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Rural Domestic Wastewater Treatment by Small-scale Horizontal Subsurface Flow Constructed Wetlands at Different Temperatures

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Abstract This study assessed the performance of a small-scale horizontal sub-surface flow constructed wetland (HSSF-CWs) for rural domestic wastewater treatment with different species of vegetative plants capsicum annuum (A), Allium sativum (B), Apium graveolens (C), Spinacia oleracea (X), Apium graveolens (Y) & cilantro (Z).The system operational time was over three months as a tertiary treatment for both summer and winter season to improve the effluent quality before disposal. The average temperatures during the experimental operation were 27°C and 11.6°C in summer and winter respectively. The average pH value ranges between 6.98-7.19 and 6.72-6.98 respectively. The average hydraulic residence time (HRT) of 2 and three days with the hydraulic loading rate (HLR) set to 180ml/min in summer and winter respectively. The average removal efficiency (RE) concentrations for plants A, B & C in summer were 77.2%, 77.2%, 81.4% & 93% for TN, NO3-N, NH4+N & TP. Whereas in the winter season the RE were 67.6%, 65%, 69.4% & 86.6% for TN, NO3-N, NH4+N & TP for plants X,Y,& Z respectively. All the vegetative plants almost performed similarly in nutrient removal under HRT of two and three days with the best performance revealed in summer. HSSF-CW successfully achieved high removal efficiency due to its self-adaptability, low-cost, secure operations and maintenance and above all is high effluent quality reuses and self-remediation. HSSF-CW is a good alternative for wastewater treatment system.

Keywords: *rural wastewater, HSSF-CWs, nutrient, hydraulic loading rate, HRT*

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1. Introduction

Wastewater is any water used and has been affected by human activities, and it could be domestic, commercial, agricultural, industrial, stormwater, surface runoff, any inflow of sewer or infiltration of sewer [1]. Globally; approximately, 80% of wastewater produced is discharged into the environment prior treatment resulting into water contamination [2,3,4]. Improper wastewater dispose into watersheds or bodies is of higher effects on water quality and uses, thus, needs adequate treatment beforehand [5,6]. There is a wastewater management crisis in developing countries. As a result of about 2.6 billion men worldwide lack adequate sanitation due to scarce resources, poor management system, little research, and expensive operations [7,8]. In most small rural areas of developing Countries with fewer population densities, wastewater is treated using on-site sanitation system such as septic tanks connected to drain fields, on-site sewage system (OSS), and so on. An alternative solution to domestic wastewater treatment is HSSF-CW technology; it is built, smooth operations, low cost, and maintenance and higher efficiency in treating different types of wastewater [9-13] and appropriate technology for removing different types of nutrients [14]. An environmental problem in some parts of the world is water bodies enriched with nutrients, the of nutrients removal such as phosphorous and nitrogen from the water bodies is of vital importance. The plants are essential in nutrient removal because during the growing time they absorb and incorporate many elements in their tissues [15]. The mechanisms involved in nitrogen removal in constructed wetlands (CWs) are manifold and includes volatilization, ammonification, matrix adsorption, plant uptake and nitrification/denitrification [16,17]. It has was accepted that the primary removal mechanisms for nitrogen removal are bacterial nitrification and denitrification [18,19]. While phosphorous removal in the constructed wetland is a result of bacteria activity, plant uptake, microbial immobilization, aeration of wetland soils adsorption by porous media and precipitation in the water column [16,20]. This research objective is to examine the temperature differences in the nutrient removal efficiencies of total nitrogen (TP), nitrate (NO3-N), ammonium (NH4+N) and total phosphorus (TP) in a year-round on a small-scale HSSF-CWs system for rural domestic wastewater treatment receiving wastewater from Taihu lake environmental program; Southeast University, Wuxi, China located in Wuxi city /Nanjing Jiangsu province. The HSSF-CWs were operated under the average temperatures of 27°C warm periods and 11.6°C cold periods.

2. Materials and Methods

2.1. Study Site

This study was conducted at Taihu lake environmental program, Southeast University, Wuxi (119º33´-120º38´ longitude E 31º7´-32º2´ latitude N.

