the unplanted (control) and 26% in the planted HSSF-CW.

The WSP effluent values are within the Kenya National Environmental Management Authority (NEMA) effluent discharge guidelines, except for NH_4^+–N and TP (NEMA-Kenya, 2003). The planted and the unplanted HSSF-CWs exceeded the discharge limit values for NH_4^+–N and TP as well. For the planted HSSF-CW, it must

Table 1
Effluent water quality values and removal efficiencies of the different systems.

System	BOD_5			COD			TSS			NH_4^+–N			TP		
	mg/l	SD	%	mg/l	SD	%	mg/l	SD	%	mg/l	SD	%	mg/l	SD	%
Influent	232	133.3		424	277.4		118	87.6		39	13.6		4	0.9	
Primary facultative pond	74	17.7	68	216	110.9	49	56	14.9	52	34	10.6	14	4	0.7	5
Secondary facultative pond	48	14.6	79	160	77.3	62	39	22.9	67	35	13.8	11	3	0.6	21
Maturation pond	20	16	91	100	37	76	10	20	91	**17**	11	56	**3**	0.6	21
HSSF-CW (planted)	29	9	87	58	17.4	86	19	8.7	84	**36**	8	8	**3**	0.3	26
HSSF-CW (unplanted)	39	14.5	83	98	17.6	77	34	15	71	**39**	5.6	0	**3**	0.6	13

Values in bold don't comply with the NEMA standards. (NEMA guidelines for effluent discharge into surface waters are: less than 120, 40, 35, 1 and 1 mg/l for, COD, BOD_5, TSS and ammonium compound, TP, respectively (NEMA, 2003)).
SD: Standard deviation.

be noted that the plants (above ground biomass) were harvested and only below-ground plant parts, i.e. live *C. papyrus* roots and rhizomes, were present in the HSSF-CW during the study. Compared with the planted HSSF-CW, effluent values for pollutants from the unplanted HSSF-CW are relatively high (Table 1). This is an indication that plants play a role in the wastewater purification processes of the HSSF-CW (Kadlec and Knight, 1996; Stottmeister et al., 2003).

It also should be noted that in this set-up the HSSF-CW are providing up to secondary treatment only. Nevertheless the HSSF-CW achieved a better effluent quality with regard to the bulk pollutants, i.e. organic matter and the suspended solids compared to the WSP (Table 1). This is attributed to the difference in the type of treatment (i.e. biofilm attached to the gravel media in the HSSF-CW and suspended growth in the WSP) and the generation of secondary BOD and TSS from algal and duckweed biomass in the WSP. Thus despite the low HRT of only 1.5 days in the HSSF-CW, compared to the recommended up to 8 days for acceptable removal efficiency of organic matter (Akratos and Tsihrintzis, 2007), the HSSF-CW was found to provide a comparable treatment performance with the WSP. The WSP included an extra treatment (tertiary) step and an overall longer retention time.

The higher NH_4^+–N concentration (Table 1) and the resulting poor removal performance observed in the HSSF-CW compared to the WSP effluent are attributed to the inadequate re-oxygenation capacity in the subsurface flow environment of the HSSF-CW system (Okurut, 2000; Mburu et al., 2012). Indeed, the direct contribution by atmospheric re-aeration and algal photosynthesis, as is the case for a WSP is insignificant in the global aeration process of the HSSF-CW. This reduces the extent of possible nitrification and subsequently limits denitrification due to a lack of nitrates. This was clear from the consistent drop in dissolved oxygen (DO) between the influent and effluent, with a mean effluent DO concentration of 0.6 mg/l, in contrast to an increase to 3.2 mg/l DO at the WSP effluent (data not shown).

