Influence of high organic loads during the summer period on the performance of hybrid constructed wetlands (VSSF + HSSF) treating domestic wastewater in the Alps region

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ABSTRACT

One of the limits for the application of constructed wetlands (CWs) in mountain regions (such as the Alps) is associated with the considerable land area requirements. In some mountain areas, the treatment of domestic wastewater at popular tourist destinations is particularly difficult during the summer, when the presence of visitors increases hydraulic and organic loads. This paper aims to evaluate whether a hybrid CW plant designed on the basis of the resident population only, can treat also the additional load produced by the floating population during the tourist period (summer, when temperatures are favourable for biological treatment), without a drastic decrease of efficiency and without clogging problems. The research was carried out by considering two operational periods: the first one was based on literature indications (3.2 m²/PE in the VSSF unit) and the second one assumed higher hydraulic and organic loads (1.3 m²/PE in the VSSF unit). The removal efficiency in the hybrid CW system decreased slightly from 94 to 88% for COD removal and from 78 to 75% for total N removal, even after applying a double hydraulic (from 55 to 123 L m⁻² d⁻¹) and organic load (from 37 to 87 g COD m⁻² d⁻¹ and from 4.4 to 10.3 g TKN m⁻² d⁻¹). The results showed that in the summer period the application of high loads did not affect the efficiency of the hybrid CW plant significantly, suggesting that it is possible to refer the CW design to the resident population only, with subsequent considerable savings in superficial area.

Key words | Alps region, constructed wetlands, nitrogen removal, organic overload, summer period

INTRODUCTION

The regulation of the European Union requires all agglomerations with a population equivalent (PE) of more than 2000 PE to be provided with wastewater collection and treatment and agglomerations with less than 2000 PE to be provided with a collecting system and an appropriate wastewater treatment. The treatment of urban wastewater is appropriate when, after discharge, it allows the receiving waters to meet the relevant quality objectives. In the case of mountain regions, the domestic wastewater produced from small agglomerations cannot always be collected to a centralised wastewater treatment plant (WWTP) as a consequence of the difficult geomorphologic conditions and the high costs of long collecting pipes. In some cases, after collection, wastewater produced in small agglomerations is treated by sieving and settling in a septic tank/Imhoff tank, but effluent may be characterised by a significant presence of suspended solids and the reduction of pollution is limited, calling for an improved treatment that may preserve water resources.

The advantages of constructed wetlands (CWs) for the treatment of wastewater, such as relatively low cost, simple operation, low maintenance, stable effluent quality, effective treatment in terms of BOD, nitrogen, suspended solids (inter alia Wallace & Knight 2006) make CW systems a suitable secondary treatment for domestic wastewater produced by small agglomerations. The hybrid CW systems (first stage vertical subsurface flow-VSSF + second stage horizontal subsurface flow-HSSF) are known for their efficiency in performing carbon oxidation, nitrification and a partial denitrification, but they also present important
limitations: namely, reduced efficiency with low temperatures and considerable land requirements. This makes their use in mountain regions difficult. Langergraber et al. (2009) and Chen et al. (2008) showed that effective treatment, including nitrification, can also be obtained in winter. The significant spatial extent of CW systems is actually the main barrier to their wide application in decentralised wastewater treatment projects in single homes, tourist villages, tourist resorts and small mountain agglomerations. Further research is needed to design and verify technical solutions that may reduce the area required for CW construction.

In many mountain areas in the Alps (excluding ski areas) the tourism is mostly concentrated in a 2.5 month period (from mid-June through to the end of August). Therefore, the population increases significantly during the summer due to the presence of a large floating population compared with the resident population who live there for the whole year. In the Province of Trento (north-eastern Italy) the amount of resident population and total population (resident + floating in the 2-month tourist period) was monitored for 31 small tourist alpine villages (with less than 1,000 resident population and not collected to a centralised WWTP) and the results are shown in Figure 1.

Because the total population is twice the resident population for just two months throughout the year (Figure 1), it may be very expensive to design a CW plant for wastewater treatment based on the high organic load discharged during the summer period. For example, a small tourist village with a resident population of 600 and a tourist population of 600 would require a hybrid CW plant for 1,200 PE. When considering a specific surface of approximately 4 m²/PE, 4,800 m² of contiguous land surface would be needed, which represents an amount of land rarely found in a mountain region due to slope characteristics and the importance of conserving wilderness.

