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Applicability of Constructed Wetlands for Water Quality Improvement in a Tea Estate Catchment: The Pussellawa Case Study

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Abstract: Water in agricultural catchments is prone to pollution from agricultural runoff containing nutrients and pesticides, and contamination from the human population working and residing therein. This study examined the quality of water in a drainage stream which runs through a congested network of 'line houses' (low-income housing, typically found arranged in straight 'lines' on estates) in the tea estate catchment area of Pussellawa in central Sri Lanka. The study evaluated the applicability of vertical subsurface flow (VSSF) and horizontal subsurface flow (HSSF) constructed wetlands for water polishing, as the residents use the stream water for various domestic purposes with no treatment other than possibly boiling. Water flow in the stream can vary significantly over time, and so investigations were conducted at various flow conditions to identify the hydraulic loading rate (HLR) bandwidth for wetland polishing applications. Two wetland models of 8 m $\times$ 1 m $\times$ 0.6 m (length $\times$ width $\times$ depth) were constructed and arranged as VSSF and HSSF units. Stream water was diverted to these units at HLRs of 3.3, 4, 5, 10, 20, and 40 cm/day. Results showed that both VSSF and HSSF wetland units were capable of substantially reducing five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), fecal coliform (FC), total coliform (TC), ammonia nitrogen (NH_4^+-N), and nitrate nitrogen (NO_3^--N) up to 20 cm/day HLR, with removal efficiencies of more than 64%, 60%, 90%, 93%, 70%, and 59% for BOD_5, TSS, FC, TC, NH_4^+-N, and NO_3^--N, respectively, in the VSSF wetland unit; and more than 66%, 62%, 91%, 90%, 53%, and 77% for BOD_5, TSS, FC, TC, NH_4^+-N, and NO_3^--N, respectively, in the HSSF wetland unit.

Keywords: agriculture catchment; constructed wetlands; contaminated drainage stream; hydraulic loading rate; pollutant removal

1. Introduction

The pollution of water resources is a growing problem around the globe, due to inadequately treated wastewater discharges from ever-increasing populations, industrial and economic development, and agricultural interventions, resulting in the decline of fresh water resources suitable for human consumption [1]. This may affect human health as well as lead to various socioeconomic conflicts among groups of people. It has been estimated that about 80% of diseases and over one-third of deaths in the developing world are caused by the ingestion of contaminated water [2]. According to the World Health Organization (WHO), diarrheal diseases are the leading cause of illness in the developing world, and the second-leading cause of death among children under five years of age [3]. Thus, effective control of the contamination of natural water bodies is necessary [4]. However, wastewater treatment is far from satisfactory in developing countries [5,6], especially in semiurban and rural areas, due to constrained economic conditions and the lack of information. Therefore, some contamination of waterbodies can be expected, and hence development of appropriate and affordable water and wastewater treatment technologies is necessary in these contexts [7].

In Sri Lanka, many drainage streams in agriculture-based catchments, e.g., tea estates, are vulnerable to pollution, resulting in health issues among users. Agriculture-based communities are typically clustered around streams, and often, because of their economic situation, do not pay adequate attention to sanitation and hygiene practices. In addition to affordability constraints, there are also social issues, such as low education levels and traditional habits, in waste disposal. For example, such residents do locate their cesspits at stream banks, and so risk polluting the water sources. The problems can be further compounded by space constraints, water scarcity, a shallow water table, and rocky ground conditions [8]. Rajapaksha [9] investigated fecal pollution in vulnerable small streams in the Pussella-Oya catchment following the severe hepatitis A outbreak in May 2007 at the downstream location of Gampola, Sri Lanka [10], and this data, as presented in Table S1 in Supplementary Materials, would indicate seemingly good quality water in terms of some water quality parameters, but may not be so in terms of others, such as those in the microbiological category.

