Journal of Water Process Engineering 80 (2025) 109175

Contents lists available at ScienceDirect

Journal of Water Process Engineering

journal homepage: www.elsevier.com/locate/jwpe

Innovative low-tech approach for domestic wastewater treatment using vertical constructed wetlands with sugarcane bagasse substrate and *Canna indica* in tropical climates

Donald Louis Jean [a,b,*], Nesrine Alili [a], Yvens Cheremond [b], Frédéric Monette [a]

[a] École de technologie supérieure, Montreal, Quebec, Canada
[b] Faculty of Science, Université d'État d'Haïti, Port-au-Prince, Haiti

ARTICLE INFO

Editor: Meng Wang

Keywords:
Vertical flow
Constructed wetlands
Sugarcane bagasse
Canna indica
Wastewater
Tropical climate

ABSTRACT

Vertical flow constructed wetlands are increasingly adopted for domestic wastewater treatment due to their effective contaminant removal and low energy use. However, availability of conventional filter media can limit implementation in some communities. This study evaluates sugarcane bagasse as an alternative filter medium during the first 10 months (start-up phase) of operation.

Four pilot units (0.26 m^2 each), planted with four *Canna indica* seedlings, were studied under controlled tropical conditions and fed synthetic domestic wastewater. Three units contained a transition layer of bagasse fragments (5.0–10.0 mm) and retention layers consisting of P_1 (0.9–2.0 mm), P_2 (2.0–5.0 mm), and P_3 (1.2–5.0 mm). A control unit (T) included a 20 cm transition layer of gravel (5.0–10.0 mm), and a 30 cm retention layer of sand (2.0–5.0 mm) was also monitored. Each unit featured a 20 cm drainage layer of stones (19.0–45.0 mm).

Results showed 43–46 % compaction of bagasse filter media height. Media size and nature affected plant growth and density, crucial for performance. After 300 days, plant densities were P_1: 259, P_3: 204, P_2: 193, T: 146 stems/m^2. Removal efficiencies (%) for TSS, BOD_5, COD, NH_4^+/NH_3, and TP were: P_1 (88, 93, 87, 76, 49), P_3 (80, 88, 82, 61, 37), P_2 (77, 87, 78, 63, 34), and T (77, 80, 79, 62, 50). The P_1 unit, featuring the finest bagasse retention layer, demonstrated promising potential for community-scale potential applications in low-income tropical areas. Increasing the heights of the transition and retention layers is recommended to offset compaction and improve performance further.

1. Introduction

Constructed wetlands (CWs) are a wastewater treatment technology that integrate filter media, microorganisms, and plants [1,2]. This technology is versatile and used for the treatment of various types of wastewater [3–6] such as domestic wastewater [7,8], industrial wastewater [9,10], and some other types of water (swine wastewater, winery wastewater, etc.) [11,12]. Its effectiveness in different climates around the world makes it a proven technology [13]. Indeed, this technology ensures significant removal efficiency for most pollutants [14,15] and requires low or no electrical energy consumption for its operation [16,17]. Moreover, it provides ecosystem services [18], promotes broad biodiversity [19], and is particularly suitable for medium and small-sized communities [20].

Among the various types of available CWs, the vertical flow system has the particularity of purifying raw wastewater without any pretreatment, except for coarse screening. The filter media of the upper layer intercepts the majority of total suspended solids (TSS) in the water, creating a layer of sludge on the surface which contributes to the efficiency of the treatment system [20,21]. Treatment is conducted in aerobic conditions, promoting the degradation of organic matter and the nitrification of ammoniacal nitrogen [22–24]. Studies conducted in tropical regions have demonstrated that this type of constructed wetland is promising, robust, and compact [25,26]. Indeed, according to the literature, the surface area per French population equivalent (PE) required for wastewater treatment in these regions varies from 0.60 m^2/PE [21], 0.79 m^2/PE [27], 0.80 m^2/PE [28,29], and 0.90 m^2/PE [21], compared to non-tropical regions (France), where the surface area ranges from 1.2 to 1.5 m^2/PE [30].

The use of ornamental plants in constructed wetlands has been

* Corresponding author at: École de technologie supérieure, Montreal, Quebec, Canada.
E-mail address: donald.louis-jean.1@ens.etsmtl.ca (D. Louis Jean).

https://doi.org/10.1016/j.jwpe.2025.109175
Received 3 October 2025; Received in revised form 14 November 2025; Accepted 19 November 2025
Available online 1 December 2025

recorded in various works [31–34]. The most common ornamental species are *Thalia dealbata* Fraser, *Iris tectorum* Maxim, *Canna indica*, *Heliconia psittacorum* [32,35–37], mainly because they are widely available, highly adaptable to wetland conditions, tolerant to pollutants, and valued for their aesthetic appeal. Planting density in the different systems studied is variable, but generally has fewer than 10 plants/m^2, (4 plants/m^2 [38,39], 6.7 plants/m^2 [40], 8 plants/m^2 [36], 9 plants/m^2 [41,42]), or 16 plants/m^2 [43] or 40 plants/m^2 [32,44]. Plants play a mechanical role due to their movement under the effect of winds and thus ensure good water evacuation [4] by creating rings (space) around the stems in the upper layer [28]. This then prevents the clogging of the wetland [34,35]. Moreover, they improve the removal of contaminants, especially organic matter, due to purifying bacteria present in the rhizosphere [1]. Plants also participate in the transformation and removal of nutrients such as nitrogen and phosphorus [35]. *Canna indica* provides significant biological advantages such as high biomass production and a rapid growth rate that exceeds that of *Phragmites australis*, making it particularly effective in constructed wetlands (CWs) [45,46]. Its fibrous root system forms structures that create highly aerobic conditions, thereby enhancing the removal of conventional pollutants including total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), total phosphorus (TP), and nitrogen compounds [45,47]. In addition, *Canna indica* offers a strong potential for the removal of heavy metals such as cadmium (Cd), zinc (Zn), chromium (Cr), etc. [45,48]. It has also proven effective in eliminating pesticides, pharmaceuticals, and personal care products (PPCPs), a key factor for the future treatment of increasingly complex wastewater streams [45]. Notably, *Canna indica* outperforms *Phragmites australis* and *Typha orientalis* in the removal of chlorpyrifos (CP) and its hydrolytic metabolite [45,48].

The substrate is an essential component in the effectiveness of treatment within constructed wetlands. In addition to its availability, its chemical and physical characteristics play a decisive role in the overall performance of the system [49]. Furthermore, the substrate's ability to promote or limit the growth of plants and microorganisms influences the ecological balance of the CWs, highlighting the interdependence between its various components [50]. The works of Altenor and Joseph [51,52] suggested using agricultural residues, particularly vetiver and sugarcane bagasse, to develop appropriate wastewater treatment solutions when possible. The work of Kataki et al. [53] confirms the choice of utilizing agricultural waste, especially for its environmental benefits. Sugarcane bagasse is a by-product of the sugar and alcohol industry. The work of Joseph [52] showed improvement in the adsorption capacities of heavy metal on to sugarcane bagasse. This residue from sugarcane (*Saccharum officinarum*), a plant cultivated in many tropical countries including the island of Haiti (Republic of Haiti and Dominican Republic), is made of cellulose, hemicellulose, and lignin [52,54]. Its elemental composition consists of 48.57 % C, 5.41 % H, 0.36 % N, less than 0.10 % S, and 45.58 % O [54]. In its raw state, bagasse was studied as a filter medium for removing fats from industrial wastewater [55]. Bagasse fragmented between 2.4 and 9.5 mm was also investigated as a medium for a vertical flow CW for the treatment of textile wastewater [56]. This treatment was followed by a horizontal wetland with Sylhet sand media. In another study, bagasse was compared with other conventional and non-conventional materials as a retention layer filter medium in a vertical wetland, with fragment sizes in the range of 10–20 mm [57]. Moreover, bagasse has been used to manufacture activated carbon for water treatment, particularly for the adsorption of metals, dyes, and pharmaceutical compounds in aqueous media [58]. However, no studies on bagasse as a filter medium for domestic wastewater treatment have been reported. Furthermore, the existing studies conducted on bagasse have not considered fragments smaller than 2 mm. Consequently, the potential of a layer made of bagasse fragments, or of a configuration simulating conventional constructed wetland systems, remains unknown.

Despite the existence of constructed wetland technology and many other wastewater treatment technologies, several low-income tropical countries face difficulties in accessing these sanitation facilities. This is mainly due to marked economic insecurity, insufficient attention to improved sanitation solutions, and often ineffective water and sanitation management [59–61]. This situation leads to the discharge of wastewater and excreta into the natural environment without any prior treatment [60]. In urban areas of Haiti, for example, populations are exposed to high health risks associated with the disposal of excreta from latrines by bayakous and wastewater in gutters into the natural environment [62,63]. Although the Haitian authorities have implemented measures to improve sanitation in the country [64], this wastewater and fecal sludge ultimately ends up in waterways, ravines, abandoned land, or the sea [63,65]. In addition, open defecation is a common practice in some communities in the country [62]. Other environmental efforts have been made in the country, such as the creation of marine protected areas (MPA). 13.95 % of these areas managed by Haiti are designated as MPA [66]. However, untreated wastewater discharges pollute surface water, groundwater, and marine waters along virtually all the coasts of Haiti's major cities [67,68]. This situation runs counter to the objectives of protecting fisheries and other resources present in Haiti's continental and marine waters intended for a blue economy [66]. However, to ensure the protection of their natural environments, the Dominican Republic and the Republic of Haiti have established standards on their territories [69,70].[1] The Republic of Haiti has set up for the first time following the arrival of the cholera epidemic in 2010 a few lagoon-based wastewater treatment plants that are not connected to a sewer network [67].

In the present work, various fragment sizes of crushed and sieved bagasse were studied in three pilot units of CW planted with *Canna indica* to treat synthetic domestic wastewater. In particular, one of the units tested incorporated fragments smaller than 2 mm. In addition, a control guide unit made of conventional granular materials (sand, gravel) was also studied. This study aimed to evaluate the effectiveness of sugarcane bagasse as a filter medium for wastewater treatment in a tropical climate. Performance was assessed in terms of the removal efficiency of major pollutants, namely TSS, organic matter [biochemical oxygen demand (BOD_5), chemical oxygen demand (COD)], ammoniacal nitrogen and total phosphorus. The presence of bagasse as a filter medium is expected to improve purification processes by increasing the surface area for bacterial growth and creating a higher porosity to maintain better aerobic conditions. The work will also address the behavior and ability of bagasse to promote plant growth, by comparing plant growth in bagasse CW with that in the control guide made of conventional material. The results of this study will contribute to a better understanding of the behavior of sugarcane bagasse-based treatment systems, supporting their potential integration into future design.

2. Materials and methods

2.1. Pilot plants

To carry out the work, four vertical flow CW units, each with a gross volume of 166 L were set up. These units were installed in a climate-controlled chamber measuring 2.0 m × 2.0 m × 2.5 m (L × W × H). The four pilot units were filled with their respective filter media, then fed 6 times a day with potable water (City of Montreal) for 15 min per feeding for 15 days. This procedure allowed the removal of fine particles (and residual sugar in the case of the bagasse units). *Canna indica* seedlings were then planted on day 15 (Fig. 1), with the potable water supply maintained until day 18. The feeding with synthetic wastewater began on day 18, along with the experimental monitoring of the four pilot units. Day 18 is therefore considered the first day of operation.

[1] [69]: confidential communication.