This paper aims to evaluate whether a hybrid CW plant designed on the basis of the resident population only, can treat the additional nitrogen and organic load produced by the floating population during the 2-month tourist period, without drastic decrease of efficiency in organic matter removal and nitrification, and without clogging problems. If the performance of the CW plant during this overloaded period were maintained at acceptable levels, a significant reduction of the land area for the hybrid CW system would be obtained.

**MATERIALS AND METHODS**

**Hybrid CW plant**

The outdoor CW pilot plant was located in a mountain region of the Alps (Ranzo, Province of Trento, Italy) at an elevation of 739 m above sea level (coordinates 46°03′N and 10°56′E). Meteorological data for the whole period were collected from the nearest meteorological station located 2 km from the pilot plant (S. Massenza, Province of Trento, Italy). The raw wastewater passed through a mechanical grid and an Imhoff tank and then entered the CW plant. The configuration was a hybrid CW system composed of a first stage Vertical Subsurface Flow CW (VSSF; depth: 0.6 m; length: 1.5 m; width: 1.5 m; surface area: 2.25 m²) and a second stage Horizontal Subsurface Flow CW (HSSF; depth: 0.6 m; length: 3 m; width: 1.5, surface area: 4.5 m²) (Figure 2).

![Figure 1](image) Correlation between resident population and total population (resident + floating) in 31 small tourist villages and fractions (Province of Trento, Italy) during 2-month summer period.

The filling media in the VSSF was: bottom 0.2 m gravel Ø15–30 mm (porosity p = 31%); middle 0.1 m gravel Ø7–15 mm (p = 30%) and top 0.3 m sand-fine gravel Ø1–6 mm (p = 50%). We chose a filling material with a grain size distribution higher than the typical one used in conventional VSSF, because we wanted the filling material to have a lower risk of clogging during the high-load period. The pilot VSSF unit was completely unplanted. The influent wastewater was applied in the VSSF unit discontinuously (3.6 cycles/day on average, see Table 1) and pumping of influent wastewater took a few minutes. The hydraulic behaviour of the VSSF was evaluated by measuring effluent flow rates and by flow simulation. The first results of the flow simulation carried out with the HYDRUS-CW2D model (Langergraber & Šimůnek 2006) indicate the presence of dead zones and hydraulic short-circuiting, but these effects need further work to be exactly quantified. The VSSF effluent drained and flowed by gravity into the HSSF unit.
The filling media in the HSSF (gravel) was: initial drainage 0.5 m gravel Ø15–30 mm (p = 30%); middle gravel Ø3–7 mm (p = 26%); final drainage 0.5 m gravel Ø15–30 mm (p = 30%). The HSSF reactor was equipped with three taps installed at different positions along the reactor, in order to sample the treated wastewater in different sections along the bed. The pilot HSSF unit was planted with 3–4 units/m² of Phragmites australis.

Chemical analyses

Samples of influent and effluent from VSSF and HSSF systems were collected twice a week (30 samples in the whole period for each CW section). Intensive monitoring campaigns were conducted during the VSSF normal operation cycle to obtain the concentration time-profiles of wastewater effluent from the VSSF over eight different time frames (track-studies): 0–5 min, 5–10 min, 10–20 min, 20–30 min, 30 min–1 h, 1–2 h, 2–4 h and 4–6 h. Samples along the HSSF unit were taken from taps to obtain the longitudinal profile of concentrations in the bed (two sample points). Track-studies were performed three times when steady-state conditions in VSSF and HSSF systems were reached.

Concentrations of chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), NH₄-N, NO₂-N, NO₃-N, PO₄-P and total P were analyzed according to Standard Methods (APHA 1995). Soluble COD was measured after filtration of the sample on a 0.45-μm-membrane.