While there are many techniques available to treat and improve the quality of water [11], the challenge in this paper's context is to identify a simple and economical method which requires little attention from the users, and yet be able to address water quality upgrading needs, e.g., microbiological needs, sufficiently. The creation of constructed wetlands (CWs) for wastewater treatment was thought to be a possible candidate and alternative to conventional systems [12,13]. CWs utilize wetland plants, soils, and associated microbial assemblages to remove pollutants [14–16]. They have been used in many parts of the world for wastewater treatment [5,17,18], but there have been few reports on their application in water polishing. Of concern would be the treatment efficiencies of CWs, depending on various factors such as influent pollutant characteristics, hydraulic loading rate (HLR), climatic variation, and the required effluent characteristics [19].

In general, CWs require larger land areas compared to conventional methods [20]. This is because CWs require longer hydraulic retention time (HRT) or lower HLR [21] for substantial reduction of pollutants. Metcalf and Eddy [22] reported that pollutant removal in CWs is more efficient at 4–15 days HRT. However, since the stream flow and pollutant loads in these agriculture-based drainage streams do fluctuate over time and with the latter typically low, there is a need to know how CWs would perform when faced with high hydraulic loading rates (i.e., possibly shorter HRTs) but otherwise relatively low loads in relation to specific pollutant measures. The objectives of this study included identifying possible causes of human excreta pollution in a selected agriculture-based drainage stream in a congested tea estate human settlement, and to investigate the treatment performance of vertical subsurface flow (VSSF) and horizontal subsurface flow (HSSF) CWs under various HLRs to identify the applicable HLR bandwidth of CWs used to polish stream water.

2. Materials and Methods

2.1. Selection of the Study Site

Following the hepatitis A outbreak in Gampola, Sri Lanka in 2007 [10], and evidence of fecal pollution in the streams in the catchment as reported by Rajapaksha [9], a stream running through a cluster of line houses at a tea estate in Pussellawa (7°06′40.5″ E, 80°38′14.5″ N) was selected for this study. To identify the level of pollution, water quality examinations, including for BOD_5, FC, TC, NH_4^+-N, and NO_3^--N, were carried out over a one-month period at one-week intervals. A map of the study area is shown in Figure 1, and photographs of the environmental condition at a number of locations in the area are shown in Figure 2.

Figure 1. Map of the study area showing congested housing plots. (https://www.google.lk/maps/place/Tea+Estate,+Pussellawa).

Figure 2. Photographs of the environmental conditions at locations in the study area. (**a**) A congested row of line houses. (**b**) A polluted drain which flows to the stream. (**c**) A pit latrine close to the drain. (**d**) Wastewater disposal to the drain through a pipe line. (**e**) Septic tank effluent directed to the stream. (**f**) A cesspit close to a drainage stream.

2.2. Identification of Sources of Stream Pollution

In order to identify the possible causes of stream pollution in the selected community, a questionnaire survey was conducted on the 74 households located along the stream. The data collected included information such as family size, age groups, sources of drinking water, available sanitation facilities, the distance between the sanitation facility and the stream, personal hygiene habits, gray water disposal methods, and waterborne disease history. The questionnaire is presented in Supplementary Materials. Data obtained from the survey was then analyzed to determine the routes of stream pollution.

2.3. Use of Constructed Wetlands for Stream Water Quality Improvement

Two units of subsurface flow CWs of size 8.0 m × 1.0 m × 0.6 m (length × width × height) were constructed using brick masonry and cement mortar, close to the selected stream as illustrated in Figure 3a. One was prepared as a HSSF wetland unit, while the other was prepared as a VSSF wetland unit, according to Figure 3b,c, respectively, using 10–20 mm gravel as the wetland media. To facilitate the easy distribution and collection of water in each unit, the inlet and outlet zones of the HSSF wetland unit and the drain field of the VSSF wetland unit were filled with 30–50 mm-sized gravel. In addition, each wetland unit had a surface layer of 10 cm-deep soil (<5 mm particle size) to support the vegetation. The two wetland units were planted with approximately 30 cm-high *Typha angustifolia* (Narrow-leaved Cattail) rhizomes, with each containing at least two nodes. The plantings were made 30 cm apart to achieve a plant density of 4 plants/m^2. The wetland units were then kept wet for four weeks for the plants to grow. Subsequently, a part of the stream water was diverted to a constant head tank, and applied to the wetland units at predetermined flow rates. This arrangement is shown in Figure 4.