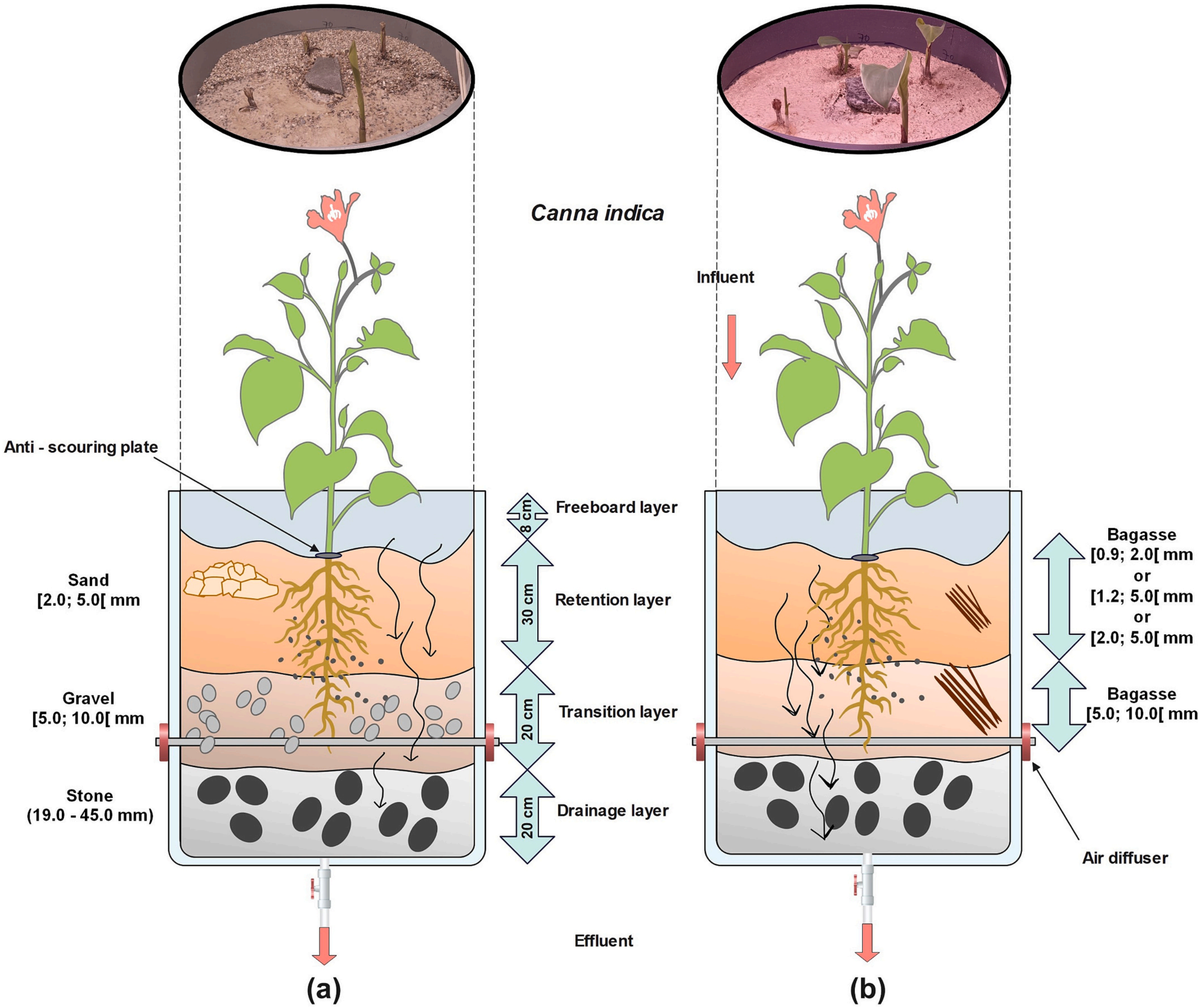

Fig. 1. Configuration of pilot-scale treatment units with initial growth of young shoots (shown in the photos at the top of the images): (a) conventional system and (b) system tested with bagasse.

2.2. Climatic management of the chamber

Various measures were implemented to recreate tropical climate conditions during the experiments. Specifically, thirty-two (32) Barrina T5 grow lights (model INWT504009650Ec) were used to simulate solar radiation. Six (6) lamps per wetland unit were initially installed at a vertical height of 60 cm above the plants. This distance was kept constant during the first months by adjusting the lamp height according to average plant growth. It was later readjusted at the end of the plant growth period, so that the height of the flowers exceeded that of the lamps. An additional eight (8) lamps were installed vertically around the perimeter of the climate chamber to ensure full irradiation of the units. The lamps maintained an irradiation level between 2.3 and 20.9 klux, measured at a distance of 100 cm and 15 cm respectively. The temperature inside the climate chamber was regulated through the use of two General Electric lamps (model 73790) installed on the ceiling, along with a FOR LIVING fan heater (model 043-5866-8) positioned at the upper level of the units. These devices were controlled by an INK BIRD thermostat (model ITC 308) in accordance with the daily sunshine cycles observed in Haiti from 10 h/d to 13 h/d, with a temperature variation ranging between 22.5 °C and 34.0 °C. Finally, relative humidity was maintained using two LEVOIT Classic160 humidifiers (model LUH-A251-WCA) operated every 40 min for a duration of 30 min to reproduce conditions in Haiti (40 to 98 % relative humidity). Two other fans: LR8647, model 1148; and LR104132 model HF-30ST-W were used sporadically to simulate wind turbulence.

2.3. Details of the experimental set-up

The experimental set-up comprises three tested units based on sugarcane bagasse and a control unit based on inorganic aggregates. The circular HDPE units have an average diameter of 570 mm (surface area 0.26 m^2) and a total height of 785 mm (Fig. 1). The units were filled with layers of different filter media (substrates) to a total initial height of 700 mm, according to the values shown in Table 1. A freeboard of 85 mm prevents water overflow during the feeding cycle. The pilot units tested were composed mainly of sugarcane bagasse fragments (retention and transition layers) and a drainage stone layer at the bottom. The pilot control unit was composed of materials conventionally found in constructed wetlands (sand, gravel, stone) [71]. Anti-scouring plates were installed at the center of the upper surface to prevent surface erosion and distribute water over the surface of each unit. At 30 cm from the bottom

Table 1
Configuration and composition of pilot units (surface area: 0.26 m^2/unit) and granulometry of filling media.

Characteristics	Thickness	Sugarcane bagasse-based constructed wetland			Control
		Unit 1 (P_1)	Unit 2 (P_2)	Unit 3 (P_3)	Unit 4 (T)
Freeboard layer	85 mm				
Retention layer	300 mm	Bagasse [0.9; 2.0[mm	Bagasse [2.0; 5.0[mm	Bagasse [1.2; 5.0[mm	Sand [2.0; 5.0[mm
Transition layer	200 mm	Bagasse [5.0; 10.0[mm			Gravel [5.0; 10.0[mm
Drainage layer	200 mm	Stone 19.0-45.0 mm			

of the device, halfway up the transition layer, an air diffuser (PVC pipes; Φ = 2.5 cm) perforated with 3.2 mm holes in three rows and connected to a vent ensured air flow into the device. An effluent pipe installed 2.0 cm from the bottom (within the drainage layer) allows treated water to be discharged.

The bagasse used in the tested units (Fig. 2) was prepared from sugarcane originating from Mexico. A Retsch rmbH SM300 mill [72] was used to reduce the size of the bagasse stem (1500 r/min; 20.0 mm mesh sieve). The crushed bagasse was then dried without the aid of a fan for one day. After the crushing and drying sequences, a set of sieves was used to remove extreme fractions such as fine particles (≤0.9 mm) and coarse particles (>10.0 mm).

Three batches of bagasse fragments were then prepared from the retained fractions. Thus, the [0.9; 2.0[mm, [1.2; 5.0[mm, and [2.0; 5.0[mm batches were respectively assigned to the retention layers of the tested units P_1, P_2, and P_3 (Table 1). In addition, the remaining bagasse residues [5.0; 10.0[mm were used as the transition layers of the tested units. Sieves with 2.0 mm, 5.0 mm, and 10.0 mm mesh sizes were used to prepare the media for the control wetland unit T. The sand ([2.0; 5.0[mm) and gravel ([5.0; 10.0[mm) were respectively assigned to the retention and transition layers. Each unit was planted with 4 seedlings of *Canna indica*, corresponding to approximately 16 seedlings/m^2.

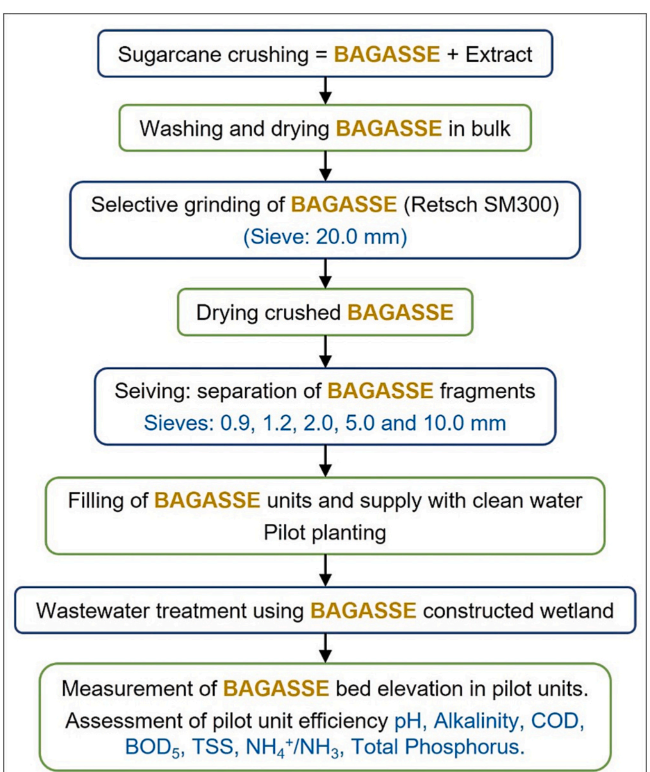

Fig. 2. Experimental procedure for preparation and use of bagasse in constructed wetlands.

2.4. Feeding

The four pilot units were fed simultaneously by tarpaulins using a MASTERCRAFT™/MC pump (model 062-3421-2). The feeding rate was adjusted to be greater than 0.5 $m^3/m^2/h$ for each unit in order to ensure uniform water distribution across the entire surface, in accordance with [73]. Initially, each unit was operated under a regime of 3.5 days of feeding, followed by 7.0 days of resting, in accordance with the recommendations of [74,75]. Subsequently, a 3.5 day feeding and 3.5 day resting regime was adopted, as suggested by [76]. The feed schedule for each unit was set to deliver 12 batches per day, each corresponding to a water depth of 2.53 cm, yielding a total daily loading of 30.4 cm. During each feeding cycle, the influent was first homogenized with a Neptune M3912 mixer for 50 s, and then pumped, while maintaining agitation for 1 min 10 s (equivalent to 1.0 $m^3/m^2/h$). The batches were separated by an interval of 1 h 58 min.

A daily volume of 310 L of synthetic wastewater was prepared, of which approximately 95 % was used to supply the experimental units. The composition of the synthetic wastewater is detailed in Table 2. This composition was inspired by those reported by [41,77–80]. Potable water from the City of Montreal served as the base for preparing all solutions. To ensure iron solubilization, EDTA (a chelating agent) was first dissolved, followed by the addition of $FeCl_3$-6H_2O. The other inorganic compounds were then dissolved in water and subsequently added to the chelated solution. The toilet paper was first shredded into square pieces with 5 cm long sides, then blended in an Oster household blender with a volume of approximately 500 mL. All components were then mixed together in a 340 L tank. Two liters of municipal wastewater from the City of Montreal were also added to provide a source of microorganisms.

The characteristics of the resulting synthetic wastewater are presented in Table 3. The VSS/TSS and BOD_5/COD ratios obtained from analyses of similar samples indicate the good biodegradability of this wastewater and therefore the potential of biological systems to purify it [81].

Table 2
Chemical compounds and other products of synthetic wastewater (adapted from [41,77–80]).

Chemical compound	Brand or CAS No	Target concentration (mg/L)
$NaHCO_3$	144-55-8	331.00
NH_4Cl	235-186-4	67.00
K_2HPO_4	7758-11-4	11.00
$CaCl_2{\cdot}2H_2O$	10035-04-8	18.00
$MgSO_4{\cdot}7H_2O$	10034-99-8	28.50
$FeCl_3{\cdot}6H_2O$	10025-77-1	1.00
$MnSO_4$	10034-96-5	1.50
$NaMoO_4{\cdot}2H_2O$	10102-40-6	12.60
$C_{10}H_{16}N_2O_8$ (EDTA)	60-00-4	3.75
Milk powder	Carnation™	59.00
Yeast	Pakmaya™	26.50
Corn starch	Fleismann's™	111.00
Oil (sunflower)	Unico™	14.50
Beef extract	Sélection™	170.00
Glycerol ($C_3H_8O_3$)	56-81-5	100.00
Sodium dodecyl sulfate ($C_{12}H_{25}NaSO_4$)	205-788-1	25.00
Toilet paper	Cashmere	62.50
Urea (CH_4N_2O)	57-13-6	67.50

Table 3
Characteristics of the synthetic wastewater used.