Kadlec and Knight (1996) further stress that a HSSF-CW system is good in nitrate removal (denitrification), but not for ammonia oxidation since oxygen availability is the limiting step in nitrification. On the other hand, similar poor ammonia removal was observed for the secondary facultative pond (SFP) despite the high mean oxygen concentration in its effluent (mean 10.2 mg/L) compared to the influent wastewater (1.3 mg/l). There was only a slight decrease in ammonium concentration in the SFP, which was finally reduced to 17 mg/L in the MP effluent. The results, nonetheless, are comparable to the findings of Babu (2011), who reported an increase in the ammonium concentration in the facultative pond effluent and a reduction in the ammonium concentration in the MP effluent. The mineralization of organic compounds within the aerobic layer of the SFP due to the supply of oxygen from algae could be responsible for the high NH_4^+–N concentration observed in the SFP effluent (Senzia et al., 2003; Shammas et al., 2009). Further, lack of attachment surfaces for the nitrifiers could be responsible for the high NH_4^+–N concentration in the effluent of WSP (Zimmo et al., 2003; Babu, 2011). Several studies have shown that the introduction of attachment surface for nitrifiers in the ponds improves nitrogen removal (Pearson, 2005; Babu, 2011).

Phosphorus removal through assimilation by algae to support cell synthesis seems to have been considerable in the WSP judging from the higher removal rate calculated at 2.54 g TP m^{-2} d^{-1} compared to 0.13 g TP m^{-2} d^{-1} achieved in the HSSF-CW. Reasons for the lower phosphorus removal efficiency of the HSSF-CW system may be related to the lower sorption and retention capacity of the granitic gravel media and the saturation of phosphorus uptake by plants.

3.2. Performance of the systems based on area and HRT

The WSP receives the wastewater of 2700 PE and has a total area of 22,350 m^2 and a hydraulic loading rate of 698 m^3/day, resulting in a HRT of 41 days, and an area of 8.3 m^2 per PE. Since the HSSF-CW is receiving the influent from the PFP, it does not need a sedimentation pond in this set-up, and therefore the area per PE is rather small at 1.9 m^2. The sedimentation pond is of utmost importance to avoid clogging the HSSF-CW filter bed which results directly on the accumulation of suspended solids introduced with the influent (solids entrapment and sedimentation). In the calculations for cost, we assumed the need of a sedimentation basin, and therefore the area per PE increased from 1.9 to 3.4 m^2/PE. This area for the HSSF-CW is somewhat low compared to the applied hydraulic loading and to values in the literature for secondary wastewater treatment with HSSF-CW estimated at 6 m^2/PE (Mara, 2006). This can be part of the explanation of the rather fair performance by the HSSF-CW. However, as the overall performance for both systems is comparable, it can be deduced that the area requirement for the HSSF-CW is 2.5 times less that of the WSP.

3.3. Cost evaluation

The cost for construction and maintenance of the WSP and the HSSF-CW at JKUAT have been calculated and Table 2 gives a detailed overview. The costs are based on a lifetime of 20 years and 2700 PE. Initially, the cost for the small pilot HSSF-CW (12 PE) is given, for which an extrapolation is made to match the 2700 PE to enable direct comparison with the WSP costs. The operation and maintenance tasks are supposed to be necessary in order to achieve optimal treatment and attain the expected durable and reliable performance (Rousseau et al., 2008). For example after desludging,

Table 2

Capital, operation and maintenance costs (EUROs) of WSP and HSSF-CW for 2700 PE at JKUAT (design lifetime of 20 years).

	Unit	Rates	Quantity	Amount	%
WSP (based on 2700 PE)					
Capital/investment cost					
Land cost	m^2	15	22,350	335,250	47.6
Excavation	m^3	0.5	28,600	14,300	2.0
Lining-sides + Bottom	m^2	5	17,640	352,800	50.1
Inlet–outlet structure	No.	250	10	2500	0.4
Total investment cost (Euros)				704,850	
Annual recurrent cost					
Personnel	Manpower	86.4	2	172.8	61.1
Repair works	Piecework	10	1	10	3.5
Desludging every 5 years	Piecework	500	0.2	100	35.4
Total annual recurrent (Euros)				282.8	
CW (based on 11.6 PE)					
Capital/investment cost					
Land cost	m^2	15	39.9	598.5	50.6
Excavation	m^2	0.5	40	20	1.7
Masonry and concrete works	No. (Piecework)	500	1	500	42.2
Cost of gravel	t	10	6	60	5.1
Planting	Piecework	5	1	5	0.4
Total investment cost (Euros)				1183.5	
Annual maintenance cost					
Maintenance (hired labour)	Piecework	5	6	30	30.0
Repairworks	Piecework	10	2	20	20.0
Plant harvesting	Piecework	10	1	10	10.0
Desludging every 5 years	Piecework	200	0.2	40	40.0
Total cost (Euros)				100	

these systems are ready to perform a new cycle of operation without having to change any electromechanical equipment. This ensures a lower operation cost as well as a reliability of performance which is not negatively affected by the occasional malfunctioning of such equipment.