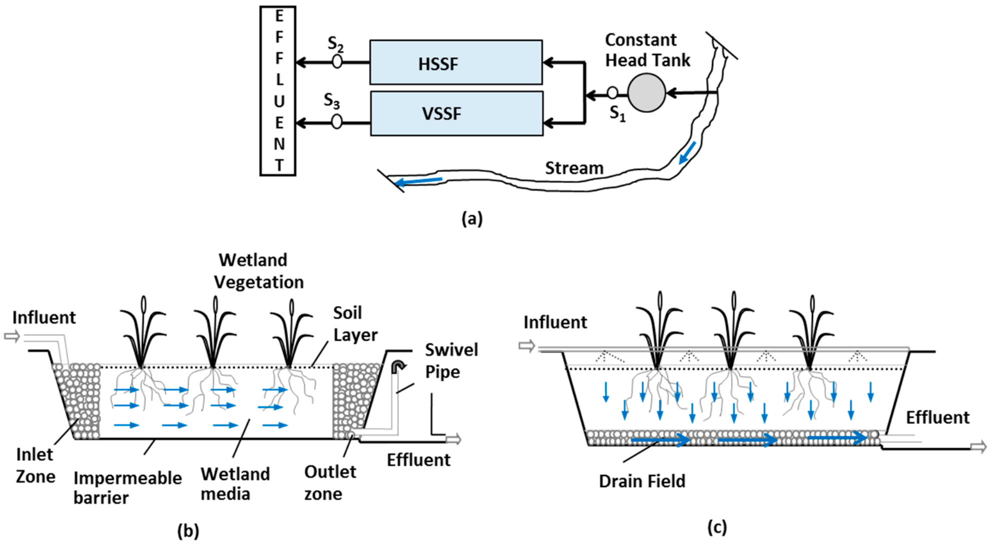

Figure 3. (**a**) Wetland arrangement: S_1, S_2 and S_3 are sampling points. (**b**) Schematic diagram of a horizontal subsurface flow (HSSF) wetland system. (**c**) Schematic diagram of a vertical subsurface flow (VSSF) wetland system.

(**a**) (**b**)

Figure 4. Arrangement of wetland units in the field: (**a**) just after planting; and (**b**) mature wetland units.

2.4. Water Application

The performance of the VSSF and HSSF wetland units was investigated by diverting stream water at various HLRs in two phases as described below, according to the sequence shown in Figure 5.

(i) Fed with stream water at three HLRs of 3.3, 4, and 5 cm/day
(ii) Fed with stream water spiked with a nitrogen source at HLRs of 10, 20, and 40 cm/day. This was to allow the investigation of situations where nitrogenous pollutants can be higher, as in during periods when the fertilization of tea plants with animal waste occurs.

The flow rate corresponding to each HLR was calculated using the wetland area, and flow was applied to each wetland unit using a flow control valve. The applied flow rates were monitored regularly to minimize fluctuations.

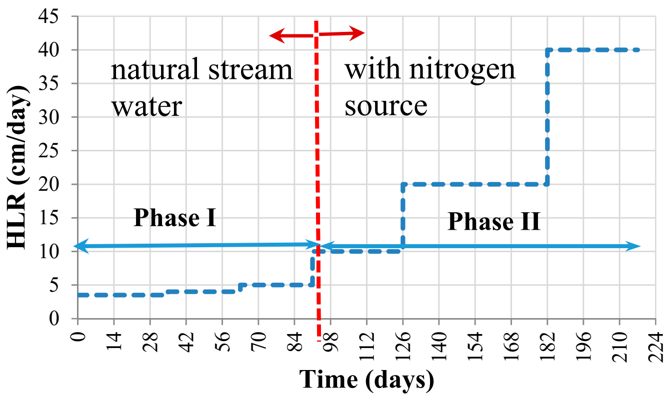

Figure 5. Sequence of water application in VSSF and HSSF wetland units. HLR: hydraulic loading rate.

2.5. Nitrogen Source

In order to evaluate the nitrogen removal capability of the VSSF and HSSF wetland units, cow dung was mixed with the stream water and stored in two 20 L cans. The mixture was then added to the wetland units' feed at a predetermined rate, using a pipe and valve arrangement as shown in Figure 6.