Small-Scale horizontal subsurface flow constructed wetland located in Wuxi new district area was established. The location of Wuxi city is in the hinterland of Yangtze River Delta (Southern part of Jiangsu province), and it is a transit hub in the Taihu lake basin (in the South). Yangtze River in the North while Suzhou in the east bordered by Changzhou in the west. Wuxi city has a population of 4,679,600 with seven districts of 32 villages and towns with a total area of 4627.47 square kilometers [21]. The climate of the area is hot and humid in summer and damp in winter. Months of June-August are the warmest periods. August is the hottest Month with temp. Of 37.3°C, while Months of January-March are the cold period and January is the coldest Month with temperature averaging to -5.6°C.

2.2. Constructed Wetland

Horizontal subsurface flow constructed wetland is an ecological constructed wetland designed to minimize processes in the natural environment. In this study, the HSSF-CWs was designed of three concrete basin cells 2.3m, 0.3m and 0.5m (length x width x height) respectively. In the first and second round of experimental operations, the hydraulic loading rate was set to 180 ml/m and the hydraulic retention time was set to 2, 2 and three days respectively. The three different layers of matrix particles in the constructed wetland were of different sizes: At the bottom grit gravel (40-60 mm in diameter), coarse middle gravel (30-50 mm in diameter) and on the top fine sand particle (0.5-1.2 mm in diameter) respectively. The three constructed wetlands were planted with A, B & C that was well-established and it covered the whole surface area of the wetland bed. The plant spacing was 20-25 cm in order to give the same shoot density for the established constructed wetland. The same methods were applied in the second round of experiment but using winter plants X, Y, and Z.

2.3. Estimation of Parameters

2.3.1. Hydraulic Loading Rate (HLR)

Hydraulic loading rate (HLR) is the ration of the wastewater inflow rate divided by the surface area of the wet basin or vault. The below equation gives it.

$$H_{LR} = \frac{Q}{A} \tag{1}$$

Where HLR is the Hydraulic loading rate ($m.day^{-1}$), Q is the ratio of wastewater inflow rate ($m^3.day^{-1}$) Moreover, A is the surface area of the wet basin or vault (m^2).

2.3.2. Hydraulic Retention Time (HRT)

Hydraulic retention time is defined as the volume of the aeration tank to that of the influent flow rate. It is expressed as:

$$H_{RT} = \frac{V}{Q} \tag{2}$$

Where HRT is the Hydraulic retention time (day), V is the water volume (m^3), and Q is the average wastewater inflow rate ($m^3.day^{-1}$).

2.3.3. Removal Efficiency

Removal efficiency is the difference between the concentration of influent and the concentration of the effluent divided by the concentration of the influent. This equation expresses it.

$$R_e = \frac{\text{Cinf} - \text{Ceff}}{\text{Cinf}} \times 100\% \tag{3}$$

Where R_e is the removal efficiency (%), C_{inf} is the influent concentration (mg/L^{-1}), and C_{eff} is the effluent concentration (mg/L^{-1}).

2.3.4. Total Suspended Solids

Total suspended solids are the difference between the dried weight of residue and filter paper used to that of the weight of the filter paper all divided by the sample of wastewater used (ML 100)

$$TSS = \frac{\text{Final reading} - \text{Initial reading}}{\text{Sample Ml}(100)} \times 1000 \tag{4}$$

Where TSS is the total suspended solids (mg/L^{-1}), final reading is the dry weight residue of filter paper; initial reading is the weight of the filter paper and ML is the wastewater sample used.

2.4. Experimental Procedure

The experimental period was conducted for over three Months, and it was of two rounds, the first round from July through September with the temperature ranges between 23.71°C to 30.96°C with the average temperature of 27°C while the second round was from January through March with the temperature ranges from 9°C to 15°C. The inlet wastewater used was from the storage tank. The anaerobic degradation and organic pollutants take place in the storage tank. The wastewater flows slowly from the storage tank and passes into the filtration granular media under the bed surface of the constructed wetland. The wastewater was in contact with the network of aerobic, anoxic and anaerobic zones. The aerobic zone is essential around the plant's roots and rhizomes which introduces oxygen in the substrate. Finally, the wastewater is discharged into the nearby pond after the sample was collected and the enhancement of oxygen, acclimatization and nutrient removal is achieved.