Biodegradable COD

The measurement of biodegradable COD in influent and effluent wastewater taken from the CW units was performed by respirometry. The respirometers used in this research were described previously in Ziglio et al. (2002). Twenty-four respirometric tests were carried out according to the approach proposed by Vanrolleghem et al. (1999) for COD characterisation in raw wastewater. The respirogram obtained for a conventional activated sludge used as reference was compared to the respirogram obtained after the addition of a known amount of wastewater to the activated sludge. The comparison allows calculation of the amount of biodegradable COD in the tested wastewater on the basis of the oxygen consumed for its oxidation.

RESULTS

Two operation periods were tested in this study (Table 1).

In the first period the typical hydraulic and organic loads were applied in the hybrid CW units (55 L m⁻² d⁻¹...
and 37 g COD m⁻² d⁻¹ on average in the VSSF) in order to represent the typical loads usually considered in the conventional design of hybrid CW systems. This organic load corresponded to 3.2 m²/PE in the VSSF system and to about 6.4 m²/PE in the HSSF system.

In the second period, which lasted 2 months from the beginning of July to the end of August 2010, higher hydraulic and organic loads were applied to simulate the additional presence of the tourist floating population, according to the ratio of Figure 1. In this case the hydraulic and organic loads in the VSSF reached 123 L m⁻² d⁻¹ and 87 g COD m⁻² d⁻¹ on average, correspondent to the use of 1.3 m²/PE in the VSSF system (2.6 m²/PE in the subsequent HSSF system). The specific area used in the VSSF unit during the second high-load period (1.3 m²/PE) can be considered significantly low and not so common in the design of VSSF systems.

During the whole monitoring period the precipitation was 105 mm/month on average (about nine raining days per month), which was about 7.6 and 2.2% of the hydraulic loads applied in the pilot plant during the first low-load and the second high-load periods respectively. Evapotranspiration was estimated to be approximately 1–2% of the applied hydraulic loads.

The characterisation of the influent and effluent wastewater in the first low-load and the second high-load periods are indicated in Table 2. Due to the dependence of the profile of COD and nitrogen on time during a VSSF cycle (as described more in depth in the following paragraphs), flow-weighted composite samples were collected and analysed to assess the average value indicated in Table 2. During the second high-load period the concentrations of COD, nitrogen forms and phosphorus in the influent wastewater increased compared with those observed in the first period, as expected when the tourist floating population is present. Furthermore, occasional high TKN peaks appeared in the effluent during the second high-load period, reaching values higher than 90 mg TKN/L.

Due to the configuration used in this Hybrid CW system, the major role in the removal of COD and nitrogen forms was played by the VSSF unit, while the HSSF unit completed the treatment by providing a ‘polishing/finishing function’, mainly in the second high-load period, when the COD concentration effluent from the VSSF was higher (179 mg COD/L). In the VSSF unit the nitrification process occurred in both periods as demonstrated by the significant decrease of TKN and NH₄-N concentration in the effluent from the VSSF unit.

The organic and nitrogen loads applied and removed in the VSSF unit during the first low-load period and the second high-load period are shown in Table 3.

**Comparison of COD removal during low-load and high-load conditions**

Due to the discontinuous feeding in the VSSF unit, the effluent is drained and flowed by gravity with a flow rate variable during the time. During the first low-load period, when the hydraulic load applied was low, the COD removal efficiency was 81% even in the first 30 min after

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**Table 2** | Characterisation of the influent and effluent wastewater during the first low-load period and the second high-load period

<table>
<thead>
<tr>
<th>Parameter (mg/L)</th>
<th>First low-load period (May–June 2010)</th>
<th>Second high-load period (July–August 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total COD</td>
<td>572</td>
<td>692</td>
</tr>
<tr>
<td>Soluble COD</td>
<td>325</td>
<td>360</td>
</tr>
<tr>
<td>CODₜotal COD$^*$</td>
<td>0.71</td>
<td>0.78</td>
</tr>
<tr>
<td>TKN</td>
<td>72.3</td>
<td>79.8</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>57.5</td>
<td>64.7</td>
</tr>
<tr>
<td>NO₂-N</td>
<td>0.046</td>
<td>0.02</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>3.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Total N</td>
<td>75.5</td>
<td>82.6</td>
</tr>
<tr>
<td>Total P</td>
<td>7.9</td>
<td>9.6</td>
</tr>
<tr>
<td>pH (–)</td>
<td>8.3</td>
<td>7.8</td>
</tr>
<tr>
<td>ORP (mV)</td>
<td>–103</td>
<td>–190</td>
</tr>
<tr>
<td>Temp. (°C)</td>
<td>17.8</td>
<td>21.1</td>
</tr>
</tbody>
</table>