Figure 6. Arrangement for nitrogen (N) supplementation to the wetland units, H_{in}: Influent to the HSSF unit and V_{in}: Influent to the VSSF unit.

2.6. Sampling and Water Quality Analysis

In the first phase, influent and effluent samples were collected from the sampling points S_1, S_2, and S_3 (Figure 3). In the second phase, influent water samples were collected from H_{in} (Influent to the HSSF unit) and V_{in} (Influent to the VSSF unit) separately (Figure 6), while effluent samples were collected from S_2 and S_3. Samplings were conducted following a week of acclimatization after each flow adjustment. At least four samples were collected at each flow investigated at one-week intervals before switching into the next HLR level. Samples were collected in 500 mL cleaned plastic bottles, and sent to the Environmental Engineering laboratory, Faculty of Engineering, University of Peradeniya to measure the water quality parameters, such as five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), fecal coliform (FC), total coliform (TC), ammonia nitrogen (NH_4^+-N), and nitrate nitrogen (NO_3^--N), in accordance with APHA standard methods [23]. The removal efficiency (RE) of each parameter on each sampling occasion was calculated using Equation (1). The respective mass loading rates (MLR) and mass removal rates (MRR) in g-P/m^2·day (P = pollutant concentration) for BOD_5, TSS, NH_4^+-N, and NO_3^--N, as well as in cfu/m^2·day (cfu = colony forming units) for FC and TC, were calculated using Equations (2) and (3), respectively.

$$\mathrm{RE} = \frac{C_i - C_o}{C_i} \times 100\% \quad (1)$$

$$\mathrm{MLR} = C_i \times HLR \quad (2)$$

$$\mathrm{MRR} = (C_i - C_o) \times HLR \quad (3)$$

where, C_i = influent concentration and C_o = effluent concentration for the water quality parameter.

2.7. Statistical Analysis

In this study, statistical analysis was conducted using the "MINITAB 16" statistical software (16, Minitab Ltd., Coventry, UK). Normality of influent and effluent water quality characteristics was determined by performing the Anderson–Darling test. The significance in treatment differences between the VSSF and HSSF wetland systems subjected to various HLRs was evaluated using the one-way ANOVA test for normally distributed data and Mann–Whitney test for non-normal data at a 0.05 significance level. Correlation between MLR and MRR was identified using linear regression analysis.

3. Results

3.1. Characteristics of the Inhabitants

The total population in this community numbered 325 people, of which 53% were between 18 and 50 years of age, while 19% were between 5 and 17 years, 9% less than 5 years, and 19% more than 50 years of age. Their living conditions can be considered poor, with the majority living in line houses of either the single barracks (43%) or double barracks (49%) type. Only 8% owned their own homes.

Water availability could be summarized as: 84% of households had piped water supply, 14% used unprotected wells, and 2% used spring water for drinking and cooking. About 7% of the people had used stream water to wash kitchen utensils, bathing, and in their toilets. Even though a large portion of the group was supplied with piped water, the quality was aesthetically poor as sediments were present. Nonetheless, the incidence of water-borne diseases in this community was low.

In terms of sanitary facilities, 95% of homes had latrines, while 2% shared their neighbors' latrines. However, 3% defecated on open ground near the stream, and used water from the stream to wash after defecation. There were also six persons with walking difficulties in this community, two of whom disposed excreta into the stream. In addition, excreta of 31% of the children (<2 years old) were disposed of on the open ground or washed into the stream. Almost all latrines in this community were pit latrines/pour-flush latrines with cesspits, and 26% of them were very close to the stream (<15 m). All of these contribute to the pollution of stream water. In addition, 22% of households directed their gray water into drains which finally flow into the stream, 38% discharge it into longer drains (>20 m long) leading elsewhere, and only 40% had safe disposal.