Ninety-eight % of the construction cost of the WSP goes to the cost of land and the lining. Therefore, costs will be less when land is cheap and no liner is needed (e.g. due to soil conditions). For maintenance of the WSP the main costs are personnel and desludging. For the HSSF-CW, 93% of the construction cost is in the purchase of land, the masonry and the concrete works. Thus land is an important cost factor, while a construction not involving concrete and masonry structures can save upto 40% in construction cost. Indeed for both systems, the variability of the soil conditions at various different sites and the need to prevent leakage of the wastewater into the ground water will influence the cost that goes into the preparation of the sides and bottom. Again desludging is costly in the maintenance cycle of HSSF-CW accounting for 40% of the operation and maintenance cost. The construction costs of the HSSF-CW are lower than those of the construction of the WSP, but the annual maintenance costs are higher. The overall costs per PE for the two systems are in the same range (Table 3). For the HSSF-CW it should be noted that both the area and costs have been extrapolated from the pilot scale system to a potential full-scale systems, and in reality the total cost will be less considering the extensive concrete and masonry works in the experimental pilot scale HSSF-CW. Nevertheless, the costs for some tasks such as plant harvesting cannot be easily reduced because the type of equipment necessary is the same and this operation has to be done manually.

The determined land area requirement for the HSSF-CW to serve 2700 PE is three times less compared to that for the WSP. Such a footprint is especially an advantage in countries with high land prices. These results corroborate with those of Senzia et al. (2003), who also reported that a WSP needed more land area than a HSSF-CW based on the same effluent quality. However, Mara (2006) computed a higher land area requirement for a secondary HSSF-CW compared to a secondary facultative pond. The comparisons were made at three levels of effluent quality in the UK i.e. (i) that specified in the Urban Waste Water treatment Directive (UWWTD) of 25 mg filtered BOD l^{-1} and 150 mg suspended solids (SS) l^{-1} for WSP effluents, and 25 mg unfiltered BOD l^{-1} for CW (and all other) effluents, (ii) two common requirements of the Environment Agency (the environmental regulator for England and Wales) for small works (a) the "40/60" requirement i.e. 40 mg BOD l^{-1} and 60 mg SS l^{-1} and (b) the "10/15/5" requirement i.e. 10 mg BOD l^{-1}, 15 mg SS l^{-1} and 5 mg ammonia-N l^{-1}. Yet, it is difficult for WSP systems to meet such requirements, especially those for SS, so WSP effluents must be 'polished' (Johnson et al., 2007). In Brazil, Bastos et al. (2010) indicated that HSSF-CW and WSP require similar land areas to achieve a bacteriological effluent quality suitable for unrestricted irrigation (10^3 *Escherichia coli* per 100 mL), but HSSF-CW would require 2.6 times more land area than ponds to achieve quite lenient ammonia effluent discharge requirement (20 mg NH_3 L^{-1}), and, by far, more land than WSP to produce an effluent complying with the WHO helminth guideline for agricultural use ($\leq$1 egg per liter).

Table 3
Comparison of costs (Euros) and area (m^2) of the WSP and HSSF-CW based on population equivalent (PE).

Area/cost	System	
	WSP	HSSF-CW
Area	22,350	39.9
Design PE	2700	11.6
Area per PE	8.3	3.4
Area for 2700 PE	22,350	9287.1
Total Investment (2700 PE)	704,850	275,872
Investment/yr (2700 PE)	35,242	13,747
Maintenance/yr (2700 PE)	283	23,300
Total cost/yr (2700 PE)	35,525	37,047
Total cost/PE yr	13.2	13.7

Table 3 compares the area requirement and cost of the WSP and HSSF-CW. The investment cost for the WSP is 3 times more than for the HSSF-CW. However, the maintenance cost for the WSP is much less, making the total cost about equal. Expressed per PE, the cost is about 13 euro per PE per year for maintenance and investment (based on a 20 years lifetime).

