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A modified constructed wetland system for greywater treatment

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ABSTRACT

Green spaces in urban areas improve the local microclimate, promoting reduction of energy consumption and benefiting public health, besides other advantages. The use of greywater for developing such spaces should be considered and the use of natural treatment systems is an attractive option. For this purpose, a modified constructed wetland system, named "EvaTAC" was proposed. The system is a combination of an evapotranspiration and treatment tank (CEvaT) with an inbuilt anaerobic digestion chamber (AnC), followed by a horizontal subsurface flow-constructed wetland (HSSF-CW). The hypothesis was that the AnC would replace a pre-treatment unit, with a double function: (i) retaining solids and (ii) equalising the inflows, avoiding clogging and improving the stability of the system. To better understand the capacity of the AnC to equalise daily variations of flow and organic load, two 24-h and one 8-d monitoring profiles were performed. The results show that the two units complement each other. The 8-d profile shows that, within the CEvaT, the AnC presents the highest removal efficiency of the studied parameters. The HSSF-CW operates as an efficient polishing unit, resulting in an average effluent turbidity of 8 NTU. During 3 years of operation, neither sludge withdrawal nor maintenance of the pipes was required. The system was quite acceptable to the householders, not disturbing their routine, rendering a green site totally integrated into the garden, without the use of potable water for irrigation.

Keywords: Domestic sewage; Greywater; Source separation; Resource oriented sanitation; Water conservation

1. Introduction

Global concerns about water scarcity and increasing pressure on freshwater supplies have become an incentive for wastewater reuse. Greywater (GW) is a term which refers to domestic wastewater from all sources except toilets, and it has been estimated to account for about 60%–80% of all domestic sewage [1]. As GW typically has a lower pathogen content and lower organic matter load than combined domestic sewage, it has been considered a potential source of water to meet current and future needs, even though treated GW is mostly considered for non-potable use [2–5]. This holds true especially for the light greywater (GW_L) fraction, which apart from excluding the toilets also excludes the kitchen sink and dishwasher fractions, which are the GW fractions that carry the highest chemical oxygen demand (COD) loads and have the highest content of suspended solids [6,7]. GW can be highly variable in composition and volume generated per person, being heavily dependent on the behaviour of individuals, sanitary standards, age, lifestyle, eating habits, dynamics of water use, choice of personal care and household products, and water availability, amongst others. According to a review from Li et al. [8], an analysis of GW characteristics by different categories indicated that the

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kitchen and the laundry fractions contain higher concentrations of organic matter when compared with the bathroom and the mixed GW fractions, with the biochemical oxygen demand (BOD) ranging up to 1,460 mg L^{-1}. Additionally, they found that all GW fractions show good biodegradability, even though COD:BOD ratios, according to Boyjoo et al. [9], can be as high as 4:1. This can be explained by the high load of chemicals and surfactants, present in these GW flows, due to personal care and cleaning products used in a household [1,10].

Existing GW treatment systems show a wide range of design principles and sophistication, from simple single-household soil filter systems to more elaborate community-scale multistage rotating biological contact reactors, constructed wetlands and membrane bioreactors, amongst others – all based on chemical, physical, and biological processes such as settling, filtration, adsorption, aeration, precipitation, aerobic/anaerobic digestion, and disinfection [3,11].The choice of a GW treatment system includes considering different treatment steps that may be applied, depending on the required quality of the effluent [3]. For the sustainability of household or small-scale decentralised treatment systems, several aspects have to be taken into account, like for instance: cost, operation and maintenance requirements, odour nuisance, and health risks. Natural systems are considered sustainable ecotechnologies for small-scale treatment of domestic wastewater and its fractions [12–14]. In this view, filters (planted or unplanted) and several variations of constructed wetlands have been used for GW treatment [3,8,15–17]. One advantage of these ecotechnologies is that they can be totally integrated into the gardens (if individual) or into the landscaping of available common areas, increasing the green sites in urban zones, and contributing to an improvement of the microclimate, where an improvement of thermal and environmental comfort is expected [13]. Natural systems appear to be a feasible option to promote water reuse for ornamental gardens and urban landscaping as there is no direct contact with the GW, thus promoting water conservation with reduced risks. However, care needs to be taken when designing GW treatment systems. Based on (i) our daily experience dealing with GW, (ii) unpublished reports from the internet, and (iii) literature, we can infer that the solids present in GW may cause clogging in the inlet portion of filter media, both for combined GW as well as for light GW, where hair, and the lint present in the laundry and shower fractions are the major solid constituents. Therefore, considering the importance to treat and reuse GW, by means of a simplified system, we propose a hybrid system, called evapotranspiration and treatment of greywater (EvaTAC), which is composed of an evapotranspiration and treatment tank with an inbuilt anaerobic digestion chamber (AnC), followed by a horizontal subsurface flow-constructed wetland (HSSF-CW). The combination of an evapotranspiration and treatment tank (CEvaT) replaces the pre-treatment, usually done in a septic or sedimentation tank, and it was chosen for its capacity to digest organic matter and retain coarse material. The CEvaT is an adaptation of the TEvap [13], used here not with the purpose of zero discharge but rather with the objective to infiltrate treated GW into groundwater reservoirs. It is a soil and plants based system, consisting of an impermeable tank, filled with layers of different substrates. The GW enters the system through the AnC, raises and percolates through its holes, permeating upwards, until reaching the top soil layer, from where capillary forces, wind and heat, as well as uptake by plants' roots cause partial elimination of the water by evapotranspiration. The pre-treated GW will then drain to the HSSF-CW. With this configuration, we expected to reduce maintenance and avoid problems with clogging and odours. Thus, the objective of this study was to assess the behaviour of a real-scale EvaTAC system, installed in a three person's household, based on 24 h and 8 d monitoring profiles, and to better understand the capacity of the AnC to equalise the daily variation of flow and organic load in the EvaTAC.