3.2. Stream Water Characteristics

Average influent stream water and VSSF and HSSF wetland unit effluent characteristics operated with 3.3–5 cm/day HLRs are shown in Table 1, and the characteristics of stream water spiked with the nitrogen source at the influents and effluents of VSSF and HSSF wetland units operated with 10–40 cm/day HLRs are shown in Table 2. Since NH_4^+-N and NO_3^--N concentrations were very low in the natural stream water (less than 0.40 and 1.76 mg/L, respectively), they were not analyzed in the first phase of the study. It was observed that the average water quality had varied over the period, and this could be due to rain during the study period.

Statistical analysis showed that only BOD_5 and TSS in the influents and effluents of both VSSF and HSSF wetland units operated with natural stream water, as well as water spiked with a nitrogen source, were normally distributed ($p > 0.05$) while FC, TC, NH_4^+N, and NO_3^--N were not normally distributed ($p < 0.05$) at a 95% significance level. The average quality variation corresponding to different HLRs at the influent and effluents of VSSF and HSSF wetland units for BOD_5, TSS, FC, TC, NH_4^+N, and NO_3^--N are shown in Figure S1 in Supplementary Materials.

Table 1. Average characteristics of natural stream water at the influent and effluents of VSSF and HSSF wetland units.

Parameter	Influent	Effluents	
		VSSF	HSSF
BOD_5 (mg/L)	3.2 ± 0.6	0.7 ± 0.3	0.9 ± 0.4
TSS (mg/L)	157.8 ± 56	49.2 ± 22.7	42.7 ± 21.5
FC (cfu/100 mL)	793 ± 389	7 ± 5	2 ± 3
TC (cfu/100 mL)	1669 ± 853	26 ± 19	33 ± 23

Table 2. Average characteristics of stream water spiked with a nitrogen source at the influents and effluents of VSSF and HSSF wetland units.

Parameter	VSSF		HSSF	
	Influent	Effluent	Influent	Effluent
BOD_5 (mg/L)	9.7 ± 2.2	3.4 ± 0.7	9.3 ± 1.9	3.1 ± 1.0
TSS (mg/L)	236.8 ± 91.2	105.4 ± 63.0	245.6 ± 103.4	93.9 ± 54.3
FC (cfu/100 mL)	1672 ± 1411	226 ± 218	1653 ± 1324	188 ± 167
TC (cfu/100 mL)	3115 ± 2353	353 ± 410	3028 ± 1904	353 ± 286
NO_3^--N (mg/L)	14.9 ± 10.6	6.3 ± 3.9	15.7 ± 12.7	3.8 ± 2.9
NH_4^+-N (mg/L)	9.39 ± 3.34	2.25 ± 1.63	9.78 ± 3.18	4.57 ± 2.87

4. Discussion

4.1. Drainage Stream Water Characteristics

The selected drainage stream, which flowed through the human settlement, was more contaminated with fecal coliforms than with organic matter and nutrients (Table 1), exceeding the proposed ambient water quality standards for inland waters in Sri Lanka [24]. This was obviously a consequence of the inadequate sanitation arrangements. From the survey, it was noted that open defecation was still practiced, and was followed by cleaning at the stream. Excreta generated in homes were also sometimes disposed at the stream. Furthermore, people washed small children after defecation into the house drains, which then lead to the stream. The latrines and cesspits were old and located close to the stream. It was therefore possible for contamination from the pits to leak into the stream. However, BOD_5 concentration in the stream water was low, and this was likely due to dilution. The presence of fecal coliforms indicated a higher risk of pathogens being present in water, which may cause waterborne diseases.

4.2. Pollutant Removal

Figure 7 shows the variation in average removal efficiencies (REs) of BOD_5, TSS, FC, TC, NH_4^+-N, and NO_3^--N at various HLRs in the VSSF and HSSF wetland units. The VSSF and HSSF units had the same removal trend for all the measured water quality parameters: i.e., a decreasing RE with increasing HLR; except for NH_4^+-N, which showed an increase of RE corresponding to increasing HLRs. This was seemingly an unusual phenomenon and contradicted expectations, and will be investigated further.