2.5. Wastewater Sampling and Its Characteristics

It was twice a week sample collection as from July-September 2018 and from January –March 2018 respectively. The inlet wastewater was from the students' laboratories, dormitories, and restaurants at Taihu Lake Environmental Engineering Research Center of Southeast University campus, Wuxi/China. The outlet wastewater was taken after every two days in a 500 mili liter plastic bottles and stored under the temperature of 5°C in the refrigerator before the experimental test in the laboratory. The collected wastewater samples were analyzed for total phosphorus (TP), total nitrogen (TN), nitrate and ammonia respectively. The pre-results were not incorporated into the final results. All the parameters were analyzed according to the standard methods for water and wastewater examination [22,23]. The composition of the studied raw wastewater is shown in Table 1 and Table 2 respectively.

Table 1. Composition of studied raw wastewater in the first round of operations (July-Sep.)

Parameters	pH	TN	NO_3^-N	NH_4^+N	TP	TSS
		Mg/L^{-1}				
Range	6.98-7.19	25-43	5-6.5	16.4-35	2-3.5	175-369
Average	7.09	34	5	25.7	2.75	272

Hence, TN=total nitrogen; NO_3^-N=nitrate; NH_4^+N=ammonium; TP=total phosphorous; TSS=total suspended solids.

Table 2. Composition of studied raw wastewater (Jan-March.)

Parameters	pH	TN	NO_3^-N	NH_4^+N	TP	TSS
		Mg/L^{-1}				
Range	6.72-6.98	16-30	2.8-4.5	12-24	1-1.5	98-176
Average	6.85	23	3.65	18	1.25	137

Hence, TN=total nitrogen; NO^-_3N=nitrate; NH^+_4N=ammonium; TP=total phosphorous; TSS=total suspended solids.

2.6. Methods of Analysis

The initial wastewater quality (influent) and the final (effluent) of each stage were critically monitored. The below-listed parameters were analyzed according to the standard methods in the laboratory [22,24,25]. The temperature, pH and dissolved oxygen (DO) were tested by pH 100 and DO probes (YSI) respectively.

Table 3. Laboratory tests methods for wastewater quality.

No	Parameters	Test methods
1	TN	Potassium persulfate spectrophotometry
2	NO_3^-N	Persulfate UV spectrophotometry
3	NH_4^+N	Salicylic acid spectrophotometry
4	TP	Molybdenum antimony antipoints spectrophotometry
5	TSS	Gravimetric analysis.

2.7. Data Analysis.

The initial and final data were analyzed using MS Excel (office package 16).

3. Results and Discussion

3.1. Total Nitrogen (TN) Removal

The results shown in the tables below explained the seasonal variation effect of temperature and HRT on total nitrogen removal concentrations in HSSF-CW. The total nitrogen influent and effluent concentrations in the first round of experimental operations of (plant A) were 30, 39.8, and 37.6 mg/L^{-1} and 8.6, 10.2 and 6.5 mg/L^{-1}, with removal efficiency of 71%, 74%, and 83% respectively. The total influent and effluent concentrations were 36 and 8.4 mg/L^{-1} with the total removal efficiency of 77% at a total temperature of 27°C respectively. (Plant B) were 30, 39.8 and 37.6 mg/L^{-1} and 8.4, 9.4 and 6.8 mg/L^{-1} respectively with removal efficiency of 77.2%, 76.4% and 82% respectively. The total influent and effluent concentrations were 36 and 8.2 mg/L^{1-} with the total removal efficiency of 77.2% at a total temperature of 27°C. (Plant C) were 30, 39.8 and 37.6 mg/L^{-1} and 8.6, 9 and 7 mg/L^{-1} respectively with removal efficiency of 71%, 77% and 81.3% respectively. The total influent and effluent concentration of total nitrogen were 36 and 8.2 mg/L^{-1} with the total removal efficiency of 77.2% at a total temperature of 27°C. The high the temperature and hydraulic retention time, the best removal efficiency as shown in Table 4. While in the second round of experimental operation, the concentrations of TN influent and effluent of (plant X) were 18, 25 and 18.3 mg/L^{-1} and 5.8, 5.6 and 6 mg/L^{-1} respectively with removal efficiency of 68%, 69%, and 67.4% respectively. The total influent and effluent concentrations were 20.4 and 5.8 mg/L^{1} with the total removal efficiency of 72% at a total temperature of 11.6°C respectively. (Plants Y) Effluent concentrations were 18, 25 and 18.3 mg/L^{-1} and 8.6, 8.4 and nine respectively with removal efficiency of 65%, 67%, and 64%. The total influent and effluent concentration of total nitrogen were 20.4 and 8.7 mg/L^{-1} with the total removal efficiency of 58% at a total temperature of 11.6°C respectively. (Plant Z) were 18, 25 and 18.3 mg/L^{-1} and 5.6, 5.5 and 5.3mg/L^{-1} respectively with removal efficiency of 69.4%, 70% and 71%. The total influent and effluent concentration of total nitrogen were 20.4 and 5.5mg/L^{-1} with the total removal efficiency of 73% at a total temperature of 11.6°C respectively as shown in Table 5. The effect of temperature and HRT is not observed probably due to below temperature below 15°C [26,27] that means denitrifying bacteria activity cannot comply to the addition of organic matter [28]. The overall nitrogen removal efficiency is higher in warm periods than in cold periods due to activities of denitrifying bacteria in constructed wetland sediment mostly occurring in spring to summer than in autumn and winter [29,30]. The mechanisms involved in total nitrogen (TN) removal in constructed wetland include volatilization, ammonification, matrix adsorption, plant uptake [31] and nitrification/denitrification [16,17,18]. The TN removal depends on temperature which is more significant [32]. The temperature dependence of the mechanisms involved in nitrogen transformation process has been widely reported, and several systems in cold climate did reveal decrease ability for nitrifying/denitrification during winter Months [26]. In a study done by Vera et al. [33], 11 HSSF-CWs was set in Catalonia (Spain), the total removal (%) for TN ranges between 48% and 66% also Puigagute et al.[34] indicated RE of 51% for TN in HSSF-CWs which is lower than in this study with the total RE for TN of 71.3% in warm periods. Vyamazal et al. [34]reported RE for TN in cold season ranges between 40% and 55% which is also lower compared to this study showing RE for TN of 67.8%.