2. Materials and methods

The system was implemented in a three person's household, located in Campo Grande-MS, Brazil (20°31′S and 54°39′W) and was in operation for 3 years on the occasion of this study. The climate in the city of Campo Grande-MS, according to Köppen and Geiger classification [18], is the humid mesothermic subtype without drought. Most of the precipitation occurs in the hottest period of the year, between the months of October and April, with an average annual precipitation of 1,416 mm, and a mean temperature of 23.4°C. To design the system, the family was interviewed, and during 21 d, data were collected regarding the daily routine for each GW generating point, including frequency of use, duration, and time. Based on these data, a physicochemical and microbiological characterisation was performed, by simulating the family routine, using grab and composite samples. Based on the obtained information, the system was dimensioned, considering the highest GW flow generated (when using the washing machine), which was 126.7 L per inhabitant per day. Another factor taken into account was the available area. We wanted to build the system along the external wall, 1 m wide, in the front garden, where the length available was 5.5 m. To decide the length of each unit, we started by calculating the minimum volume required for the anaerobic chamber, following the NBR 7229 guideline [19] for the design of a septic tank, which suggests a minimum HRT of 1 d when flows are lower than 1,500 L d^{-1}.

2.1. Experimental setup

A schematic view of the complete system is shown in Fig. 1. The EvaTAC was built in masonry and lined with fiberglass. The dimensions (L × W × D) of the units were: CEvaT: 2.0 m × 1 m × 1.05 m and HSSF-CW: 2.0 m × 1 m × 0.60 m (0.7 m^2 hab^{-1}). The average water depth was approximately 0.74 m for the CEvaT and 0.50 m for the CW. For the CEvaT, the layers, starting from bottom to top were: gravel no. 4 (porosity: 0.50; particle size: 32–150 mm; and layer height: 0.6 m), gravel no. 2 (porosity: 0.48; particle size: d_{10} = 20 mm, d_{30} = 17 mm, d_{60} = 12 mm; and layer height: 0.15 m) and (on top of a geotextile blanket): 0.30 m of soil.

The AnC, placed inside the CEvaT, was made of a fiberglass pipe, with 0.5 m diameter and 2.0 m length, with a useful volume of 392.7 L. It was perforated along all its extension and top part of its circumference, with the lowest perforations at 40 cm from the bottom, as sludge was expected to settle in the bottom part. The diameter of the holes was 1 cm