*CODₜotal = biodegradable COD measured by respirometry.*
feeding with no significant differences until the end of the cycle (see time-profile in Figure 3). In the second high-load period the hydraulic load was doubled, which caused an immediate effluent peak from the VSSF unit (hydraulic short-circuit caused by the higher volume applied): about 50% of the applied wastewater volume passed through the VSSF unit in the first 5 min in which COD removal was about 48% and COD concentration in the VSSF effluent was 360 mg COD/L (see time-profile in Figure 3). However, COD concentration decreased progressively during the cycle and after 1 h from the feeding it reached 135 mg COD/L, while after 6 h it reached the minimum value of 60 mg COD/L (Figure 3). The significant removal of COD observed in the first hour for both periods (Figure 3) may be due to two phenomena: (1) physical retention of COD, especially in particulate form, by sedimentation and filtration; (2) a dilution effect due to the mixing of the influent wastewater with the pore water content during its rapid passage throughout the VSSF bed. When the VSSF was drained by gravity, a small amount of liquid is retained in the interparticle voids. Considering that the pore water content at the end of the typical VSSF cycle was approximately 5% of the gravel weight (corresponding to 120 L in the whole bed), a partial dilution of the influent wastewater can occur. As confirmed by Giraldo & Zárate (2001), when the hydraulic retention time inside the bed is of only a few minutes, the physical retention into the bed is the major mechanism for the removal of organic matter, while the biological oxidation takes place for a longer time until the next feeding and therefore low concentrations are expected in the pore water at the end of the cycle.

### Table 3 | Applied and removed loads in the VSSF system and removal efficiency

<table>
<thead>
<tr>
<th>Parameter</th>
<th>First period (low organic load) May–June 2010</th>
<th>Second period (high organic load) July–August 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>Applied COD load in VSSF (g COD m⁻² d⁻¹)</td>
<td>36.7</td>
</tr>
<tr>
<td></td>
<td>Removed COD load in VSSF (g COD m⁻² d⁻¹)</td>
<td>29.9</td>
</tr>
<tr>
<td></td>
<td>COD removal efficiency in VSSF (%)</td>
<td>82%</td>
</tr>
<tr>
<td></td>
<td>COD removal efficiency in VSSF + HSSF (%)</td>
<td>94%</td>
</tr>
<tr>
<td>TKN</td>
<td>Applied TKN load in VSSF (g TKN m⁻² d⁻¹)</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>Removed TKN load in VSSF (g TKN m⁻² d⁻¹)</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>TKN removal efficiency in VSSF (%)</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>TKN removal efficiency in VSSF + HSSF (%)</td>
<td>80%</td>
</tr>
<tr>
<td>Total N</td>
<td>Applied total N load in VSSF (g N m⁻² d⁻¹)</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Removed total N load in VSSF (g N m⁻² d⁻¹)</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Total N removal efficiency in VSSF (%)</td>
<td>24%</td>
</tr>
<tr>
<td></td>
<td>Total N removal efficiency in VSSF + HSSF (%)</td>
<td>78%</td>
</tr>
</tbody>
</table>

**Figure 3** | Profiles of COD in the hybrid CW system: time-profiles in the VSSF unit, longitudinal profiles in the HSSF unit.
The COD load removed in the VSSF during the second high-load period (Table 2) was 64.3 g COD m$^{-2}$ d$^{-1}$, more than double the load removed during the first low-load period (29.9 g COD m$^{-2}$ d$^{-1}$). Despite this high organic load applied in the VSSF unit, COD removal during the second high-load period remained acceptable, around 74%, compared with the removal efficiency of 82% in the first low-load period. The increase of COD concentration in the VSSF effluent during the second high-load period, especially at the beginning of the cycle, was compensated by a further reduction of COD concentration in the subsequent HSSF system, whose mean effluent concentration was lower than 82 mg COD/L in both periods (see longitudinal profile in Figure 3). Despite the double organic load applied during the second high-load period, the overall COD removal efficiency in the hybrid CW system (VSSF + HSSF) did not change significantly and it was 94% in the first low-load period and 88% in the second high-load period. That is because the peaks of COD concentration from the VSSF unit at the beginning of the cycle were removed in the subsequent HSSF, which contributed to remove 14% of the influent COD during the second high-load period compared with 12% in the first low-load period.