Parameter	n	Unit	Value
pH	28	–	7.0 ± 0.2
Alkalinity	22	mg $CaCO_3$/L	333 ± 38
TSS	21	mg/L	175 ± 19
VSS	16	mg/L	164 ± 14
VSS/TSS	16	–	0.96 ± 0.17
COD	19	mg O_2/L	531 ± 35
BOD_5	18	mg O_2/L	330 ± 48
COD/BOD_5	9	–	1.59 ± 0.24
$CBOD_5$	6	mg O_2/L	280 ± 57
TOC	6	mg C/L	216 ± 35
NH_3/NH_4^+	16	mg N-NH_4^+/L	44.3 ± 4.9
TP	15	mg P/L	3.01 ± 0.31

2.5. Sampling and analysis

Samples at the influent (synthetic wastewater) and effluent of the units were collected weekly at the end of the cycle during the feed period, i.e., between 74 and 84 h after cycle start-up. Sampling was conducted as a composite type, consisting of three successive batches, with 1 L collected from each batch. During a sampling operation, a container is placed at the outlet of each unit and receives approximately 90 % of the volume entering the unit. Then, the water from each unit is homogenized, and a portion of this water is collected as a sample. This collection process can last between 25 and 60 min. All collected samples were preserved and analyzed in accordance with the methods described in the Standard Methods for Examination of Water and Wastewater [82]. Table 4 shows the parameters analyzed, the principle of the methods and their references, as well as the equipment used. The pH of each sample was measured in situ at the time of sampling. Due to logistical constraints, sampling and/or analysis of certain parameters were not conducted during some weeks.

Other parameters were also analyzed on the different units studied. Specifically, the number of *Canna indica* stems per pilot unit was recorded twice a month to determine plant density and the multiplication rates (K). In addition, as bagasse is a new material for this type of application, the elevation of the top layer was recorded twice a month.

2.6. Performance evaluation and statistical analyses

The experimental results were presented in graphical form. In addition to the conventional presentation of data for each experimental unit, certain values related to contaminant removal were expressed as percentages. For selected parameters, such as TSS, BOD_5 or COD, the results were also expressed as pollutant load rates. The pollutant load rate ($g/m^2/d$) was calculated from the pollutant concentration in the influent (g/L), divided by the hydraulic flow rate (L/d), then divided by the surface area of the unit (m^2). The pollutant removal rate ($g/m^2/d$) was determined from the difference in concentration between the influent and effluent (g/L), divided by the hydraulic flow rate (L/d), then divided by the surface area of the unit (m^2).

Prior to applying statistical tests, analysis of variance (Fisher's F-test) and comparison of means (Student's *t*-test), the normality of the raw data for each analyzed parameter was evaluated using the Shapiro–Wilk test. This step aimed to verify that all water characterization parameters followed a normal (Gaussian) distribution before performing statistical analyses. When the normality assumption was not met for a given dataset, no further statistical analysis was applied to it. The objective was to detect any statistical differences between the different experimental units, either between the mean values (Student's *t*-test) or between the variances (Fisher's F-test). Comparisons were made pairwise for each parameter studied. For all statistical tests, the significance threshold was set at $\alpha = 0.05$.

Table 4
Summary of analyzed parameters.

Parameter	Principle	Method (s)	Apparatus
Alkalinity	Titrimetry	2320 B	Burette (25.0 ± 0.2 mL)
pH	Potentiometry	4500-H^+ B	pH-meter OATKON™, PC 2700
TSS	Gravimetry	2540 D	Filter bench
VSS		2540 E	Glass-fiber filter disks (Φ = 4.7 cm; porosity = 1.2 to 1.5 µm) Precision balance - SI-234 DENVER (±0.1 mg) Oven - SHEL LAB 1305 U (103–105 °C)
NH_3/NH_4^+	Titrimetry	4500-NH_3 B	Distillatory Selecta Pro NITRO S
		4500-NH_3 C	Burette (25.0 ± 0.2 mL)
COD	Closed reflux digestion Titrimetry	5220C	Thermoreactor VELP Scientifica DK20, 150 ± 2 °C Burette (25.0 ± 0.2 mL)
BOD_5	Respirometry	5210 D	WTW Oxitop system Incubator VELP Scientifica, foc 225d (20 ± 1 °C) Achat OC version 3.2.0.0
TOC	IR detection	5310 B	Carbon analyzer SKALAR
TP	Spectroscopy	4500-P B 4500-P E	Autoclave T Lab Eco V60 & V85 Spectrophotometer Cary 300 UV–Vis ou Cary 60 UV–Vis

3. Results and discussion

3.1. Behavior of bagasse media

During the start-up period, the wetting of the wetland surfaces with wastewater under tropical conditions promoted the development of midges, as reported by another study [17]. Their presence naturally decreased to a barely noticeable level with plant growth during the first three months.

A progressive compaction of the bagasse medium (Fig. 3) was also observed during the first three months of testing. For each unit, the total height of the pilot unit beds rapidly decreased from 70 cm to 43 ± 1 cm during the first two months. From the third month onward, the height stabilized at approximately 40 cm for units P_1 and P_3. A relatively more pronounced compaction was observed in unit P_2 (final height of 38 cm), which was characterized by a range of bagasse fragment sizes (2.0–5.0

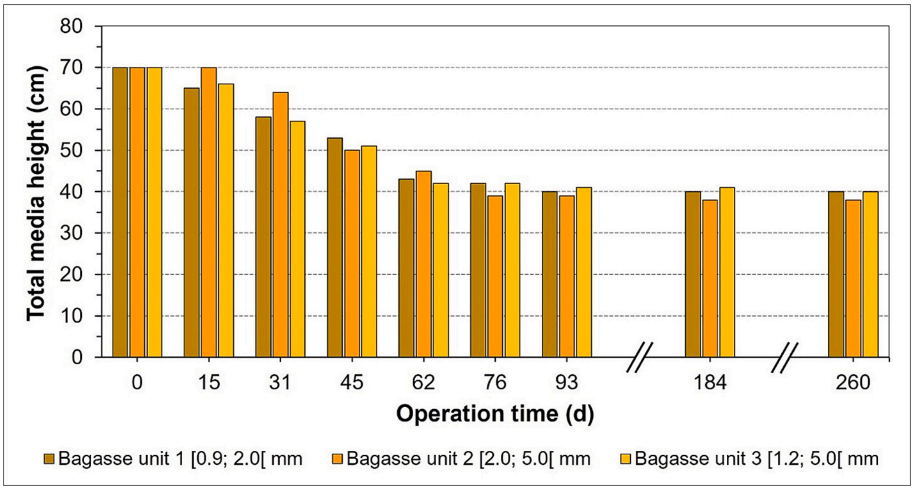

Fig. 3. Temporal evolution of settlement in the units tested during the 300 first operation days.

mm) in the upper layer (Table 1). This compaction reduced the void ratio within the medium composed of bagasse fragments. Despite these reductions in bed height, no clogging was observed in any of the test units during the 300-day experimental period.

3.2. Plant growth

Fig. 4 presents the variation in plant density over the trial period. An initial acclimatization phase (prior to multiplication) was observed during the first 30 days for the units containing bagasse media, and during the first 45 days for the control unit. At day 304, the densities reached 146, 193, 204, and 259 stems/m^2 for units T, P_2, P_3, and P_1, respectively. Between day 45 and day 304, the average multiplication rates (K) were 0.53, 0.63, 0.69, and 0.90 stems/m^2/d for units T, P_2, P_3, and P_1, respectively. The bagasse-based units were more flexible and provided more favorable conditions for root development compared to the control unit filled with sand and gravel, whose media were more rigid and angular. In particular, the fine particle size of the bagasse in unit P_1 appeared to facilitate root penetration and, consequently, enhance stem growth and multiplication, with a multiplication rate 21–26 % higher than in units P_2 and P_3.

High plant density creates a microclimate that can enhance temperature regulation within constructed wetland units [7,34,83]. It also promotes the retention of suspended solids [83] and accelerates nitrification processes [7]. The vegetation cover increases the rhizosphere surface area available for microbial colonization and growth, in addition to preventing clogging of the filter media [1]. Specialized internal air channels that facilitate oxygen transport promote gas exchange, particularly the transfer of atmospheric oxygen to flooded zones, thereby maintaining aerobic conditions during feeding cycles [84,85]. Additionally, vegetation participates in nutrient processing, such as nitrogen and phosphorus uptake, which supports plant metabolism [86].

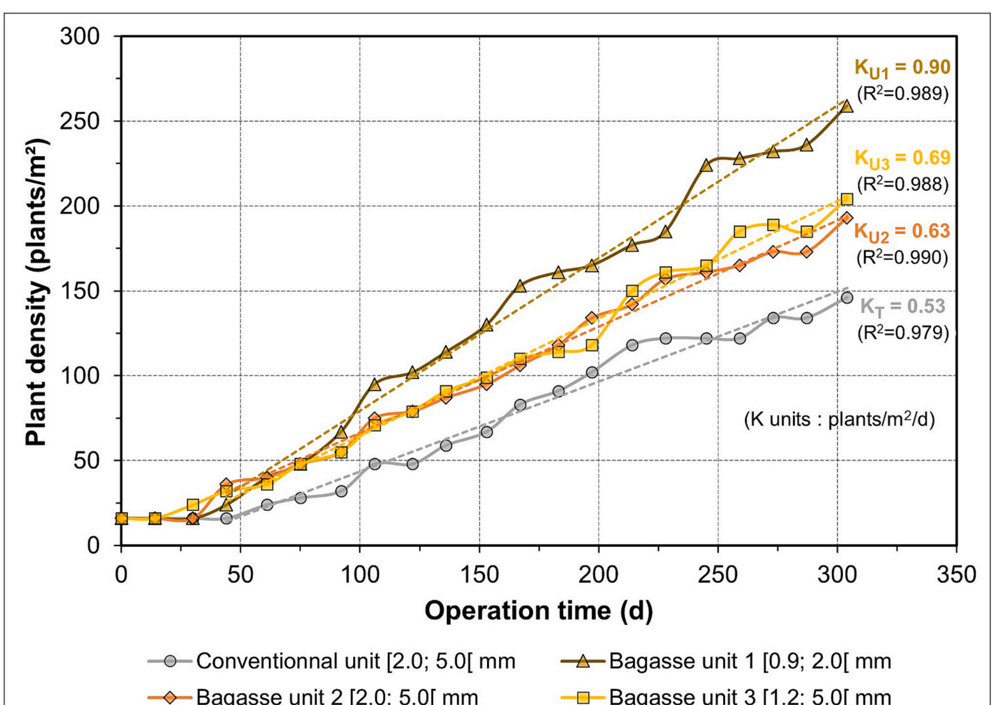

Fig. 4. Temporal evolution of the plant density in the four units studied during the first 10 months of operation.

Filter media that are flexible and have fine particles support higher plant densities, enhancing contaminant removal by more effectively trapping pollutants within the roots, as the rhizosphere microbial richness in such media is greater than in media composed of rigid, coarse particles [34,87]. In addition, the organic carbon derived from bagasse [54] can further stimulate microbial activity and improve plant density. Based on these advantages, along with the observed plant densities, unit P_1 is expected to provide superior removal performance for most monitored contaminants.

3.3. pH and alkalinity

After 300 days, the results presented in Fig. 5 show an influent alkalinity of 333 ± 38 mg $CaCO_3$/L (n = 22) and a pH of 6.9 ± 0.2 (n = 28). Overall, the analysis highlights an increase in alkalinity at the effluent of the control unit (T), with an average value of 352 ± 57 mg $CaCO_3$/L. This increase was accompanied by a rise in pH, with an average observed value of 7.0 ± 0.2, although the median was slightly lower than that of the raw water. This behavior is consistent with the nature of the control unit's filter medium, which contains limestone residues ($CaCO_3$), potentially leading to an increase in alkalinity [88,89].