Table 4 compares the JKUAT results with Ahmad and Van Bruggen (2010), where a WSP, various constructed wetland combinations and a floating wetland system were compared. Table 4 also includes data from a HSSF-CW and WSP in Uganda and an activated sludge (AS) system in The Netherlands (personal communication). The total cost of the "green" systems (WSP and CW) ranges from 12 to 33 Euro/PE.yr, with an average of 14.4 Euro/PE.yr, whereas the cost for the activated sludge wastewater treatment (AS) system is at least three times higher. Their area needed per PE ranges from 1.5 to 10.1 m^2/PE compared to 0.4 m^2/PE for the AS.

Although the "green" systems are not capable of achieving the same consistent treatment performance efficiency as activated sludge plants, many studies report quite acceptable levels of effluent quality of both WSPs and HSSF-CWs (Kadlec and Wallace, 2009; Vymazal, 2011). These good performances are also indicated by the data presented in this work (Table 1). However, what the decision makers are most interested in is the reliability of performance. For both the WSPs and HSSF-CWs, this is not as dependent on complex and strict operational constraints as it is for many conventional/intensive processes. Once they are properly designed, built, operated and maintained, the probability of malfunctioning of WSP and CWs is low (Rousseau et al., 2008; Kadlec

Table 4
Comparison of the WSP and CW with various systems.

System	HRT	PE	Area/PE	Euro/PE yr	Description
WSP	41	2700	8.3	13.2	Waste stabilization pond (this work)
HSSF-CW	1.5	12	3.4	13.7	Planted constructed wetland (this work)
CW1	24.3	105	5.3	19.4	Constructed wetland combination[a]
CW2	38.3	53	10.1	33.3	Constructed wetland combination[a]
CW3	21.4	97	5.1	20.9	Constructed wetland combination[a]
F-W	10.6	13	1.5	11.8	Floating wetland system[a]
WSP	73.4	65	9.4	12.8	Waste stabilization pond[a]
CW-Uganda			1.8	2	CW without liner and concrete[a]
WSP-Uganda			2.1	2.5	Waste stabilization ponds without liner[b]
AS Netherlands			0.4	50	Activated sludge wastewater treatment plant[c]
HSSF-CW (UK)			6		Effluent quality 25 mg unfiltered BOD l^{-1}[d]
HSSF-CW (UK)			6.7		Effluent quality 40 mg BOD l^{-1} and 60 mg SS l^{-1}[d]
HSSF-CW (UK)	34		2.8		Effluent quality 10 mg BOD l^{-1}, 15 mg SS l^{-1} and 5 mg ammonia-N l^{-1}[d]
WSP (UK)			3.75		Effluent quality25 mg filtered BOD l^{-1} and 150 mg SS l^{-1}[d]

[a] Ahmad and Van Bruggen (2010).
[b] Okurut (2000).
[c] Personal communication.
[d] Mara (2006).

and Wallace, 2009; Ahmad and Van Bruggen, 2010). Further, these technologies are quite suitable for the tropical and subtropical regions where temperature is normally high (Yu et al., 1997). It can be expected that biofilm formation in these regions will be higher and probably provide diverse microenvironments for effective wastewater treatment (Babu, 2011). As such, the systems can achieve the required effluent quality at treatment works serving either large populations or small communities ($\leq$2000 PE).

4. Conclusion

Comparable medium to high levels of organic matter and suspended solids removal were attained in both the WSP and HSSF-CW systems investigated. However, the WSP attained a better removal for NH_4^+–N. The total annual cost estimates consisting of capital, operation and maintenance costs had little difference between both systems. However, the evaluation of the capital cost of either system showed that it is largely influenced by the cost of land and the required construction materials. The HSSF-CW showed less land requirement per unit volume of treated wastewater compared to that of the WSP. Hence, one can select either system in terms of treatment efficiency. When land is abundantly available, other factor including the volume of wastewater to be treated and the economies of scale, determine the final costs.

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