**Comparison of nitrogen removal during low-load and high-load conditions**

In the VSSF unit the nitrification process was stable during both the first low-load period and the second high-load period with similar removed concentrations. In fact in the VSSF unit, the mean TKN concentration decreased from 72.3 to 18.3 mg TKN/L in the first low-load period (reduction of 54 mg TKN/L), while it decreased from 79.8 to 30.2 mg TKN/L in the second high-load period (reduction of 49.6 mg TKN/L) (see Table 2). However the applied and removed TKN loads were significantly different. The average applied and removed TKN loads in the VSSF unit during the first low-load period were 4.4 and 3.3 g TKN m$^{-2}$ d$^{-1}$ respectively, while in the second high-load period the applied and removed loads were higher (applied load 10.3 g TKN m$^{-2}$ d$^{-1}$; removed load 6.6 g TKN m$^{-2}$ d$^{-1}$). The increased TKN load resulted in a decrease of the removal efficiency in the VSSF unit from 75 to 62%.

Observing the time-profile during the first low-load period (Figure 4), it can be observed that NH$_4$-N concentration dropped from 56.4 mg N/L in the influent wastewater to 15.1 mg N/L in the first 30 minutes and successively the NH$_4$-N concentration remained quite constant until the end of the cycle. Conversely, when a high load was applied during the second period, the removal efficiency in the first 10 minutes from the feeding was modest (about 46–58%), compared with a removal of 68–72% between 2 and 6 h. The NH$_4$-N concentration effluent from the VSSF unit during the second high-load period was 26.3 mg NH$_4$-N/L compared with 17 mg NH$_4$-N/L in the first low-load period. This higher concentration of NH$_4$-N remained also along the longitudinal profile in the HSSF unit (Figure 4) and a decrease of 28–35 mV in ORP was observed along the HSSF bed (Table 2).

Considering the difference between NH$_4$-N in the influent and in the effluent from the VSSF unit, it was possible to
estimate the specific nitrification rate in the VSSF, which resulted in 2.4 g NH$_4$-N m$^{-2}$ d$^{-1}$ in the first low-load period and 4.7 g NH$_4$-N m$^{-2}$ d$^{-1}$ in the second high-load period. Despite the high organic load applied, we did not observe a decline in nitrification rate during the 2-month research period. The amount of nitrifying biomass developed in the previous low-load period and the favourable temperatures during the summer allowed the activity of the nitrifying biomass and a significant nitrification rate.

Due to nitrification in the VSSF unit, the NO$_3$-N concentration increased by 35.6 mg NO$_3$-N/L in the first low-load period, while the increase was lower in the second high-load period. The dynamic of NO$_3$-N production in the two periods was different due to the different influence of simultaneous denitrification. In the first low-load period the NO$_3$-N concentration was quite constant during the entire cycle, from the first minutes until the end of the cycle after about 6 h (see time-profiles in Figure 4). Conversely, in the second high-load period, NO$_3$-N concentration was lower at the beginning of the cycle (during the first 30 min after the feeding) and increased drastically after 30 min (Figure 4). The VSSF unit adsorbs a huge amount of COD immediately after feeding, the oxygen in the bed decreases rapidly (for the rapid oxidation of readily biodegradable COD), the water content in the bed increases and oxygen transfer is limited and these are suitable conditions for the occurrence of the simultaneous denitrification. After 0.5–1 h from the feeding, 80% of the water volume was drained and aerobic conditions are restored, causing a progressive increase of NO$_3$-N concentration (Figure 4).

The HSSF unit played an important role in denitrification, especially during the second high-load period, when a higher COD concentration was discharged from the VSSF unit to the HSSF unit (Figure 4). The biodegradable COD measured by respirometry in the VSSF effluent was 55% of total COD: this high presence of biodegradable compounds (mainly due to the hydraulic short-circuit in the first minutes after the feeding) supported the denitrification in the HSSF unit. In the HSSF effluent the biodegradable COD was 21% of total COD, indicating its consumption by denitrification. Contextually the NO$_3$-N concentration dropped significantly, as indicated in the longitudinal profile of Figure 4.