For the tested units P_1, P_2, and P_3, whose media consisted mainly of bagasse, decreases in both alkalinity and pH were observed compared to the raw water. The respective average alkalinity values were 217 ± 66, 244 ± 61, and 228 ± 64 mg $CaCO_3$/L, and the average pH values were 6.7 ± 0.1, 6.7 ± 0.2, and 6.6 ± 0.2. These reductions are most likely due to oxidation of ammonium nitrogen processes occurring in these units (conversion of NH_4^+ to NO_3^-), which generate hydrogen ions (H^+) [90,91]. The limestone release from the control unit (T) would have partially offset this effect. This unit also exhibited greater variations in alkalinity than the others, with some extreme pH values observed in the basic range.

The pH stability observed in the influent during the experiments, supported by the presence of alkalinity, is likely beneficial to biodiversity and to the proper functioning of the constructed wetlands. Indeed, wetland plants and microorganisms require a pH between 6.0 and 8.0 to sustain the biochemical processes involved in the transformation and degradation of contaminants [83].

3.4. Total suspended solids (TSS)

The influent exhibited TSS concentrations ranging from 139 and 232 mg/L, with an average value of 175 ± 19 mg/L for the dataset considered (n = 21; 300 days). Unit P_1 was the most efficient and stable unit with an average effluent concentration of 21 ± 8 mg/L (88 % removal) and extreme variations ranging from 5 to 38 mg/L (Fig. 6 (a)). The effluent concentration of unit P_3 averaged 34 ± 15 mg/L (81 % removal), with extreme values between 9 and 77 mg/L. Unit P_2 showed similar variations of the same order (11 to 82 mg/L), with an average effluent concentration of 40 ± 19 mg/L (77 % removal). Finally, the control unit (T) exhibited an average value close to that of unit P_2, namely 42 ± 17 mg/L (76 % removal), with values ranging between 13 and 77 mg/L.

The results indicate that effluent TSS concentration from the tested units vary according to the size of the bagasse fragments in the retention layer. In fact, the finer the fragments in a unit's retention layer, the greater the TSS removal efficiency. The results obtained for P_1 (88 %), whose retention layer particle size ranged from ≥0.9 mm to <2.0 mm confirm this trend. Unit P_3, which contained a fraction of its media with smaller particle sizes than P_2 in its retention layer (ranging from ≥1.2 mm to <5.0 mm), achieved a higher removal efficiency of 80 %. Both P_2 and T, with retention layer media of comparable particle sizes (fragment diameters from ≥2.0 mm to <5.0 mm) showed similar average removal efficiencies (77 % and 76 %), despite their different nature (bagasse vs. sand).

The work of Monteagudo-Hernández et al. reported a correlation between plant density and TSS removal [83]. In the present study, the units containing filter media of the same nature (bagasse) confirm this observation, showing improved performance with increasing plant density. At plant maturity, the results were as follows P_1 (259 stems/m^2; 88 %), P_3 (204 stems/m^2; 80 %), and P_2 (193 stems/m^2; 77 %). However, P_2 (193 stems/m^2; 77 %) and T (146 stems/m^2; 76 %) exhibited similar removal efficiencies despite considerable differences in plant density between these two units. The particle size of the media in the retention layer thus appears to be the key parameter influencing TSS removal, regardless of the nature of the medium. Statistical analyses showed that unit P_1 differed significantly from each of the three other units (p < 0.05). The removal of total suspended solids (TSS) is also presented as a temporal evolution in the supplementary information (Fig. S. 1). This is characterized by the constancy of units T and P_1, and a deterioration of units P_2 and P_3.

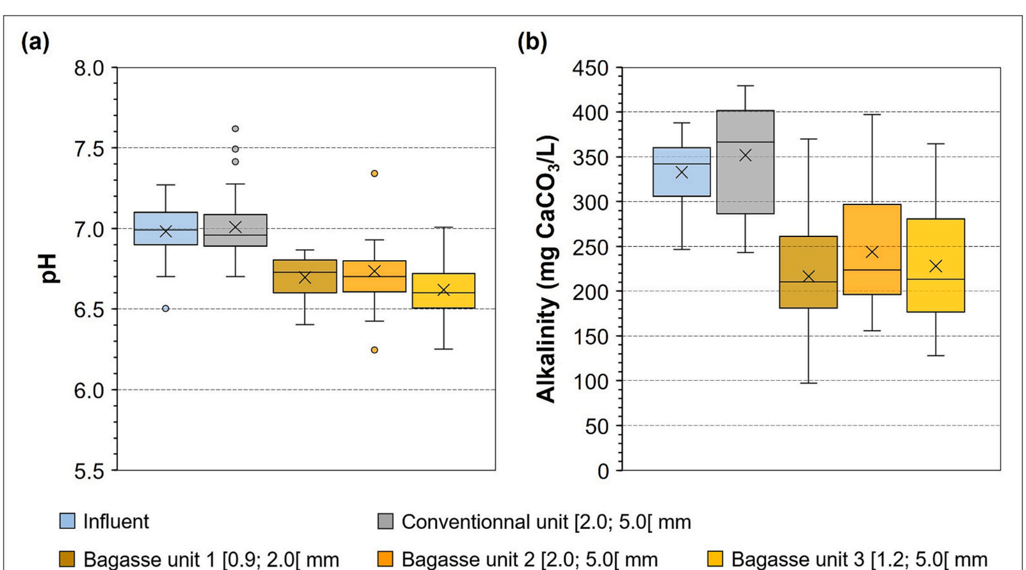

Fig. 5. a) pH, n = 28 and b) alkalinity, n = 22 at the influent and effluents of the units after 300 days.

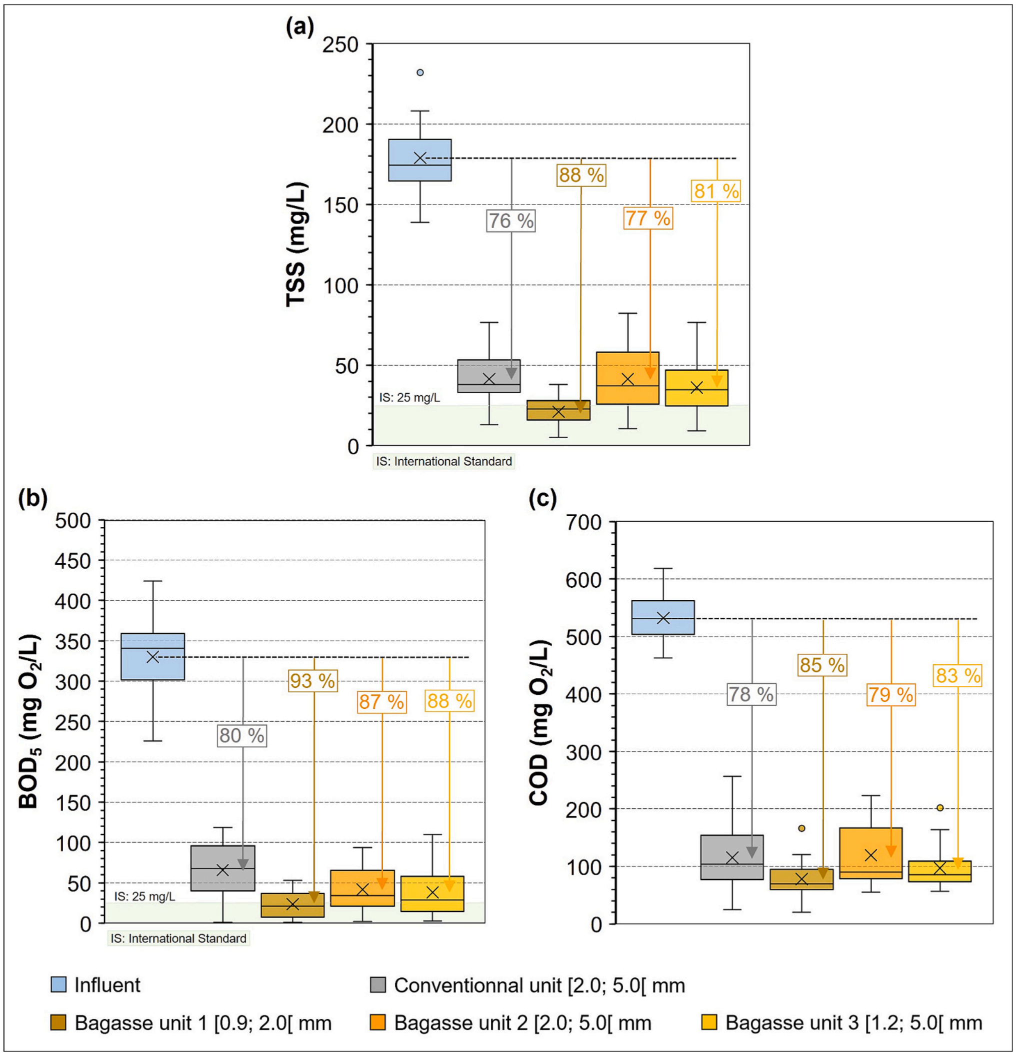

Fig. 6. Removal of a) TSS and oxidizable matter b) BOD_5 c) COD in the various units.

3.5. Organic matter (BOD_5, COD)

The average influent concentrations of BOD_5 and COD during the monitoring period (10 months) were 330 ± 48 mg O_2/L and 531 ± 43 mg O_2/L, respectively, corresponding to a BOD_5/COD ratio of 0.63. The effluent BOD_5 concentrations of the tested units P_1, P_3, and P_2 were 24 ± 15 mg O_2/L, 38 ± 29 mg O_2/L, and 42 ± 28 mg O_2/L, respectively, compared to 66 ± 32 mg O_2/L for the control unit T. Units T, P_2, and P_3 achieved average BOD_5 removal efficiencies of 80 %, 87 %, and 88 %, respectively, whereas unit P_1 stood out with a removal efficiency of 93 %. These results highlight the influence of plant density on BOD_5 removal. In units using bagasse-based substrates, finer fragment sizes promote higher plant density, which in turn leads to increased BOD_5 removal. Unit P_1, which at maturity had the highest plant density (259 stems/m^2), likely provided a richer rhizosphere [1], enhancing pollutant-microorganism contact, and a more substantial oxygen supply [91,92] both of which are favorable to biodegradation. This unit also demonstrated higher resilience, as indicated by the low variation in effluent BOD_5 concentrations (Fig. 6 (b)). The finer particle size of the bagasse in the retention layer (≥0.9 mm to <2.0 mm), which increases the available surface area for microbial development and improves TSS retention, likely contributed to this treatment stability and to more complete organic matter degradation. Statistical tests showed that the mean values of the three other units differed significantly from that of unit T ($p < 0.05$). Furthermore, unit P_1 differed significantly ($p < 0.05$) from each of the three other units in terms of both means and variances. The temporal evolution of treatment efficiency is characterized by consistent performance of units T and P_1, alongside a decline in P_2 and P_3 with respect to BOD_5 reduction, as presented in Supplementary Information Fig. S. 3.

COD results partially confirmed the trends observed for BOD_5. The average effluent concentrations for units P_1, P_3, T, and P_2 were 79 ± 33 mg O_2/L, 91 ± 28 mg O_2/L, 114 ± 50 mg O_2/L, and 119 ± 54 mg O_2/L, respectively, with less variability in the results for units P_1 and P_3. The finer the particle size of the media in the retention layer, the better the performance (Fig. 6 (c)). Indeed, units P_1 ([0.9; 2.0[mm; 259 stems/m^2), P_3 ([1.2; 5.0[mm; 204 stems/m^2), P_2 ([2.0; 5.0[mm; 193 stems/m^2), and T ([2.0; 5.0[mm; 146 stems/m^2) achieved respective removal efficiencies of 85 %, 83 %, 79 %, and 78 %, respectively. The plant densities observed in the tested units (P_1, P_3, and P_2) emphasize the beneficial effect of plant density on treatment efficiency. Furthermore, as observed for BOD_5, in systems using bagasse-based substrates, finer fragment sizes favor higher plant densities, thereby enhancing COD removal efficiency. However, the density of unit T does not allow us to draw the same conclusion: although unit T was 24 % less dense than unit P_2, both units produced similar removals (78 %). Statistical tests showed that unit P_1 differed significantly from unit T ($p < 0.05$). A temporal evolution of the chemical oxygen demand (COD) removal is presented in the supplementary information in Fig. S.2. This evolution is characterized by the constancy of unit P_3, improvement of units T and P_1, and deterioration of unit P_2.