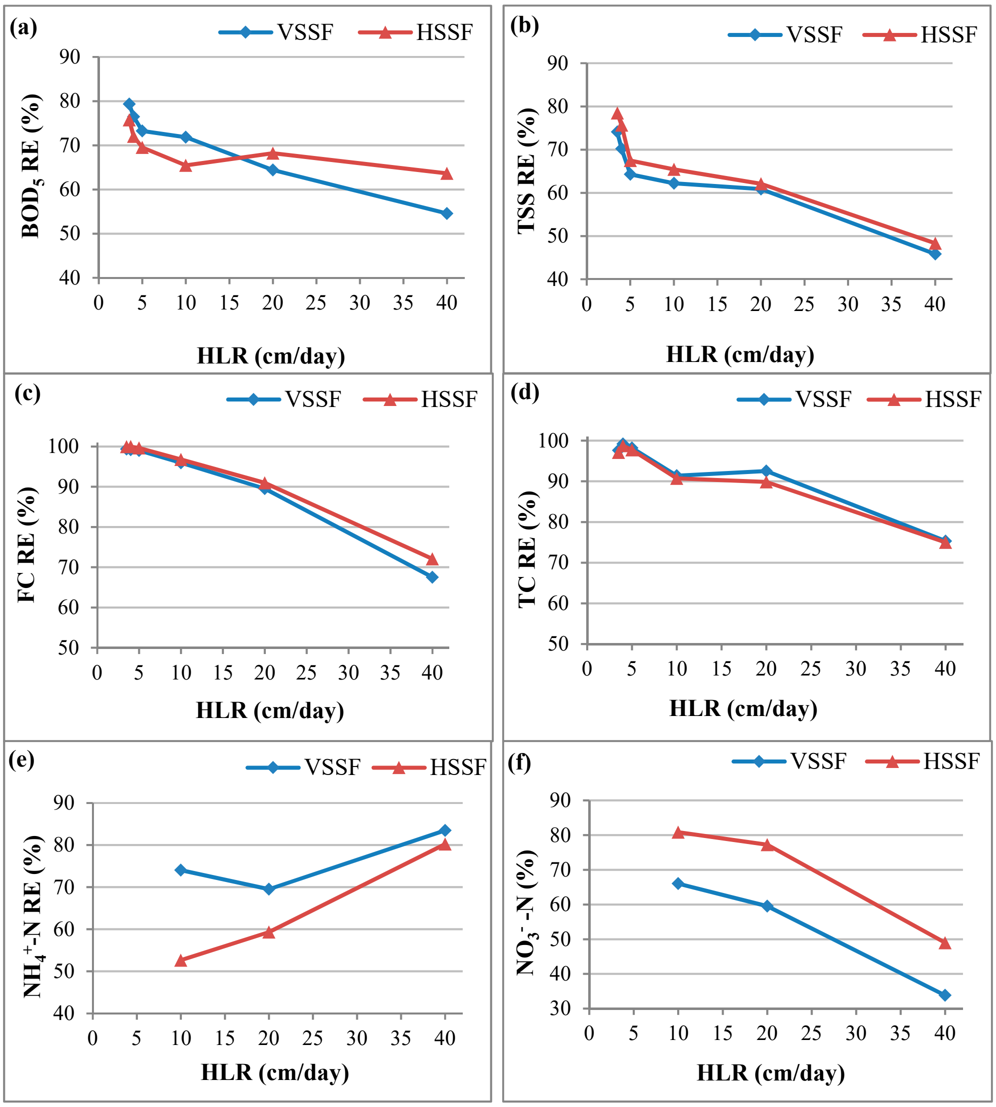

Figure 7. Variation of removal efficiencies (RE) of (**a**) BOD_5, (**b**) TSS, (**c**) FC, (**d**) TC, (**e**) NH_4^+-N, and (**f**) NO_3^--N in VSSF and HSSF wetland units versus HLR.

BOD_5 removal mechanisms in CWs include adsorption, sedimentation, filtration, and microbial degradation [25]. From Figure 7a, even though it was noted that there are slight differences in BOD_5 removal between the VSSF and HSSF wetland units, statistical analysis showed there was no significant treatment difference between the two systems ($p > 0.05$).