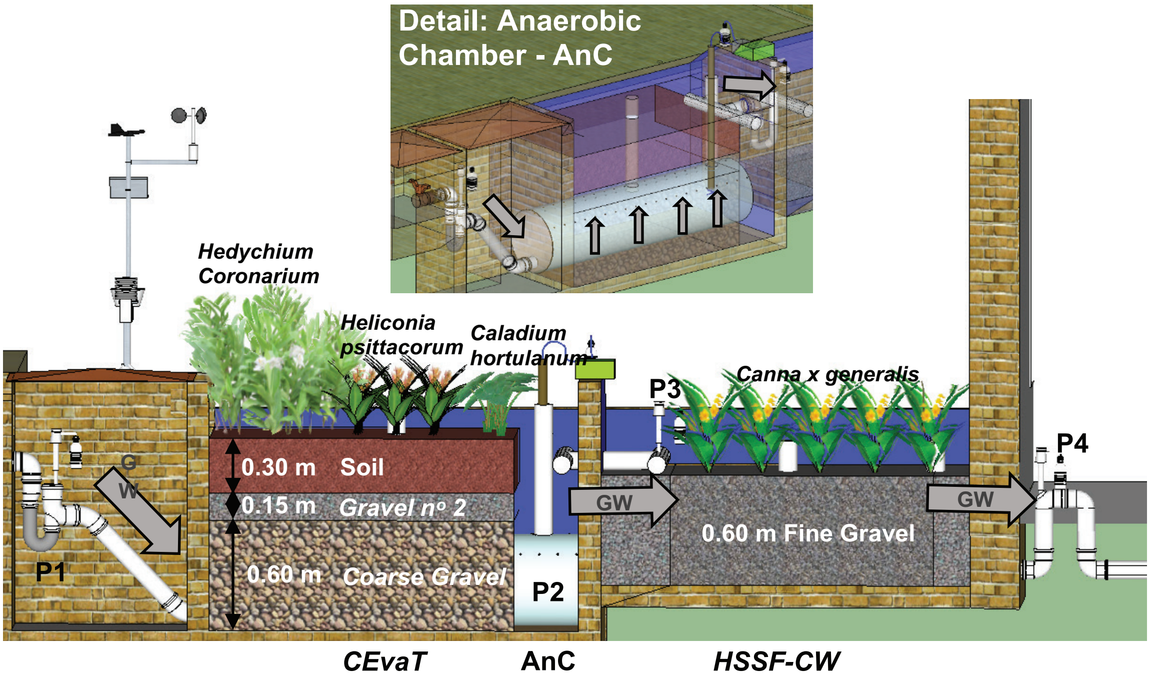

Fig. 1. Schematic view of the EvaTAC system, including sampling points P1: system inlet; P2: piezometer, inside the AnC; P3: CEvaT outlet (HSSF-CW inlet); and P4: system outlet.

each, and the distance between holes was 10 cm. The GW entered the EvaTAC system through the AnC (P1, Fig. 1) and was distributed within the CEvaT through the holes. The HSSF-CW was filled with fine gravel (porosity: 0.44; particle size: d_{10} = 13 mm, d_{30} = 11 mm, d_{60} = 10 mm; and height: 0.60 m). The 0.2 m inlet and outlet portions were filled with gravel no. 2. Both in CEvaT and HSSW-CW two piezometers were installed: one in the centre and one 20 cm before the outlet. The bottom slope of the EvaTAC was 1%.

For collecting grab and composite samples, as well as for positioning the level loggers and multiparameter sensors for continuous monitoring, flow cells were constructed: one at the inlet for monitoring raw GW (sampling point P1), one at the exit of CEvaT (inlet of the HSSF-CW; sampling point P3), and one at the outlet of the HSSF-CW (sampling point P4). Sampling point P2 was in the second piezometer installed in the CEvaT, representing the contents in the AnC.

At the entrance part of the CEvaT, 13 specimen of white ginger (*Hedychium coronarium*) were planted, followed by 11 parrot's beak (*Heliconia psittacorum*) plant cuttings, and in the final part of the system 10 cuttings of caladium (*Caladium hortulanum*) were planted, all with a 20 cm distance between plants. In the HSSF-CW 10 cuttings of beri (*Canna* x *generalis*) were planted, with a 30 cm space between them.

2.2. Monitoring profiles

There are two typical conditions of flow and loading for the EvaTAC system: receiving inflow originating mainly of bathroom/shower effluents, or receiving inflow from the effluent of the washing machine, probably combined with the GW produced in the bathrooms. Based on these data, two 24-h and one 8-d qualitative and quantitative monitoring profiles were performed, simulating three routines: (A) only showers, (B) showers and washing machine, and (C) same as B, during 8 d. Profiles A and B were considered preliminary and served to better understand the behaviour of the treatment system, considering hydraulic, hydrologic, and water quality parameters, and were used later on to delineate the continuous monitoring procedure used during the 8-d monitoring period (profile C).

2.3. Quantitative and qualitative characterisation

To quantify the GW generated at point P1, individual electromagnetic flow meters were installed. Besides, a questionnaire was to be filled in during the days that monitoring was carried out, to know exactly the type and location of water use, and the user. This methodology is comparable with that used by Antonopoulou et al. [20] except that, in our case, the frequency, duration, and volumes generated were also monitored by the flow meters. An ultrasonic flow meter (PT878, GE, USA) was used to quantify the flow at the exit of the system (P4). Leveloggers (Solinst, 3001, Canada), placed in the piezometers located closest to the exits of both units, were used to monitor the water level inside the units. Multiparameter sensors (Hanna Instruments, HI 9829, USA) were installed at the sampling points P1, P3, and P4 to continuously measure temperature, conductivity, and redox potential whilst carrying out the three monitoring profiles. Sample collection and preservation were performed according to "Standard Methods for the Examination of Water and Wastewater" [21]. A meteorological station (Squitter, S1220, Brazil) monitored the hydrological conditions on-site such as relative humidity, reference evapotranspiration, temperature, and precipitation. All sensors had their internal clocks synchronised, and sampling was performed according to the routine of the GW generation.

The experimental planning for profiles A and B was designed so that we could assess the influence of different flows and uses before and after each activity generating GW. Samples were taken at the entrance of the system (flow cell P1), sampling use from bathroom sinks (grab samples), showers and washing machine (both composite samples). At piezometer P2 samples were always collected in intervals between flows (grab samples) to assess whether flow patterns affected internal mixing in the anaerobic digestion chamber. At sampling points P3 and P4 the effect of inflow on the outflow of the CEvaT and HSSF-CW, respectively, was quantified, immediately after any significant flow (grab samples). Based on the results, it was possible to draw an experimental planning for the long-term (8 d) profile C. Grab samples were taken from all sampling points (1–4) to determine total and dissolved chemical oxygen demand (COD_{total} and $COD_{soluble}$) and turbidity, amongst others, but in this paper only the COD and turbidity will be discussed.