During the start-up phase (300 days), better performance was observed with the units made of bagasse media compared to the control unit (made of conventional materials). These findings do not align with those of Soundaranayaki and Gandhimathi [57]. This is likely due to the fact that their study only varied the type of transition layer material, while the present work focused on the effect of varying the materials of both the retention and transition layers. The rigidity and particle size of the media are the main disadvantages of the conventional unit for the removal of organic matter, especially during the start-up phase. By contrast, the high porosity of the bagasse medium (favoring aerobic conditions) and its high specific surface area (promoting fixed biomass development) can confer a notable advantage, although compaction may have the opposite effect, particularly if it reduces wastewater contact time. The influence of particle size on contaminant removal has been examined by other researchers, and the present results agree with those of Compaoré et al. [93], who found that media with the finest particle size where the most efficient. Superior BOD_5 removal efficiencies, compared to those for COD, were consistently observed for all units. This is consistent with other work, further confirming the biological purification effect exerted by constructed wetlands [57,94,95]. To improve the efficiency of the units, it would be relevant to optimize design parameters [96], notably by increasing the layer thickness to compensate its compaction and extend the contact time with the filter media.

3.6. Removal of TSS, BOD_5, and COD loads

Fig. 7 highlights the capacity of each unit to treat respective daily loads of (a) TSS, (b) BOD_5, and (c) COD. The applied TSS loads ranged from 39.8 to 66.9 g/m^2/d, with an average value of 50.2 ± 5.5 g/m^2/d. Regarding organic matter, the loads for all units ranged between 64.8 and 121.7 g/m^2/d with an average of 94.8 ± 13.7 g O_2/m^2/d for BOD_5 and between 132.8 and 177.4 g O_2/m^2/d with an average of 152.6 ±

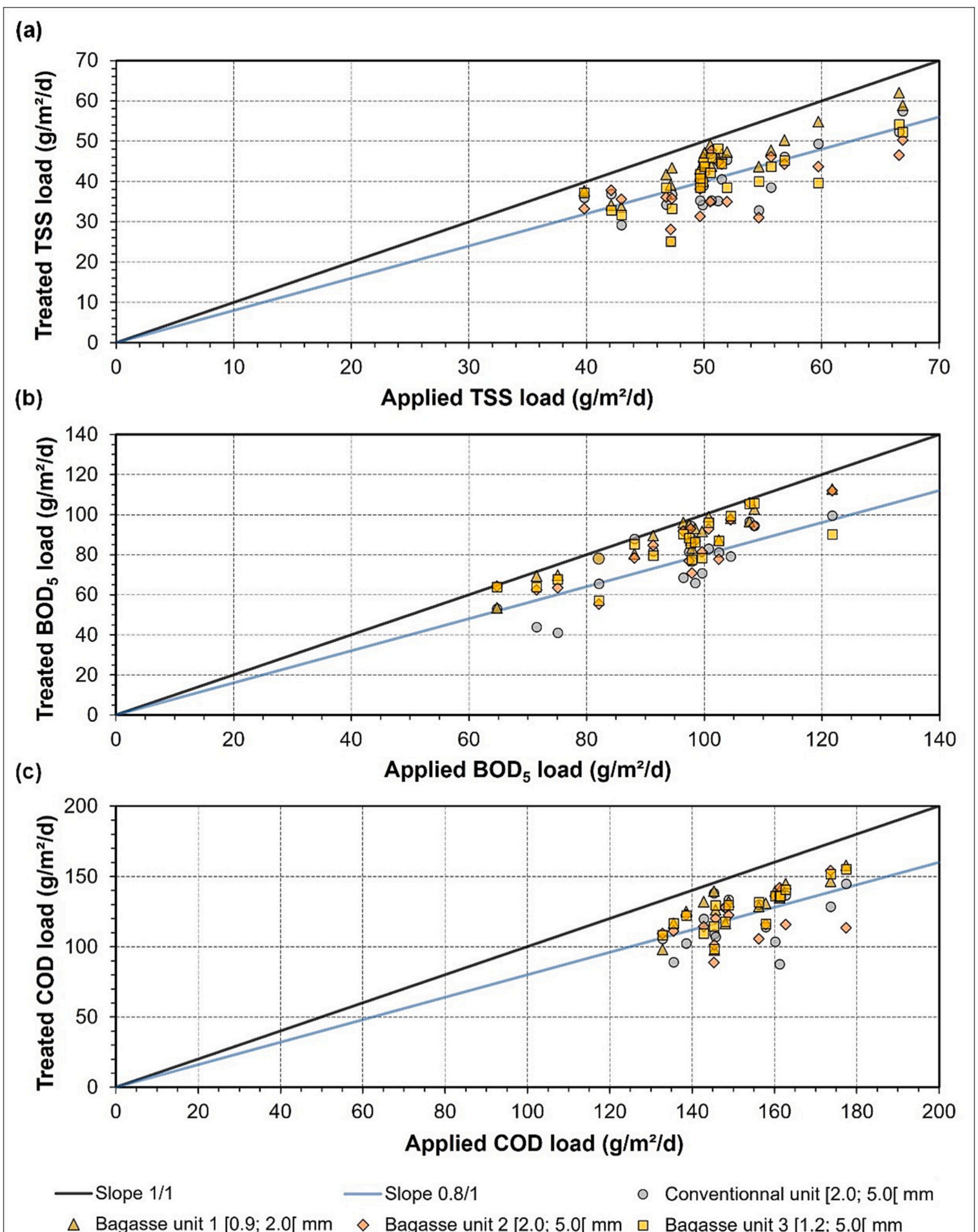

Fig. 7. Loads applied and treated by the different units: a) COD, b) BOD_5, and c) TSS.

12.3 g $O_2/m^2/d$ for COD.

TSS removal by unit P_1 showed an average efficiency of 88 % with a value of 44.2 ± 5.9 $g/m^2/d$. The variation in removed TSS load by this unit correlated well with the variation in the applied load, with a coefficient of determination R^2 of 0.83. Conversely, TSS removal by unit P_3 (40.5 ± 6.2 $g/m^2/d$) in a lower correlation, with an R^2 of 0.53, indicated a weak relationship between applied load variation and treated load variation. Units T (38.2 ± 6.0 $g/m^2/d$) and P_2 (38.8 ± 5.4 $g/m^2/d$) exhibited R^2 values of 0.39 and 0.26 respectively, showing little correlation between applied load variation and removal variation. Since applied TSS loads showed little variation throughout the period [values grouped together in Fig. 7 (a)]. These results confirm that the operational ranges of interest for the treatment units cannot be established with the available data, reinforcing the need for more in-depth investigation.

The relationship between the BOD_5 removal achieved by unit P_1 (88.0 ± 13.6 $g/m^2/d$) and the applied load was strong, with an R^2 value of 0.90. The results showed better performance for applied loads between 71.5 and 97.5 g $O_2/m^2/d$, with an average removal of 96 %, whereas for loads beyond in this range between 97.5 and 122 $g/m^2/d$, an average efficiency of 92 % was obtained. The average BOD_5 loads treated by units P_2 (82.8 ± 15.2 $g/m^2/d$), T (75.8 ± 16.7 $g/m^2/d$), and P_3 (83.8 ± 13.6 $g/m^2/d$) show relatively moderate correlations with the applied loads, with R^2 values of 0.72, 0.69, and 0.66 respectively. BOD_5 is generally used as the basis for the design of constructed wetlands. For example, one Population Equivalent (PE) in France corresponds to 60 g O_2/d of BOD_5 [73]. In this context, the average BOD_5 loads removed indicate that P_1, P_3, P_2, and T require respective surface areas of 0.68, 0.72, 0.73, and 0.79 m^2 to treat 1 PE.

With an average COD removal efficiency of 85 %, unit P_1 achieved an average removed load of 129.9 ± 15.5 g $O_2/m^2/d$. The coefficient of determination R^2 between the removed load variation and the applied load variation was 0.62, indicating a moderate correlation. P_3 treated COD with an average removed load of 126.5 ± 15.1 g $O_2/m^2/d$ and a removal efficiency of 83 %. The R^2 value was 0.71, indicating a strong correlation between COD removal and applied load variation. No clear operational preferred range was identified for COD removal in this unit. Unit T and P_2 achieved average COD removals of 118.5 ± 17.2 and 119.8 ± 15.5 g $O_2/m^2/d$, respectively. Their R^2 values were 0.23 and 0.24, indicating low proportional correlations between COD removal and applied load variation. These values suggest that COD removal is only weakly correlated to changes in the applied load. Therefore, no preferred operational zones can be established for COD removal by these units. Larger variations in applied loads, particularly lower values, would be needed to define operational ranges of interest and better size the units.

This analytical approach highlights the operational robustness of unit P_1 during the start-up phase. Beyond its higher efficiency for removing various contaminants, the strong coefficient of determination (R^2) observed for this unit confirms the system's predictive capacity regarding its response to variations in applied loads. All tested units were able to treat organic loads, expressed as BOD_5, at surface areas below 0.8 m^2/PE, demonstrating a performance level superior to recent literature references.

More specifically, the results obtained surpass those reported by Yadav et al., with a design set at 0.79 m^2/PE, as well as those from Lombard-Latune & Molle, Lombard-Latune et al. at 0.80 m^2/PE, and Trein et al. at 0.90 m^2/PE [21,27–29]. Furthermore, these performances are significantly superior to those commonly reported in non-tropical regions, such as France, where the usual design surface ranges from 2.0 to 2.5 m^2/PE [30].

These results suggest that reducing the dedicated surface area is feasible for future sizing of such technologies, potentially leading to both technical and economic optimization of the systems. Additionally, it would be relevant to consider increasing the filter layer thickness in unit P_1, particularly to compensate for its compaction, in order to achieve or even exceed the efficiency reported by Trein et al., whose system operated at only 0.60 m^2/PE [21]. Further studies focusing on modeling filter bed depth and optimizing the hydraulic loading rate would help better define operational ranges and ensure sustained performance under real operating conditions.

3.7. Ammoniacal nitrogen (NH_3/NH_4^+) and total phosphorus (TP)

Fig. 8 presents the results for ammoniacal nitrogen (a) and total phosphorus (b) at the influent (raw wastewater) and effluent of each studied unit. The average influent concentrations were 43.4 ± 4.0 mg N-NH_4^+/L and 2.96 ± 0.28 mg P-PO_4^{3-}/L for the dataset considered ($n = 16$ (N) and $n = 15$ (P); 300 days).

Regarding ammoniacal nitrogen (Fig. 8), unit P_1 performed best with 76 % removal, followed by units P_2, T, and P_3 with respective values of 63 %, 62 %, and 61 %. These results correspond to residual effluent concentrations of 9.9 ± 5.1 mg N-NH_4^+/L (P_1), 14.6 ± 7.5 mg N-NH_4^+/L (P_2), 17.0 ± 10.4 mg N-NH_4^+/L (T), and 17.4 ± 12.4 mg N-NH_4^+/L (P_3), highlighting greater variability for units P_2, P_3, and T. These values represent respective removals of 33.6 ± 10.1 mg N-NH_4^+/L (P_1), 27.7 ± 13.8 mg N-NH_4^+/L (P_2), 27.3 ± 15.3 mg N-NH_4^+/L (T), and 26.9 ± 17.3 mg N-NH_4^+/L (P_3), only part of which can be attributed to the biological oxidation of ammonium nitrogen (N-NH_4^+). Indeed, based on an alkalinity consumption of 7.1 mg $CaCO_3$/mg oxidized N-NH_4^+ [97], these removals would translate to respective alkalinity consumptions of 239 mg $CaCO_3$/L (P_1), 197 mg $CaCO_3$/L (P_2), 194 mg $CaCO_3$/L (T), and 191 mg $CaCO_3$/L (P_3), while observed alkalinity consumptions were 135 mg $CaCO_3$/L (P_1), 108 mg $CaCO_3$/L (P_2), −22 mg $CaCO_3$/L (T), and 124 mg $CaCO_3$/L (P_3) (Fig. 5 (b)). Thus, for units P_1, P_2, and P_3, only 56 %, 55 %, and 65 % of the ammoniacal nitrogen were potentially removed by biological transformation of N-NH_4^+, in particular by those of ammonium-oxidizing bacteria (AOB) that consume alkalinity, the remaining fraction being associated with other mechanisms, likely including plant biomass synthesis [46,98]. Organic nitrogen (which may have ammonified during treatment) and nitrites and nitrates were not monitored, so ammoniacal nitrogen removal through complete nitrification cannot be confirmed based solely on alkalinity consumption values. No firm explanation can be given for alkalinity results (release) in unit T, but the presence of limestone residues ($CaCO_3$) in the granular media may have disturbed the results. Unit P_1 differed significantly ($p < 0.05$) from each of the other three units.