During the second high-load period the specific denitrification rate was 0.9–1.9 g NO$_3$-N m$^{-2}$ d$^{-1}$; higher than the value of 1.0 g NO$_3$-N m$^{-2}$ d$^{-1}$ estimated in the first low-load period.

In the second high-load period the presence of nitrification and a significant simultaneous denitrification in the VSSF unit caused an appreciable increase of NO$_2$-N, which passed from 0.8 mg NO$_2$-N/L on average during the first low-load period to 1.9 mg NO$_2$-N/L during the second high-load period. However, this increase of NO$_2$-N was not a problem for the effluent discharged from the plant because the VSSF effluent passed through the HSSF unit. In the HSSF system the concentration of NO$_2$-N dropped rapidly reaching a final effluent concentration of about 0.05 mg NO$_2$-N/L.

**Phosphorus removal**

The phosphorus removal in the VSSF unit was 49.3% in the first low-load period and 36.5% in the second high-load period. P removal was completed when wastewater passed through the HSSF unit in which removal efficiency was 27–48% and this behaviour did not change significantly in the two periods.

**Operational aspects**

**Temperature**

In the first low-load period the temperature was 19.7 °C and 19.2 °C on average in the VSSF and HSSF units respectively, while in the second high-load period (summer) the temperature was 22.4 °C and 22.3 °C respectively. The period with the tourist population and with high loads in the hybrid CW system coincides exactly with the most favourable temperatures for the biological kinetics and the plants are in the period of maximum growth. Thus, better performances expected in the hybrid CW system during the summer can be advantageously exploited for the application of higher loads.

**Solid content in the influent wastewater and clogging risk**

During the high-load period the solids concentration in the influent wastewater has to be maintained at low levels. A pre-treatment of raw wastewater in an Imhoff tank/ septic tank is advised. In our case, the pre-settled wastewater had settleable solids always less than 6 mL/L. Clogging problems were not observed during the 2-month period at high load despite the progressive accumulation of the suspended solids in the VSSF (settleable solids were always lower than 6 mL/L in the pre-settled wastewater) and the growth of microorganisms, which will undergo mineralisation during the remaining 10-month period operating at low load.
Plants

During the high-load period no problems on plant growth were observed in the HSSF.

CONCLUSION

The performance of the hybrid CW system designed for the treatment of wastewater of resident population, was investigated during a high-load period of 2 months during the summer, in presence of the floating population due to tourists. The removal efficiency in the hybrid CW system decreased slightly from 94 to 88% for COD removal and from 78 to 75% for total N removal, even after applying a double hydraulic (from 60 to 123 L m\(^{-2}\) d\(^{-1}\)) and organic load (from 37 to 87 g COD m\(^{-2}\) d\(^{-1}\) and from 4.4 to 10.3 g TKN m\(^{-2}\) d\(^{-1}\)). During the high-load period, the nitrification in the VSSF system was stable and specific nitrification rate resulted 4.7 g NH\(_4\)-N m\(^{-2}\) d\(^{-1}\) compared with 2.4 g NH\(_4\)-N m\(^{-2}\) d\(^{-1}\) in the low-load period. However, a higher NH\(_4\)-N concentration in the VSSF effluent was observed (26 mg NH\(_4\)-N/L compared with 17 mg NH\(_4\)-N/L on average in the low load period). In the case of higher hydraulicus and organics loads in the VSSF, the HSSF helps to remove COD, nitrogen and phosphorus. In the high-load period the denitrification rate increased in the HSSF system due to the higher availability of biodegradable COD in the effluent from the VSSF unit. Clogging and problems on plant growth were not observed during the high-load period.

The results showed that in the summer period (when temperatures are favourable and kinetics and solids mineralisation are higher) the application of high loads did not significantly affect the efficiency of the hybrid CW plant, suggesting that it is possible to refer the CW design to the resident population, with significant savings in area and subsequently the total investment for constructed wetland.

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