3. Results and discussion

The quantitative analysis performed here permitted the characterisation of water use and GW production in the household. The results from this work reinforce literature data [19] on the variation of GW characteristics, demonstrating once more the difficulty in comparing literature data. In this study, three profiles were analysed: profile A, where bathing corresponds to 93% of influent volume of the system, profile B, where the washing machine is responsible for 58% of the GW volume, and profile C, representing the GW production during 8 consecutive days, being a combination of profiles A and B. Table 1 shows some of the operating parameters for these profiles, taking into account the effects of evapotranspiration.

Every day, influent flows of the same order of magnitude are applied to both treatment units. As both units have the same surface area, both CEvaT and HSSF-CW are subject to approximately the same hydraulic loading rates (HLR) that may vary between 50 and 120 mm d^{-1}. The maximum HLR, however, may be as high as 500–600 mm d^{-1}, depending on the family routine. Some authors recommend that for GW the HLR applied to HSSF-CW should be around 60–80 mm d^{-1} [14,22], and that the superficial organic loading rate should not exceed 16 gCOD m^{-2} d^{-1}, in cold climate regions [14,16]. In the present study, superficial organic loading rates of between 5 and 20 gCOD m^{-2} d^{-1} were applied to the HSSF-CW. In warm climates, good results were obtained with superficial organic loading rates of 60–70 gCOD m^{-2} d^{-1} and HLR above 200 mm d^{-1}, which shows that the HSSF-CW is operating in agreement with established recommendations [16]. For the CEvaT, it is still early for making such comparisons once we still do not know which configuration would be more similar. If the flow leaving the AnC is distributed evenly through the holes from the bottom to the top, it could be considered an upflow vertical filter.

Fig. 2 shows influent and effluent flows of the EvaTAC system, for light GW production in profile B. There is a great regularity in the average flow of GW from bathing and the washing machine, entering the system every day. The flow and average duration of showers are 5 L min^{-1} and 5 min, respectively. The washing machine produces an outflow of 8.5 L min^{-1} on average, and with a duration of 10 min.

In profile B, it can be verified that the two first showers taken every day cause a rise in the level of both systems, causing an overflow of the CEvaT into the HSSF-CW, and this, in its turn, produces an outflow of treated GW for irrigation and infiltration. The same happens when the washing machine is draining. In the afternoon and night, little GW enters the system at P1, and this flow is insufficient to cause any flow of GW between the compartments or out of the system, causing a reduction of the water level in both compartments in the afternoon, as a result of evapotranspiration. The effect is that in the night the inflow of GW from the shower into P1 only elevates the level in the CEvaT and HSSF-CW, not having any outflow of treated GW from the HSSF-CW. For a qualitative characterisation of the GW, synchronised sampling was performed, in such a way that samples of inflows were collected at P1 and P2, before and after GW producing events, and of the effluent of the CEvaT (P3) and of the HSSF-CW (P4) as well. This planning of synchronised sampling permitted evaluating the effect of GW flow along the sampling points, and verification of the effect of flow rate on the quality of the water treated in the different compartments of the system, as a function of this flow rate. Table 2 summarises the results of COD_{total} and turbidity monitored at sampling points P1–P4, for the GW production profiles A, B, and C. For profile A, where the average GW flow was 5.1 L min^{-1}, it could be observed that in this 24 h period, the organic and hydraulic loading did not cause any alteration of the composition of the water inside the AnC (comparing P2 and P3).

Table 1
Operating parameters of the residential EvaTAC system

Operating parameters	Profile A[a]		Profile B[a]		Profile C[b]	
	CEvaT	HSSF-CW	CEvaT	HSSF-CW	CEvaT	HSSF-CW
Influent flow (m^3 d^{-1})	0.107	0.093	0.213	0.202	0.160 ± 0.08	0.151 ± 0.09
Hydraulic loading rate (surface) (m^3 m^{-2} d^{-1})	0.05	0.05	0.11	0.10	0.08 ± 0.04	0.08 ± 0.04
Hydraulic retention time (d)	6.0	4.0	2.9	1.8	4.7 ± 1.8	3.1 ± 1.3
Organic loading rate (surface) (gCOD m^{-2} d^{-1})	16.4	5.9	30.9	5.5	31.3 ± 36.1	9.3 ± 6.6
Volumetric organic loading rate (gCOD m^{-3} d^{-1})	54.73	32.17	103.26	30.07	104.5 ± 120.6	50.5 ± 35.4

[a]The volume used for the calculations for profiles A and B are based on the total volume entering the system during 1 d (1 d profiles).
[b]For profile C, the volume is the average of the total volume daily entering the system during the 8 d (eight samples).