Total phosphorus removal did not follow the same trend as ammonia nitrogen removal. Removal rates 50 %, 49 %, 37 %, and 34 % were observed for units T, P_1, P_3, and P_2, respectively, with residual concentrations of 1.58 ± 0.44 mg P-PO_4^{3-}/L, 1.67 ± 0.50 mg P-PO_4^{3-}/L, 2.13 ± 0.48 mg P-PO_4^{3-}/L, and 2.13 ± 0.65 mg P-PO_4^{3-}/L. These performances are lower than those reported by Mateus et al. for TP removal, who achieved efficiencies between 53 % and 80 % [43]. Conventional materials (unit T) performed relatively well in phosphorus removal, with comparable results for unit P_1, but lower performance was observed for units P_3 and P_2. Phosphate precipitation by contact with limestone residues $CaCO_3$ possibly present in the medium of unit T may partially explain its more favorable removal efficiency. No correlation was found between plant density and assimilation of phosphorus (or ammoniacal nitrogen) by plants. The particle size of the retention layer media may have directly or indirectly facilitated (via incorporation into plant biomass) total phosphorus removal. Statistical analyses showed that phosphorus removal by the three other units was significantly different from unit P_2 ($p < 0.05$) based on the F-test. Unit P_3 also differed significantly ($p < 0.05$) from each of the other three units for the same test. However, the F-test value between P_1 and T ($p = 0.8582$) indicates no significant difference in phosphorus removal between these two units.

In supplementary data (Fig. S. 4 and Fig. S. 5), the temporal evolution of the treatment efficiency of the different units is presented. This evolution particularly highlights a notable improvement in the

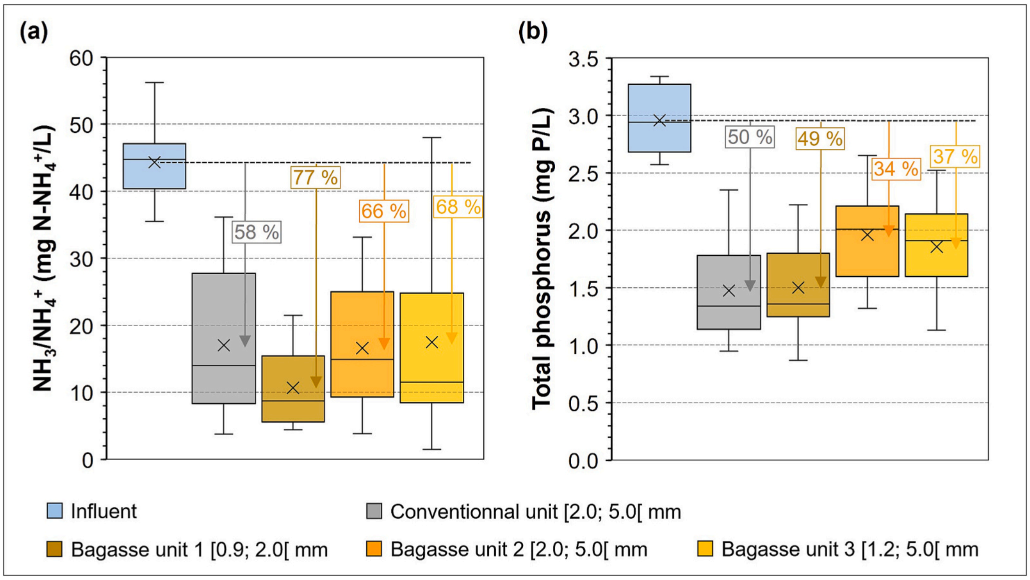

Fig. 8. Removal of a) ammoniacal nitrogen and b) total phosphorus by pilot units.

efficiency of unit T for both parameters, while unit P_1 maintains a remarkable consistency in nitrogen removal. Furthermore, a progressive deterioration in performance is observed for units P_2 and P_3 in the removal of phosphorus and nitrogen, as well as for unit P_1 specifically regarding phosphorus.

Constructed wetland systems are not recognized as effective for nitrogen and phosphorus removal through accumulation in plant biomass. These systems combine various processes to remove phosphorus, including substrate adsorption, precipitation, microbial assimilation, and plant uptake [99]. Although *Canna indica* provides good nutrient removal in CWs [100], the ability of plants to accumulate phosphorus and nitrogen remains low. The sorption capacity and chemical composition of the media (such as limestone content) can play an important role in phosphorus removal [43].

4. Conclusion

This study demonstrated that sugarcane bagasse can be effectively used as a filtering medium in constructed wetlands for domestic wastewater treatment under tropical conditions. The tested units, initially filled with 70 cm of bagasse material, experienced compaction. After three months of operation, the heights of P_1, P_2, and P_3 reached 40 cm, 38 cm, and 40 cm, respectively. Plant density was highest in unit P_1 (259 stems/m^2), followed by unit P_3 (204 stems/m^2), unit P_2 (193 stems/m^2), and finally unit T (146 stems/m^2) after 304 days. This growth was attributed to the less rigid nature of bagasse compared to sand, as well as to the particle size of the bagasse fragments (with finer sizes being favorable). Particle size also influenced TSS removal, with efficiencies of 88 % for unit P_1, 80 % for P_3, and 77 % for unit $P_{2,}$ and 76 % for unit T. Furthermore, organic matter removal, evaluated by reductions in BOD_5 and COD, was 86 % and 93 % for unit P_1, 82 % and 88 % for P_3, 78 % and 87 % for P_2, and finally 79 % and 80 % for unit T. The units achieved moderate ammoniacal nitrogen removal of 73 % for P_1, followed by 63 %, 62 %, and 61 % for units P_2, T, and P_3, respectively. Total phosphorus removal was low across units, with removal efficiencies of 50 %, 49 %, 37 %, and 34 % for units T, P_1, P_3, and P_2, respectively, in descending order.

Unit P_1, with the finest filter media in the retention layer, achieved greater reductions compared to all other contaminants, with phosphorus removal comparable to that of the control unit T (difference of 1 % less than T). Moreover, an analytical approach assessing the variation of removed pollutant loads relative to applied loads demonstrated that unit P_1 maintained an almost linear behavior, with coefficients of determination (R^2) of 0.88, 0.90, and 0.70 for TSS, BOD_5, and COD, respectively, indicating the system's predictive capacity regarding its response to variations in applied loads. If bagasse appears to be a promising material for constructed wetlands, a more detailed study of its consolidation (compaction) is still required to optimize process performance and to better understand the effect of accumulated sludge weight. Reducing the dedicated surface area is feasible for future sizing of such technologies, potentially leading to both technical and economic optimization of the systems.

CRediT authorship contribution statement

Donald Louis Jean: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nesrine Alili:** Writing – original draft, Validation, Software, Investigation, Formal analysis, Data curation. **Yvens Cheremond:** Writing – review & editing, Visualization, Validation. **Frédéric Monette:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jwpe.2025.109175.

Data availability

I have shared the link to my data at the Attach File step.

References

[1] H. Brix, Do macrophytes play a role in constructed treatment wetlands? Water Sci. Technol. 35 (1997) 11–17, https://doi.org/10.1016/S0273-1223(97)00047-4.