TSS removal in a wetland system is supported by physical processes such as filtration, sedimentation, and surface adhesion, followed by microbial assimilation within the substrate media [26]. Figure 7b shows that TSS removal efficiency in the VSSF and HSSF wetlands had been similar during the study period, though the HSSF unit had shown slightly higher removal.

Statistical analysis again indicated there was no significant treatment difference between the two wetland systems ($p > 0.05$).

Coliform removal in CWs is achieved through many physical, chemical, and biological processes, such as sedimentation, filtration, ultraviolet radiation, adsorption, oxidation, die-off due to toxins, natural die-off, and ingestion by nematodes and protozoa [27]. From Figure 7c,d, it can be noted that there was no treatment difference between the two wetland units with up to 10 cm/day HLR. Increasing HLRs beyond 10 cm/day caused a slight removal difference between the two systems for both FC and TC, but this was not statistically significant ($p > 0.05$).

In CWs, a variety of chemical and biological processes, such as ammonification, ammonia volatilization, nitrification, de-nitrification, microbial assimilation, plant uptake, and matrix adsorption, are involved in nitrogen removal [13,28]. Of these, nitrification and denitrification processes are considered the major nitrogen removal pathways [29]. For effective nitrification, the wetland bed has to be aerobic, and typically VSSF wetlands are considered aerobic. On the other hand, for effective denitrification, the wetland bed has to be anoxic, and HSSF wetlands are considered anoxic due to their waterlogged/saturated nature. Thus, VSSF wetlands are more prone to removing NH_4^+ through nitrification, and HSSF wetlands are more prone to removing NO_3^- through denitrification. From Figure 7e, it was noted that the VSSF unit was better in NH_4^+-N removal than the HSSF unit, though both wetland units had the same NH_4^+-N removal trend. Also, it was noted that NH_4^+-N removal increased with increasing HLRs. This could not be satisfactorily explained at this juncture, and the phenomenon will be investigated further. Statistical analysis showed there was no significant treatment difference between the two systems ($p > 0.05$) for NH_4^+-N removal. From Figure 7f, it was noted that both VSSF and HSSF units had a similar NO_3^--N removal trend: a decreasing removal efficiency corresponding to increasing HLRs. The HSSF unit removed more NO_3^--N than the VSSF wetland, and in this instance, statistical analysis showed that there was a significant treatment difference between the two wetland units ($p < 0.05$).

Furthermore, statistical analysis on the VSSF wetland unit showed no significant treatment difference in TC removal up to 5 cm/day HLR; FC and TSS removal up to 10 cm/day HLR; BOD_5 and NO_3^--N removal up to 20 cm/day HLR; and NH_4^+-N removal up to 40 cm/day HLR; with more than 99% of TC, 97% of FC, 62% of TSS, 64% of BOD_5, 60% of NO_3^--N, and 70% of NH_4^+-N removal. On the other hand, the HSSF wetland showed no significant treatment difference in FC and TC removal up to 10 cm/day HLR; NO_3^--N and TSS removal up to 20 cm/day; and HLR, BOD_5, and NH_4^+-N removal up to 40 cm/day HLR; with more than 97% of FC, 90% of TC, 77% of NO_3^--N, 62% of TSS, 63% of BOD_5, and 53% of NH_4^+-N removal. These results indicate that a 20 cm/day HLR would be the appropriate upper limit for the applied HLR for pollutant removal, with the HSSF configuration being more suitable for BOD_5, TSS, FC, and NO_3^--N removal. These results were consistent with laboratory-scale studies reported earlier by Weerakoon et al. [7] and Weerakoon et al. [21].