On the other hand, we can notice that, for profiles B and C the COD and turbidity results are more unstable (Table 2), which can be attributed to the contribution of the higher flow of the washing machine when compared with shower contribution or washbasin alone. However, when looking at the results on P4 (before and after flow) we can observe that this had low impact on the final effluent quality. It is clear that the GW entering the system at P1 is different from the flow leaving the system at P4 (Table 2), considering the HRT of the system (Table 1). For this reason, we do not discuss the removal efficiency of the studied parameters, since the data represent only a short monitoring period. However, considering influent and effluent data we can conclude that the system copes with flow and load variations. The system is operating over 3 years already dealing with the regular family routine and, proper interactions developed between the filter media, soil and roots. When looking closer at the results for profile C, for instance, that had an average HRT of 7.8 d (Table 1), and received COD_{total} as high as 900 mg L^{-1} (grab sample, data not shown) from washing machine discharges, the effluent quality remained stable, considering that one complete HRT has passed by the last day of the experiment. The HSSF-CW seems to be operating as an efficient polishing unit, with average COD_{total} for P4 of 73.1 mg L^{-1} and an average turbidity of 9.5 NTU. Another important observation is that along all the operating time never an increased concentration of solids was observed at P3, something that would be expected if excess sludge would be accumulating in the AnC. Permaculture practitioners do not recommend this system for domestic sewage or GW, believing that the chemicals present would cause accumulation of non-biodegradable sludge in the AnC, recommending it only for the black water fraction. When carrying out the profiles, we measured the height of the sludge layer in the anaerobic chamber, which was <2 cm. No sludge withdraw was necessary during the whole period. Also, no maintenance in the distribution pipe (inlet) of the HSSF-CW was required. Therefore, the results obtained so far encourage us to continue developing this system as it seems to combine simplicity and high efficiency with low maintenance.

Fig. 3 shows concentrations of COD_{total} and $COD_{dissolved}$ in samples withdrawn along the day at the four sampling points for profile B, which had an average flow of 8.3 L min^{-1}.

By sampling before and after each new flow entering the system, we could better understand the stability of each unit under different conditions. Three different events were sampled at P1 (P1-1...P1-3) and the effect of these events was studied after each event at points P2–P4 (hence, more samples were taken for P2–P4). It can be seen that after entry of the flow originating from a washing machine discharge, both $COD_{dissolved}$ and COD_{total} increase, although only slightly, in the effluent of the AnC, showing that this chamber functions, at least partially, as a mixed flow reactor. Still regarding the GW composition, it can also be observed that the largest part of COD is present as dissolved rather than as suspended matter. Depending on the profile studied, the HRT in the CEvaT varied between 3 and 6 d, whilst the HRT in the HSSF-CW varied between 1.8 and 4 d. Profile C showed, during its 8 d of monitoring, characteristics very similar to those of profile B, no matter the range of the HRT. The results for COD and turbidity at sampling points P3 and P4 are very similar, indicating that most of the treatment occurs in the CEvaT and,

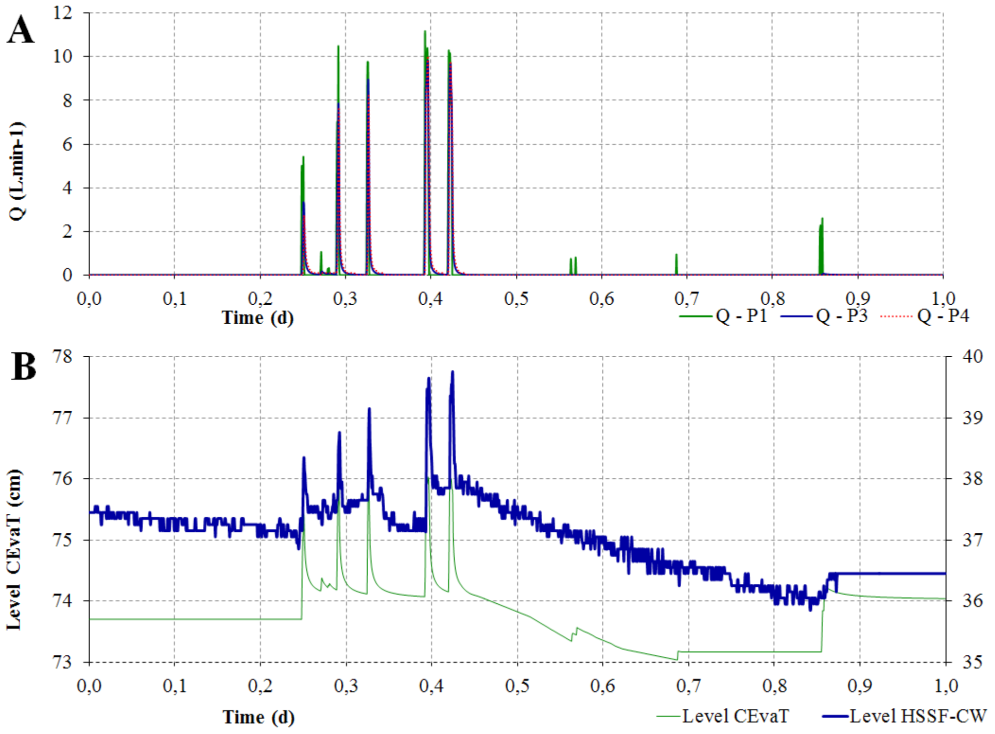

Fig. 2. (A) Flow (Q) at sampling points P1, P3, and P4. (B) Water levels inside the CEvaT and HSSF-CW units for greywater production profile B. The overflow of CEvaT is at 74 cm, and the overflow of the HSSF-CW is at 37.5 cm.