[2] F. García-Ávila, Treatment of municipal wastewater by vertical subsurface flow constructed wetland: data collection on removal efficiency using Phragmites Australis and Cyperus Papyrus, Data Brief 30 (2020) 105584, https://doi.org/10.1016/j.dib.2020.105584.
[3] J. Vymazal, The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: a review of a recent development, Water Res. 47 (2013) 4795–4811, https://doi.org/10.1016/j.watres.2013.05.029.
[4] F.Y. Wu, A.K.C. Chung, N.F.Y. Tam, M.H. Wong, Root exudates of wetland plants influenced by nutrient status and types of plant cultivation, Int. J. Phytoremediation 14 (2012) 543–553, https://doi.org/10.1080/15226514.2011.604691.
[5] Y. Man, J. Wang, N.F. Tam, X. Wan, W. Huang, Y. Zheng, J. Tang, R. Tao, Y. Yang, Responses of rhizosphere and bulk substrate microbiome to wastewater-borne sulfonamides in constructed wetlands with different plant species, Sci. Total Environ. 706 (2020) 135955, https://doi.org/10.1016/j.scitotenv.2019.135955.
[6] T. González, J. Puigagut, G. Vidal, Organic matter removal and nitrogen transformation by a constructed wetland-microbial fuel cell system with simultaneous bioelectricity generation, Sci. Total Environ. 753 (2021) 142075, https://doi.org/10.1016/j.scitotenv.2020.142075.
[7] D. Konnerup, T. Koottatep, H. Brix, Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with Canna and Heliconia, Ecol. Eng. 35 (2009) 248–257, https://doi.org/10.1016/j.ecoleng.2008.04.018.
[8] J. Chang, S. Wu, Y. Dai, W. Liang, Z. Wu, Treatment performance of integrated vertical-flow constructed wetland plots for domestic wastewater, Ecol. Eng. 44 (2012) 152–159, https://doi.org/10.1016/j.ecoleng.2012.03.019.
[9] T. Saeed, T. Khan, Constructed wetlands for industrial wastewater treatment: alternative media, input biodegradation ratio and unstable loading, J. Environ. Chem. Eng. 7 (2019) 103042, https://doi.org/10.1016/j.jece.2019.103042.
[10] T. Li, Y. Fan, D. Cun, X. Song, Y. Dai, F. Wang, C. Wu, W. Liang, Treatment performance and microbial response to dibutyl phthalate contaminated wastewater in vertical flow constructed wetland mesocosms, Chemosphere 246 (2020) 125635, https://doi.org/10.1016/j.chemosphere.2019.125635.
[11] M. Borin, M. Politeo, G. De Stefani, Performance of a hybrid constructed wetland treating piggery wastewater, Ecol. Eng. 51 (2013) 229–236, https://doi.org/10.1016/j.ecoleng.2012.12.064.
[12] B. Kim, M. Gautier, S. Prost-Boucle, P. Molle, P. Michel, R. Gourdon, Performance evaluation of partially saturated vertical-flow constructed wetland with trickling filter and chemical precipitation for domestic and winery wastewaters treatment, Ecol. Eng. 71 (2014) 41–47, https://doi.org/10.1016/j.ecoleng.2014.07.045.
[13] M. Varma, A.K. Gupta, P.S. Ghosal, A. Majumder, A review on performance of constructed wetlands in tropical and cold climate: insights of mechanism, role of influencing factors, and system modification in low temperature, Sci. Total Environ. 755 (2021) 142540, https://doi.org/10.1016/j.scitotenv.2020.142540.
[14] J. Vymazal, Constructed wetlands for wastewater treatment: a review, Proceedings of Taal 2008 (2007) 965–980.
[15] M. Simon-Várhelyi, V.M. Cristea, A.V. Luca, Reducing energy costs of the wastewater treatment plant by improved scheduling of the periodic influent load, J. Environ. Manage. 262 (2020) 110294, https://doi.org/10.1016/j.jenvman.2020.110294.
[16] S.A.A.A.N. Almuktar, S.N. Abed, M. Scholz, Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review, Environ. Sci. Pollut. Res. 25 (2018) 23595–23623, https://doi.org/10.1007/s11356-018-2629-3.
[17] W. Li, Y. Li, J. Zhang, F. Wang, B. Wang, Overview of rural domestic sewage treatment technology, in: W. Li, Y. Li, J. Zhang, F. Wang, B. Wang (Eds.), Integrated Treatment Technology of Rural Domestic Sewage: Ten Cases of Integrated Sewage Treatment in Rural Area of China, Springer Nature, Singapore, 2024, pp. 11–49, https://doi.org/10.1007/978-981-99-5906-8_2.
[18] J. Vymazal, Constructed wetlands for wastewater treatment: five decades of experience, Environ. Sci. Technol. 45 (2011) 61–69, https://doi.org/10.1021/es101403q.
[19] C.-B. Hsu, H.-L. Hsieh, L. Yang, S.-H. Wu, J.-S. Chang, S.-C. Hsiao, H.-C. Su, C.-H. Yeh, Y.-S. Ho, H.-J. Lin, Biodiversity of constructed wetlands for wastewater treatment, Ecol. Eng. 37 (2011) 1533–1545, https://doi.org/10.1016/j.ecoleng.2011.06.002.
[20] P. Molle, French vertical flow constructed wetlands: a need of a better understanding of the role of the deposit layer, Water Sci. Technol. 69 (2014) 106–112, https://doi.org/10.2166/wst.2013.561.
[21] C.M. Trein, C. Banc, K. Maciejewski, A. de Moraes Motta, R. Gourdon, P. Molle, M. Gautier, M. von Sperling, French vertical flow treatment wetlands in a subtropical climate: characterization of the organic deposit layer and comparison with systems in France, Sci. Total Environ. 742 (2020) 140608, https://doi.org/10.1016/j.scitotenv.2020.140608.
[22] A. Yalcuk, A. Ugurlu, Comparison of horizontal and vertical constructed wetland systems for landfill leachate treatment, Bioresour. Technol. 100 (2009) 2521–2526, https://doi.org/10.1016/j.biortech.2008.11.029.
[23] L. Sandoval, J.L. Marín-Muñiz, S.A. Zamora-Castro, F. Sandoval-Salas, A. Alvarado-Lassman, Evaluation of wastewater treatment by microcosms of vertical subsurface wetlands in partially saturated conditions planted with ornamental plants and filled with mineral and plastic substrates, Int. J. Environ. Res. Public Health 16 (2019) 167, https://doi.org/10.3390/ijerph16020167.
[24] C.K. Benny, S. Chakraborty, Mechanistic investigation of azo dye removal from carbon-deficient dyeing wastewater using horizontal-vertical constructed wetlands, Chemosphere 364 (2024) 143148, https://doi.org/10.1016/j.chemosphere.2024.143148.
[25] P. Molle, R. Lombard Latune, C. Riegel, G. Lacombe, D. Esser, L. Mangeot, French vertical-flow constructed wetland design: adaptations for tropical climates, Water Sci. Technol. 71 (2015) 1516–1523, https://doi.org/10.2166/wst.2015.133.
[26] C.M. Trein, J.A.G. Zumalacarregui, M.A. de A. Moraes, M. von Sperling, Reduction of area and influence of the deposit layer in the first stage of a full-scale French system of vertical flow constructed wetlands in a tropical area, Water Sci. Technol. 80 (2019) 347–356, https://doi.org/10.2166/wst.2019.278.
[27] A. Yadav, F. Chazarenc, S. Mutnuri, Development of the "French system" vertical flow constructed wetland to treat raw domestic wastewater in India, Ecol. Eng. 113 (2018) 88–93, https://doi.org/10.1016/j.ecoleng.2018.01.001.
[28] R. Lombard Latune, M. Pascal, Les filtres plantés de végétaux pour le traitement des eaux usées domestiques en milieu tropical, Agence Française pour la Biodiversité, 2017. https://www.pseau.org/outils/ouvrages/irstea_les_filtres_plantes_de_vegetaux_pour_le_traitement_des_eaux_usees_domestiques_en_milieu_tropical_guide_de_dimensionnement_de_la_filiere_tropicalisee_2017.pdf.
[29] R. Lombard-Latune, L. Pelus, N. Fina, F. L'Etang, B. Le Guennec, P. Molle, Resilience and reliability of compact vertical-flow treatment wetlands designed for tropical climates, Sci. Total Environ. 642 (2018) 208–215, https://doi.org/10.1016/j.scitotenv.2018.06.036.
[30] P. Molle, A. Liénard, C. Boutin, G. Merlin, A. Iwema, How to treat raw sewage with constructed wetlands: an overview of the French systems, Water Sci. Technol. 51 (2005) 11–21, https://doi.org/10.2166/wst.2005.0277.
[31] J. Chen, G.-G. Ying, X.-D. Wei, Y.-S. Liu, S.-S. Liu, L.-X. Hu, L.-Y. He, Z.-F. Chen, F.-R. Chen, Y.-Q. Yang, Removal of antibiotics and antibiotic resistance genes from domestic sewage by constructed wetlands: effect of flow configuration and plant species, Sci. Total Environ. 571 (2016) 974–982, https://doi.org/10.1016/j.scitotenv.2016.07.085.
[32] R. Pinninti, V. Kasi, L.K.S.V.P. Sallangi, S.R. Landa, M. Rathinasamy, C. Sangamreddi, P.R. Dandu Radha, Performance of Canna indica based microscale vertical flow constructed wetland under tropical conditions for domestic wastewater treatment, Int. J. Phytoremediation 24 (2022) 684–694, https://doi.org/10.1080/15226514.2021.1962800.
[33] F. García-Ávila, A. Avilés-Añazco, R. Cabello-Torres, A. Guanuchi-Quito, M. Cadme-Galabay, H. Gutiérrez-Ortega, R. Alvarez-Ochoa, C. Zhindón-Arévalo, Application of ornamental plants in constructed wetlands for wastewater treatment: a scientometric analysis, Case Studies in Chemical and Environmental Engineering 7 (2023) 100307, https://doi.org/10.1016/j.cscee.2023.100307.
[34] A. Stefanatou, S. Schiza, I. Petousi, A. Rizzo, F. Masi, A.S. Stasinakis, N. Fyllas, M. S. Fountoulakis, Use of climbing and ornamental plants in vertical flow constructed wetlands treating greywater, J. Water Process Eng. 53 (2023) 103832, https://doi.org/10.1016/j.jwpe.2023.103832.
[35] E. Bohórquez, D. Paredes, C.A. Arias, Vertical flow-constructed wetlands for domestic wastewater treatment under tropical conditions: effect of different design and operational parameters, Environ. Technol. 38 (2017) 199–208, https://doi.org/10.1080/09593330.2016.1230650.
[36] J. Zhang, Z. Ge, Z. Ma, D. Huang, J. Zhang, Seasonal changes driving shifts of aquatic rhizosphere microbial community structure and the functional properties, J. Environ. Manage. 322 (2022) 116124, https://doi.org/10.1016/j.jenvman.2022.116124.
[37] J. Vymazal, An updated overview of plant species used in constructed wetlands, in: Emerging Developments in Constructed Wetlands, Elsevier, 2025, pp. 3–60, https://doi.org/10.1016/B978-0-443-14078-5.00001-5.
[38] F.L. Dornelas, M.B. Machado, M. von Sperling, Performance evaluation of planted and unplanted subsurface-flow constructed wetlands for the post-treatment of UASB reactor effluents, Water Sci. Technol. 60 (2009) 3025–3033, https://doi.org/10.2166/wst.2009.743.
[39] S.E. Fanssi, N. Ouazzani, L. Mandi, Efficacité de l'épuration des eaux usées domestiques par filtres plantés et essais de réutilisation des eaux usées épurées en milieu rural marocain, 2019, p. 10.
[40] E. Gacia, S. Bernal, M. Nikolakopoulou, E. Carreras, L. Morgado, M. Ribot, M. Isnard, A. Sorolla, F. Sabater, E. Martí, The role of helophyte species on nitrogen and phosphorus retention from wastewater treatment plant effluents, J. Environ. Manage. 252 (2019) 109585, https://doi.org/10.1016/j.jenvman.2019.109585.
[41] F.M. Zahui, J.-M.P. Ouattara, M. Kamagaté, L. Coulibaly, A.I. Stefanakis, Effect of plant species on the performance and bacteria density profile in vertical flow constructed wetlands for domestic wastewater treatment in a tropical climate, Water 13 (2021) 3485, https://doi.org/10.3390/w13243485.
[42] E.M. Sonko, D. Dieng, Ma&#239, M. Lo, C. Diop, Influence of the nature of the incoming sludge on the performance of a vertical flow reed beds in Dakar-Senegal, Journal of Water Resource and Protection 16 (2024) 429–449, https://doi.org/10.4236/jwarp.2024.166024.
[43] D.M.R. Mateus, M.M.N. Vaz, H.J.O. Pinho, Fragmented limestone wastes as a constructed wetland substrate for phosphorus removal, Ecol. Eng. 41 (2012) 65–69, https://doi.org/10.1016/j.ecoleng.2012.01.014.
[44] L. Coulibaly, I. Savané, G. Gourène, Domestic Wastewater Treatment With a Vertical Completely Drained Pilot Scale Constructed Wetland Planted With Corchorus oliterius, 2008.
[45] P.N. Karungamye, Potential of Canna indica in constructed wetlands for wastewater treatment: a review, Conservation 2 (2022) 499–513, https://doi.org/10.3390/conservation2030034.
[46] L. Li, Y. Yang, N.F.Y. Tam, L. Yang, X.-Q. Mei, F.-J. Yang, Growth characteristics of six wetland plants and their influences on domestic wastewater treatment efficiency, Ecol. Eng. 60 (2013) 382–392, https://doi.org/10.1016/j.ecoleng.2013.09.044.