Table 4. The concentrations of influent, effluent and removal efficiency of (TN) in the first round of experimental operations

Months	Temp.	HRT	Inf. A, B & C	Eff. A	Eff. B	Eff. C
	°C	days	Mg/L	Mg/L	Mg/L	Mg/L
July	23.71	2	30	8.6 (71.3 %)	8.4 (72%)	8.6 (71.3%)
August	25.45	2	39.8	10.2 (74.3%)	9.4 (74.4%)	9 (77.3%)
September	30.96	3	37.6	6.5 (82.7%)	6.8 (81.9%)	7.5 (80%)

Here, HRT=hydraulic retention time, Inf=influent, Eff=effluent, A=capsicum annuum, B=allium sativum, C=apium graveolens.

Table 5 The concentrations of influent, effluent and removal efficiency of (TN) in the second round of experimental operations.

Months	Temp.	HRT	Inf. X,Y & C	Eff. X	Eff. Y	Eff. Z
	°C	days	Mg/L	Mg/L	Mg/L	Mg/L
January	9	2	18	5.8 (68 %)	5.6 (69%)	6 (67%)
February	11	3	25	8.6 (65%)	8.4 (67%)	9 (64%)
March	15	2	18.3	5.6 (69.4%)	5.5 (70%)	5.3 (71%)

Here, HRT= hydraulic retention time, Inf=influent, Eff=effluent, X=spinancia oleracea, Y=apium graveolens, Z=cilantro.

3.2. Nitrate (NO_3^-N) Removal

The concentrations of influent of NO_3^-N in the first round of experimental operations were 5.3, 6 and 5.8 mg/L^{-1} and the concentration of effluents in (plants A) were 1.4, 1.3, and 1.4 mg/L^{-1} respectively with removal efficiency of 73%, 78%, and 76 % respectively. The average concentrations of influent and effluent were 5.7 and 1.36 mg/L^{-1} respectively with the average removal efficiency of 76.1% at the average temperature of 27°C. Effluents in (plants B) were 1.2, 1.4 and 1.2 mg/L^{-1} respectively with removal efficiency of 77%, 77% and 79% respectively. The average concentrations of influent and effluent were 5.7 and 1.26 mg/L^{-1} respectively with the average removal efficiency of 78% at the average temperature of 27°C. While effluents in (plants C) were 1.3, 1.3 and 1.2 mg/L^{-1} respectively with removal efficiency of 75%, 78% and 79% respectively. The average concentrations of influent and effluent were 5.7 and 1.3 mg/L^{-1} respectively with the average removal efficiency of 77.2% at the average temperature of 27°C as shown in Table 6. In the second round of experimental operations, the influent concentrations were 3.4, 4 and 3.7 mg/L^{-1} respectively. The effluents in (plants X) were 1.3, 1.6 and 1.3 mg/L^{-1} respectively with removal efficiency of 62%, 60% and 65% respectively. The average concentrations of influent and effluent were 3.7 and 1.4 mg/L^{-1} respectively with the average removal efficiency of 62.2% at the average temperature of 11.6°C. The effluents in (plants Y) were 1.3, 1.5 and 1.4 mg/L^{-1} respectively with removal efficiency of 62%, 63% and 62% respectively. The average concentrations of influent and effluent were 3.7 and 1.4 mg/L^{-1} respectively with the average removal efficiency of 62.2% at the average temperature of 11.6°C. Effluents in (plants Z) were 1.2, 1.6 and 1.3 mg/L^{-1} respectively with removal efficiency of 64%, 60% and 65% respectively. The average concentrations of influent and effluent were 3.7 and 1.36 mg/L^{-1} respectively with the average removal efficiency of 63.2% at the average temperature of 11.6°C. The nutrient removal efficiencies were of the distinct plants were higher especially in summer than in winter seasons.