Table 2
Results of COD_{total} and turbidity at sampling points P1–P4 and average flow at sampling point P1, for the profiles A (1 d), B (1 d), and C (8 d) in the CEvaT and HSSF-CW units

Profile	Sampling point	COD_{total} (mg L^{-1})	Turbidity (NTU)
Profile A	P1	304.8	101.0
$Q_{P1}{}^{a}$ = 5.1 L min^{-1}	$P2_{BF}{}^{b}$	127.6	53.7
	$P2_{AF}{}^{c}$	128.7	51.1
	$P3_{BF}$	124.8	55.1
	$P3_{AF}$	127.2	50.0
	$P4_{BF}$	67.2	3.8
	$P4_{AF}$	75.8	4.2
Profile B	P1	289.9	60.4
Q_{P1} = 8.3 L min^{-1}	$P2_{BF}$	54.3	18.9
	$P2_{AF}$	113.2	34.8
	$P3_{BF}$	51.5	38.8
	$P3_{AF}$	54.8	39.8
	$P4_{BF}$	40.7	9.2
	$P4_{AF}$	41.0	9.3
Profile C	P1	347.1 ± 275.9(14)	65.6 ± 37.9(14)
Q_{P1} = 6.6 ± 2.2(36) L min^{-1}	P2	147.3 ± 66.7(17)	44.3 ± 10.8(17)
	P3	130.8 ± 17.3(15)	41.5 ± 12.6(15)
	P4	73.1 ± 15.7(12)	9.5 ± 1.5(12)

Sampling points – P1: system inlet; P2: piezometer inside the AnC; P3: CEvaT outlet = HSSF-CW inlet; and P4: HSSF-CW outlet.
For profiles A and B, COD_{total} and turbidity values are single samples; for profile C, numbers between brackets represent the number of samples.
[a]Q_{P1} is the average value of the predominant daily flow.
[b]BF – before flow.
[c]AF – after flow.

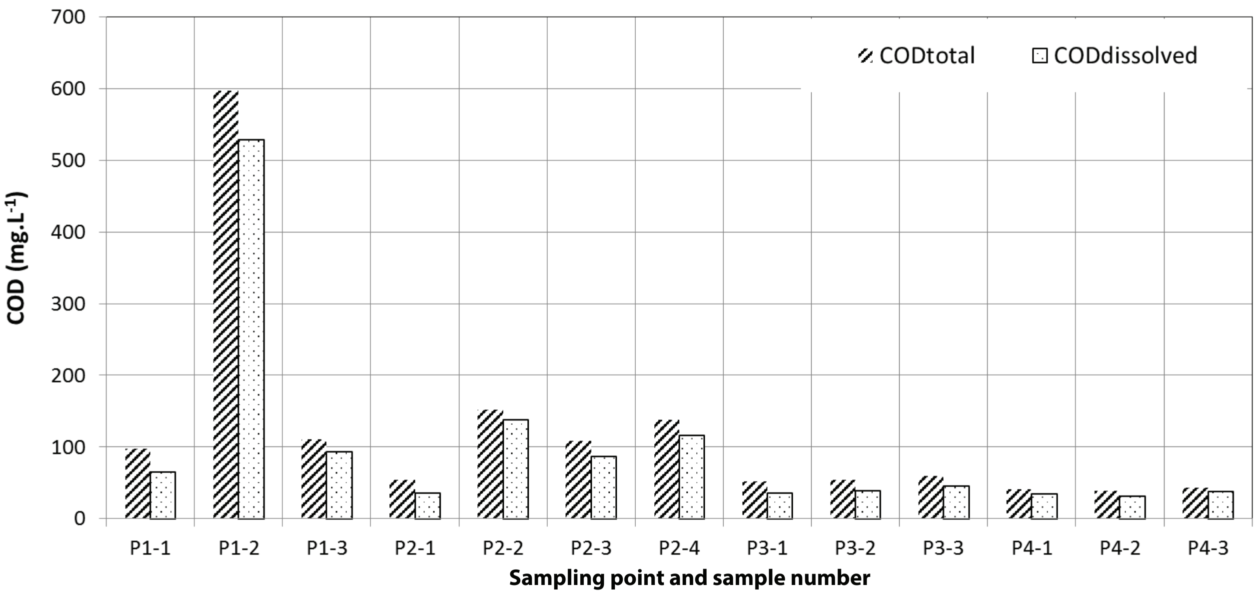

Fig. 3. Variation of COD (dissolved and total) at sampling points P1–P4 for profile B of greywater entering the system.

within it, occurred mainly inside the AnC (Table 2). These results indicate that, on the flow conditions tested, the AnC promotes stability, probably due to its mixing effect buffering organic and hydraulic loads, acting as the main compartment of the system regarding stability.