[47] T. Kamilya, A. Majumder, M.K. Yadav, S. Ayoob, S. Tripathy, A.K. Gupta, Nutrient pollution and its remediation using constructed wetlands: insights into removal and recovery mechanisms, modifications and sustainable aspects, J. Environ. Chem. Eng. 10 (2022) 107444, https://doi.org/10.1016/j.jece.2022.107444.
[48] Z. Ji, W. Tang, Y. Pei, Constructed wetland substrates: a review on development, function mechanisms, and application in contaminants removal, Chemosphere 286 (2022) 131564, https://doi.org/10.1016/j.chemosphere.2021.131564.
[49] Y. Yang, Y. Zhao, R. Liu, D. Morgan, Global development of various emerged substrates utilized in constructed wetlands, Bioresour. Technol. 261 (2018) 441–452, https://doi.org/10.1016/j.biortech.2018.03.085.
[50] A.V. Dordio, A.J.P. Carvalho, Organic xenobiotics removal in constructed wetlands, with emphasis on the importance of the support matrix, J. Hazard. Mater. 252–253 (2013) 272–292, https://doi.org/10.1016/j.jhazmat.2013.03.008.
[51] S. Altenor, Etude physico-chimiques d'algues et de charbons actifs issus de déchets lignocellulosiques de la caraïbe et faisabilité de leur application pour le traitement des eaux, These de doctorat, Antilles-Guyane, 2008, https://www.theses.fr/2008AGUY0235 (accessed August 11, 2022).
[52] O. Joseph, Etude du potentiel d'utilisation de résidus agricoles haïtiens pour le traitement par biosorption d'effluents pollués, École doctorale Chimie de Lyon, 2009.
[53] S. Kataki, S. Chatterjee, M.G. Vairale, S.K. Dwivedi, D.K. Gupta, Constructed wetland, an eco-technology for wastewater treatment: a review on types of wastewater treated and components of the technology (macrophyte, biolfilm and substrate), J. Environ. Manage. 283 (2021) 111986, https://doi.org/10.1016/j.jenvman.2021.111986.
[54] A. Moubarik, N. Grimi, Valorization of olive stone and sugar cane bagasse by-products as biosorbents for the removal of cadmium from aqueous solution, Food Res. Int. 73 (2015) 169–175, https://doi.org/10.1016/j.foodres.2014.07.050.
[55] P. de la C.M. Nodal, I.R. Rico, G.E. Pérez, J.L. Mas, Caracterización y evaluación del bagazo de caña de azúcar como biosorbente de hidrocarburos, Afinidad. Journal of Chemical Engineering Theoretical and Applied Chemistry 71 (2014). https://raco.cat/index.php/afinidad/article/view/276504 (accessed August 21, 2025).
[56] T. Saeed, G. Sun, A lab-scale study of constructed wetlands with sugarcane bagasse and sand media for the treatment of textile wastewater, Bioresour. Technol. 128 (2013) 438–447, https://doi.org/10.1016/j.biortech.2012.10.052.
[57] K. Soundaranayaki, R. Gandhimathi, Performance of various media in vertical flow constructed wetland for the treatment of domestic wastewater, Desalin. Water Treat. 146 (2019) 57–67, https://doi.org/10.5004/dwt.2019.23566.
[58] A.O. Abo El Naga, M. El Saied, S.A. Shaban, F.Y. El Kady, Fast removal of diclofenac sodium from aqueous solution using sugar cane bagasse-derived activated carbon, J. Mol. Liq. 285 (2019) 9–19, https://doi.org/10.1016/j.molliq.2019.04.062.
[59] H.V. Minh, N.V. Hung, Economic aspects of sanitation in developing countries, Environmental Health Insights (2011), https://doi.org/10.4137/EHI.S8199.
[60] K. Seetharam, Challenges and Opportunities for Sanitation in Developing Countries, 2015, p. 7.
[61] T. Bayu, H. Kim, T. Oki, Water governance contribution to water and sanitation access equality in developing countries, Water Resour. Res. 56 (2020) e2019WR025330, https://doi.org/10.1029/2019WR025330.
[62] G. Jean, Conditions pour la mise en place durable d'une filière d'assainissement par toilettes sèches à litière bio-maîtrisée dans les zones rurales des pays en développement. Application au contexte haïtien, Ph.D., Université Quisqueya, 2018, https://doi.org/10.54226/uniq.edse.33326.
[63] D. Jean-Baptiste, F. Monette, Quantitative microbial risk assessment (QMRA) of the work of manual pit emptiers, commonly known as bayakous, Water Sci. Technol. 89 (2024) 3122–3132, https://doi.org/10.2166/wst.2024.164.
[64] DINEPA, Protocole pour l'évacuation des excretas par les entreprises de vidange/nettoyage et les ONGs, 2010.
[65] D. Mazars, P. Earwaker, Improving Desludging in Haiti by Building the Capacity of Local Bayakou (Informal Manual Desludgers). https://repository.lboro.ac.uk/articles/conference_contribution/Improving_desludging_in_Haiti_by_building_the_capacity_of_local_Bayakou_informal_manual_desludgers_/9587831/1, 2013.
[66] J. Rodné-Jeanty, A.V.D. Pierre, M. Desse, Haïti et ses aires marines protégées: un binôme nouveau pour quel type de gouvernance? Études caribéennes (2022) https://doi.org/10.4000/etudescaribeennes.24840.
[67] H. MSPP, National plan for the elimination of cholera in Haiti 2013-2022, 2013, p. 114. https://stacks.cdc.gov/view/cdc/40506 (accessed August 22, 2025).
[68] L.-M. Pierre, Eaux et territoires urbanismes en Haïti face aux changements climatiques: Analyse géographique du cas de Port-au-Prince, Journal of Haitian Studies 29 (2023) 42–68. https://www.jstor.org/stable/27301702 (accessed August 22, 2025).
[69] B.H. de N. BHN, Rejet d'eaux usées - valeurs limites pour la surveillance et le contrôle, 2022.
[70] Y. Pérez, E. Vargas, D. García-Cortés, W. Hernández, H. Checo, U. Jáuregui-Haza, Efficiency and effectiveness of systems for the treatment of domestic wastewater based on subsurface flow constructed wetlands in Jarabacoa, Dominican Republic, Water Science and Engineering 17 (2024) 118–128, https://doi.org/10.1016/j.wse.2023.08.004.
[71] L.M. Ofiera, T. Wintgens, C. Kazner, Comparative analysis of conventional and modified constructed wetlands for the removal of trace organic compounds from municipal wastewater effluent, Sci. Total Environ. 987 (2025) 179796, https://doi.org/10.1016/j.scitotenv.2025.179796.
[72] Cutting Mill SM 300 - Introduction #RETSCH #cuttingmill #laboratoryinstruments. https://www.youtube.com/watch?v=29aOrWlTHjE, 2016 (accessed February 5, 2025).
[73] G. Dotro, G. Langergraber, P. Molle, J. Nivala, J. Puigagut, O. Stein, M. von Sperling, Treatment Wetlands, 2017.
[74] SATESE du Morbihan, Filtres plantés de roseaux. https://morbihan.fr/fileadmin/Les_services/Environnement/L_eau_dans_le_Morbihan/L_assainissement/Morbihan_SATESE_filtres-roseaux.pdf, 2009.
[75] A. Morvannou, N. Forquet, M. Vanclooster, P. Molle, Characterizing hydraulic properties of filter material of a vertical flow constructed wetland, Ecol. Eng. 60 (2013) 325–335, https://doi.org/10.1016/j.ecoleng.2013.06.042.
[76] L. Bassani, C. Pelissari, A.R. da Silva, P.H. Sezerino, Feeding mode influence on treatment performance of unsaturated and partially saturated vertical flow constructed wetland, Sci. Total Environ. 754 (2021) 142400, https://doi.org/10.1016/j.scitotenv.2020.142400.
[77] C. Yan, H. Zhang, B. Li, D. Wang, Y. Zhao, Z. Zheng, Effects of influent C/N ratios on CO2 and CH4 emissions from vertical subsurface flow constructed wetlands treating synthetic municipal wastewater, J. Hazard. Mater. 203–204 (2012) 188–194, https://doi.org/10.1016/j.jhazmat.2011.12.002.
[78] A. de Oliveira Souza, J.K.B. Bernardelli, L. de Carvalho Silva, F. Perretto, A. Nagalli, V. Mymrin, F.H. Passig, K.Q. de Carvalho, Plasterboard sheet applied in vertical-flow constructed wetlands: nutrients removal, microbial diversity, and mechanisms, Journal of Water Process Engineering 53 (2023) 103811, https://doi.org/10.1016/j.jwpe.2023.103811.
[79] P. Karungamye, A. Rugaika, K. Mtei, R. Machunda, The removal of ciprofloxacin from synthetic wastewater in constructed wetland, HydroResearch 6 (2023) 138–146, https://doi.org/10.1016/j.hydres.2023.04.001.
[80] M. Huang, L. Zhao, Z. Wang, X. Sun, Q. Shang, Y. Li, M. Li, H. Geng, S. Hu, Y. Yang, Effect of plant species on wastewater treatment performance of a subsurface vertical-flow constructed wetland with step-feeding at low temperature, J. Environ. Manage. 370 (2024) 122546, https://doi.org/10.1016/j.jenvman.2024.122546.
[81] J.N. Todedji, J.S. Okambawa, W.K. Chouti, C.C. Degbey, A. Dedjiho, D. Mama, Evaluation de l'efficacité du traitement chimique des effluents hospitaliers universitaires du département du littoral en République du Bénin, Journal de La Société Ouest-Africaine de Chimie (2021) 30–40.
[82] APHA, WEF, AWWA, L.L. Bridgewater, R.B. Baird, A.D. Eaton, E.W. Rice, Standard Methods for the Examination of Water and Wastewater, 24th edition, American Public Health Association, Washington, DC, 2023.
[83] G. Monteagudo-Hernández, D.A. Hernández-Castelán, T. Zamora-Lobato, M. Sandoval-Herazo, M.G. Hernández-Orduña, L.C. Sandoval Herazo, Evaluation of the pollutant removal efficiency of swine wastewater through two configurations of hybrid wetlands with tropical ornamental plants, Results in Engineering 24 (2024) 102864, https://doi.org/10.1016/j.rineng.2024.102864.
[84] M. Nakamura, K. Noguchi, Tolerant mechanisms to O2 deficiency under submergence conditions in plants, J. Plant Res. 133 (2020) 343–371, https://doi.org/10.1007/s10265-020-01176-1.
[85] T. Suriyakaew, A. Jampeetong, Effects of dissolved O2 and Fe availability on growth, morphology, aerenchyma formation and radial oxygen loss of Canna indica L. and *Heliconia psittacorum* L.f, CMUJNS 20 (2021) 1–12, https://doi.org/10.12982/CMUJNS.2021.086.
[86] J.T.A. Verhoeven, A.F.M. Meuleman, Wetlands for wastewater treatment: opportunities and limitations, Ecol. Eng. 12 (1999) 5–12, https://doi.org/10.1016/S0925-8574(98)00050-0.
[87] R.H. Kadlec, S. Wallace, Treatment Wetlands, CRC Press, 2008.
[88] W. Tao, J. Wang, Effects of vegetation, limestone and aeration on nitritation, anammox and denitrification in wetland treatment systems, Ecol. Eng. 35 (2009) 836–842, https://doi.org/10.1016/j.ecoleng.2008.12.003.
[89] D. Yao, X. Hu, X. Shen, H. Xie, Z. Hu, J. Zhang, S. Liang, Can calcium-based constructed wetlands improve fluoride removal performance? Chem. Eng. J. 450 (2022) 138314 https://doi.org/10.1016/j.cej.2022.138314.
[90] Z. Xia, G. Liu, Z. She, M. Gao, Y. Zhao, L. Guo, C. Jin, Performance and bacterial communities in unsaturated and saturated zones of a vertical-flow constructed wetland with continuous-feed, Bioresour. Technol. 315 (2020) 123859, https://doi.org/10.1016/j.biortech.2020.123859.
[91] K.K. Singh, R.C. Vaishya, Municipal wastewater treatment uses vertical flow followed by horizontal flow in a two-stage hybrid-constructed wetland planted with Calibanus hookeri and Canna indica (Cannaceae), Water Air Soil Pollut. 233 (2022) 510, https://doi.org/10.1007/s11270-022-05984-0.
[92] D. Wang, Y. Bai, J. Qu, The *Phragmites* root-inhabiting microbiome: a critical review on its composition and environmental application, Engineering 9 (2022) 42–50, https://doi.org/10.1016/j.eng.2021.05.016.
[93] C.O.T. Compaoré, Y. Maiga, A.S. Ouili, M. Nikiema, A.S. Ouattara, Purification potential of local media in the pre-treatment of greywater using vertical biofilters under Sahelian conditions, Journal of Agricultural Chemistry and Environment 11 (2022) 117–131, https://doi.org/10.4236/jacen.2022.112008.
[94] S. Kouki, F. M'hiri, N. Saidi, S. Belaïd, A. Hassen, Performances of a constructed wetland treating domestic wastewaters during a macrophytes life cycle, Desalination 246 (2009) 452–467, https://doi.org/10.1016/j.desal.2008.03.067.
[95] M. Hijosa-Valsero, R. Sidrach-Cardona, J. Martín-Villacorta, E. Bécares, Optimization of performance assessment and design characteristics in constructed wetlands for the removal of organic matter, Chemosphere 81 (2010) 651–657, https://doi.org/10.1016/j.chemosphere.2010.08.010.
[96] S. Singh, A. Majumder, P. Mandal, M.K. Yadav, Analgesics in wastewater matrix: a comprehensive review on occurrence, toxicity, and sustainability assessment of biological, tertiary, and hybrid treatment processes, Environmental

Nanotechnology, Monitoring & Management 23 (2025) 101039, https://doi.org/10.1016/j.enmm.2024.101039.

[97] G. Tchobanoglous, H.D. Stensel, R. Tsuchihashi, F. Burton, Wastewater Engineering: Treatment and Resource Recovery, Fifth, McGraw-Hill Education, New York, New York, 2014. https://www.mheducation.com/highered/product/Wastewater-Engineering-Treatment-and-Resource-Recovery-Metcalf-and-Eddy.html (accessed July 8, 2025).

[98] A. Ennabili, M. Radoux, Nitrogen and phosphorus uptake and biomass production in four riparian plants grown in subsurface flow constructed wetlands for urban wastewater treatment, J. Environ. Manage. 280 (2021) 111806, https://doi.org/10.1016/j.jenvman.2020.111806.

[99] S. Chu, F. Zhao, Y. Liu, J. Xiao, X. Ma, Z. Yan, Phosphorus activation from phosphorus-saturated substrates by constructed wetlands plants: performance and mechanism, J. Water Process Eng. 71 (2025) 107219, https://doi.org/10.1016/j.jwpe.2025.107219.

[100] L. Cui, Y. Ouyang, Q. Lou, F. Yang, Y. Chen, W. Zhu, S. Luo, Removal of nutrients from wastewater with *Canna indica* L. under different vertical-flow constructed wetland conditions, Ecol. Eng. 36 (2010) 1083–1088, https://doi.org/10.1016/j.ecoleng.2010.04.026.