Table 3 presents the range of applied mass loading rates (MLRs) and mass removal rates (MRRs) obtained for the VSSF and HSSF wetland units for polishing stream water, and Table 4 presents the range of applied MLRs and MRRs obtained for the VSSF and HSSF units with spiked nitrogen, for BOD_5, TSS, FC, TC, NH_4^+-N, and NO_3^--N at different HLRs. MRRs show a positive response to increasing the HLR for both the VSSF and HSSF wetland units with all pollutants, except for NO_3^--N in the VSSF unit. This negative response for NO_3^--N MRRs in the VSSF unit is believed to be a result of the enhanced nitrification and incomplete denitrification under an oxic environment and lack of a suitable carbon source [30]. The regression analysis confirmed these observations, with a strong linear correlation between MLRs and MRRs for BOD_5, TSS, FC, TC, and NH_4^+-N, of over 0.9 in both wetland units; a moderate correlation for NO_3^--N ($R^2 = 0.743$) in the HSSF wetland unit; and a weak relationship for NO_3^--N in the VSSF wetland unit ($R^2 = 0.25$). On the other hand, REs were negatively impacted by increasing HLRs for all measurements, except for NH_4^+-N, which was positively impacted by increasing HLRs in both the VSSF and HSSF units, though such enhanced NH_4^+-N REs with increasing HLRs were not expected.

Table 3. Mass loading rates (MLRs) and mass removal rates (MRRs) for VSSF and HSSF wetland units polishing stream water.

Parameter	MLR	MRR	
		VSSF	HSSF
BOD_5 ($g/m^2 \cdot day$)	0.106–0.171	0.088–0.125	0.080–0.119
TSS ($g/m^2 \cdot day$)	3.815–9.9	2.826–6.362	2.992–6.675
FC ($cfu/m^2 \cdot day$)	(1.65–4.95) × 10^5	(1.64–4.90) × 10^5	(1.64–4.93) × 10^5
TC ($cfu/m^2 \cdot day$)	(3.78–10.29) × 10^5	(3.70–10.29) × 10^5	(3.68–10.06) × 10^5

Table 4. MLRs and MRRs for VSSF and HSSF wetland units polishing stream water spiked with a nitrogen source.

Parameter	VSSF		HSSF	
	MLR	MRR	MLR	MRR
BOD_5 ($g/m^2 \cdot day$)	1.196–3.088	0.865–1.67	1.092–3.289	0.712–2.094
TSS ($g/m^2 \cdot day$)	16.65–110.1	10.5–48.2	19.075–112.7	12.675–54.0
FC ($cfu/m^2 \cdot day$)	(9.70–61.0) × 10^5	(9.39–40.35) × 10^5	(13.8–50.9) × 10^5	(13.2–35.9) × 10^5
TC ($cfu/m^2 \cdot day$)	(21.7–140.6) × 10^5	(20.6–104.2) × 10^5	(25.45–118.9) × 10^5	(23.7–89.2) × 10^5
$NH_4{}^+$-N ($g/m^2 \cdot day$)	1.031–4.123	0.86–3.44	0.99–3.96	0.796–3.184
$NO_3{}^-$-N ($g/m^2 \cdot day$)	1.648–2.57	1.18–2.17	1.48–3.92	1.218–1.56

5. Conclusions

Water catchments within agricultural areas can be contaminated not only with agrochemicals but also by the human settlements within the catchment. A consequence of the latter would be the occurrence of fecal contamination. The latter can then lead to waterborne diseases, as residents of such settlements do make use of the water in streams for domestic purposes.

This study revealed that both the VSSF and HSSF wetlands planted with *Typha angustifolia* could improve water quality in such streams, and hence serve as a relatively low-cost and simple-to-operate water polishing device. Both the VSSF and HSSF wetland units reduced BOD_5, TSS, FC, TC, $NH_4{}^+$-N, and $NO_3{}^-$-N substantially within the 3.3–20 cm/day HLRs operating bandwidth, though the reduction of $NO_3{}^-$-N was lower in the VSSF wetland unit. This bandwidth of HLRs is important because in the application proposed, the wetland units would be more impacted by hydraulic load variations than by contaminant levels, as the stream water would not be heavily contaminated as in wastewater.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/10/3/332/s1, Table S1: Water quality characteristics in several subcatchments in the Pussella-oya catchment during 2008; Table S2: Questionnaire for situation assessment close to the selected drainage stream in the selected tea estate, Pussellawa; Figure S1: The average water quality variation corresponding to different HLRs at the influent and effluents of VSSF and HSSF wetland units for (a) BOD_5, (b) TSS, (c) FC, (d) TC, (e) $NH_4{}^+$-N, and (f) NO^{3-}-N.

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Conflicts of Interest: The authors declare no conflict of interest.

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