Fig. 4 shows the result of the continuous monitoring of profile C, during the 8 d of continuous monitoring, and it can be seen that at sampling point P1, the variation of the conductivity, which might be seen as a proxy for the concentration of dissolved components, is much bigger than the variation of the conductivity as observed at sampling points P3 and P4, although the conductivity at these points is higher than at P1 (mineralisation of organic matter tends to convert dissolved organic compounds that do not contribute much to conductivity, into dissolved inorganic compounds, elevating the conductivity) [23–25].

In the HSSF-CW, a small additional removal of organic compounds (mineralisation) occurs, combined with a small amount of evapotranspiration, thus causing a slightly higher conductivity of its effluent (average value 0.0031 dS cm^{-1}) compared with the effluent of the CEvaT (average value 0.0012 dS cm^{-1}). In addition, excessive evapotranspiration losses may lead to an increase in salt concentration in the effluent, increasing the risk of soil salinisation in irrigated areas [26,27]. According to Ayers and Westcot [28], values of conductivity below 0.7 dS cm^{-1} and total dissolved solids (TDS) below 450 ppm do not present risks of salinisation for soil irrigation. In our system, during the studied period, the raw GW presented TDS values of 59, 96, and 157 ppm for P1 (system inlet), P3 (CEvaT outlet), and P4 (HSSF-CW outlet), respectively, indicating that possibly this system has not undergone salinisation effects, being below the limit for a moderate risk of system salinisation.

Fig. 4 also shows the rain precipitation and its effect on the electrical conductivity for the profile C. In the intervals between influent flows, the conductivity, especially at P1, rises as a result of drying out of the flow cell as a result of evapotranspiration, with rapid variations as a result of small flows (hand washing and short rain events). Rain accounted for 6% of the inflow in the period of monitoring profile C. Gleen et al. [29] when studying the effects of salinity on the growth and evapotranspiration of *Typha domingensis* Pers, verified that, the higher the salinity of the wastewater the lower was the plant growth, causing a decrease in the evapotranspiration of the system. On the other hand, rainfall can help to avoid or reduce the salinisation as its occurrence at certain periods of year would help in eliminating salts over time [30]. Our results show that conductivity values for both units dropped in the occasion of the main rain precipitation events (days 2.6 and 7.6) which was probably caused by a dilution effect.

Fig. 5 shows the inflow volumes and the evapotranspiration in each treatment unit during the three performed profiles. Evapotranspiration from the system occurs mainly in the CEvaT unit, probably as a result of more dense vegetation (the surface area of both units is the same: 2 m^2).

Climatic conditions and plant species can be determining factors influencing evapotranspiration and HRT, which are two important parameters for the design of natural treatment-based systems [24,31,32]. Pedescoll et al. [33], studying a HSSF-CW in a scale similar to ours, using gravel as substrate, found values of evapotranspiration of 36.8 ± 2.3 mm d^{-1} for *Phragmites australis* and 23.0 ± 1.9 mm d^{-1} for *Typha angustifolia*, reporting that planted systems evapotranspirated four times more than non-planted systems, concluding that vegetation was the main

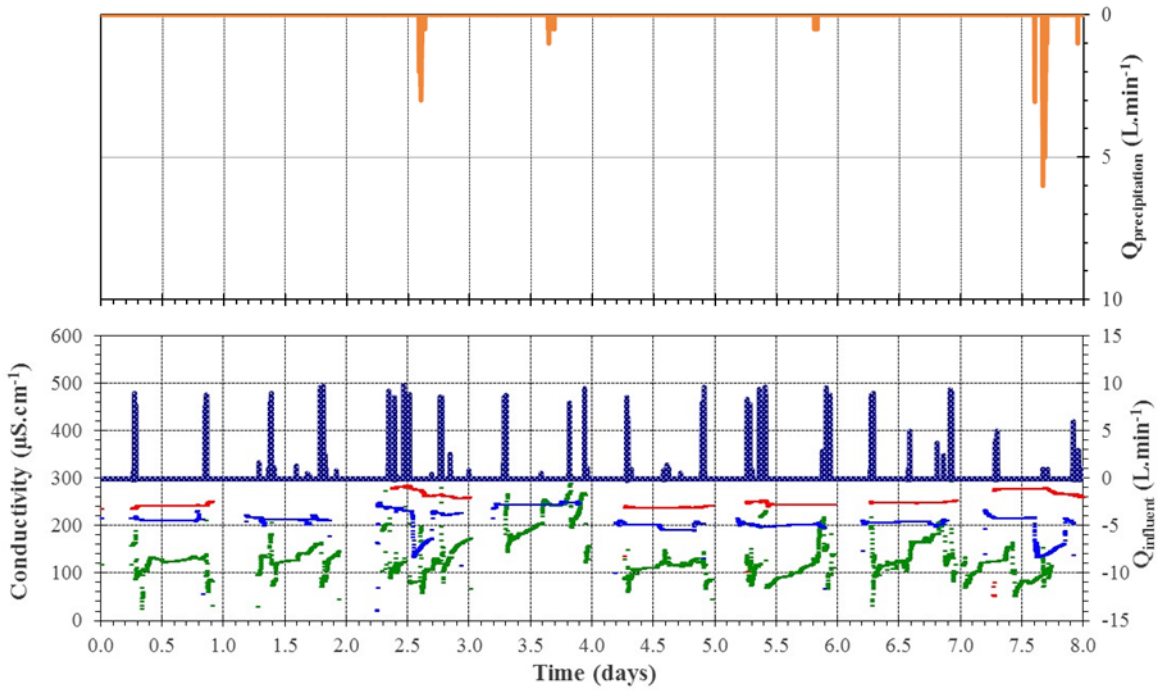

Fig. 4. Continuous monitoring of influent flow and conductivity for profile C and rain precipitation. Inflow at P1: dark blue line, rain precipitation: orange line. Conductivity: P1 – green line; P3 (CEvaT outlet): light blue line; and P4 (HSSF-CW outlet): red line.

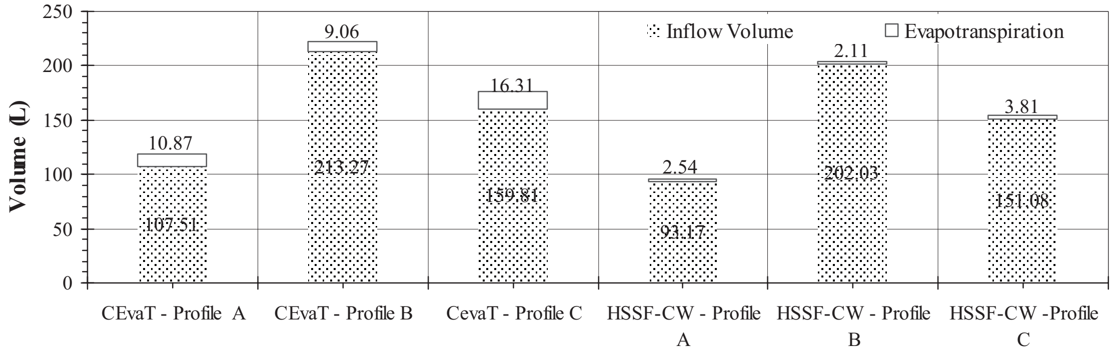

Fig. 5. Daily volume of greywater fed into each unit of the system (at P1 for CEvaT and at P3 for HSSF-CW) and evapotranspiration from each unit, as determined for profiles A, B, and C.

design parameter which affected water loss in their study. Quantification of the volumes of water (GW and rain) entering and leaving the EvaTAC system, as shown in Fig. 5, enable the calculation of the amount of water lost by evapotranspiration. For the CEvaT unit, evapotranspiration varies between 5 and 8 mm d^{-1}, whilst the HSSF-CW showed evapotranspiration of between 1 and 2 mm d^{-1}. The effect of evapotranspiration, a loss of at most 10% of influent volume, can thus be clearly observed, but is not big enough to change the HRT in a very significant way: for dimensioning the system it will not be necessary to take losses of flow into account explicitly. Based on our results we can also infer that evapotranspiration losses will not affect effluent salinity in such a way that this should be taken into account, for instance in the choice of plants to be used in the system. The CEvaT can however, if desired, be dimensioned to achieve high or total evapotranspiration, in order to allow for a zero discharge system when there is no need for water reuse or when there is no possibility to discharge or infiltrate. The number of CEvaTs and/or HSSF-CW to be used will thus depend on the household's choice.

4. Conclusions

The 24-h and 8-d monitoring profiles used to better understand the behaviour of the proposed system showed to be appropriate to the goal of the study: coupling information regarding hydraulic and organic loads with their effects on effluent quality. On a typical day (only contribution from showers and bathroom sinks), neither mixing was observed in the AnC, nor any alteration was observed in the effluent quality. When the washing machine was discharged, the AnC attenuated the peak load and stabilised the system, even when receiving COD_{total} as high as 900 mg L^{-1}. It is possible to conclude that the two units complement each other and that the AnC can replace a pre-treatment unit. The 8-d profile shows that, within the CEvaT, the AnC presents the highest removal efficiency of the studied parameters. The HSSF-CW seems to be operating as an efficient polishing unit, with effluent average COD_{total} and turbidity of 63 mg L^{-1} and 8 NTU, respectively. During the 3 years of operation, no sludge withdrawal was necessary and no maintenance in the distribution pipe (inlet) of the HSSF-CW was required. The implemented system in full scale was quite acceptable to the householders, not disturbing their routine, rendering a green site totally integrated into the garden, without the use of potable water for irrigation.

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