Table 6. The concentrations of influent, effluent and removal efficiency of (NO_3^-N) in the first round of experimental operations

Months	Temp.	HRT	Inf. A,B & C	Eff. A	Eff. B	Eff. C
	°C	days	Mg/L	Mg/L	Mg/L	Mg/L
July	23.71	2	5.3	1.4 (73 %)	1.2 (77%)	1.3 (75%)
August	25.45	2	6	1.3 (78%)	1.4 (77%)	1.3 (78%)
September	30.96	3	5.8	1.4 (76%)	1.2 (79%)	1.2 (79%)

Here, HRT=hydraulic retention time, Inf=influent, Eff=effluent, A=capsicum annuum, B=allium sativum, C=apium graveolens.

Table 7. The concentrations of influent, effluent and removal efficiency of (NO_3^-N) in the second round of experimental operations

Months	Temp.	HRT	Inf. X, Y & C	Eff. X	Eff. Y	Eff. Z
	°C	days	Mg/L	Mg/L	Mg/L	Mg/L
January	9	2	3.4	1.3 (62 %)	1.3 (62%)	1.2 (64%)
February	11	3	4	1.6 (60%)	1.5 (63%)	1.6 (60%)
March	15	2	3.7	1.3 (65%)	1.4 (62%)	1.3 (65%)

Here, HRT= hydraulic retention time, Inf=influent, Eff=effluent, X=spinancia oleracea, Y=apium graveolens, Z=cilantro.

3.3. Ammonium ($NH^{4+}N$) Removal

The concentrations of influent and effluent of ammonium in the first round of experimental operations of (plant A) were 23, 32 and 27.3 mg/L^{-1} and 5.4, 5.4 and 5.1 mg/L^{-1} respectively with removal efficiency of 77%, 83%, and 78%. The average influent and effluents were 27.4 and 5.3 mg/L^{-1} with the average removal efficiency of 81% at the average temperature of 27°C. (Plant B) were 23, 32 and 27.3 mg/L^{-1} and 5.5, 5.7 and 4.8 mg/L^{-1} respectively with removal efficiency of 76%, 82% and 79% respectively. The average influent and effluents were 27.4 and 5.3 mg/L^{-1} with the average removal efficiency of 81% at the average temperature of 27°C. (Plant C) Were 23, 32 and 27.3 mg/L^{-1} and 4.6, 5, and 4.4mg/L^{-1} respectively with removal efficiency of 80%. 84% and 81% respectively. The average influent and effluent concentrations were 27.4 and 4.7mg/L^{-1} with the average removal efficiency of 83% at the average temperature of 27°C as illustrated in Table 8. In the second round of experimental operations, the removal concentrations of influent of plants X, Y, and Z were 14, 22.6 and 18.3 mg/L^{-1} and effluents in (plants X) were 4.6, 6.4 and 5.8 mg/L^{-1} respectively with removal efficiency of 67%,72%, and 68% respectively. The average influent and effluent concentrations were 18.3 and 5.6 mg/L^{-1} with the average removal efficiency of 69.4% at the average temperature of 11.6°C. Effluents in (plant Y) were 4.4, 5.5 and 6.8 respectively with removal efficiency of 68%, 76%, and 61% respectively. The average influent and effluent concentrations were 18.3 and 5.6 mg/L^{-1} with the average removal efficiency of 69.4% at the average temperature of 11.6°C. Effluents in (plants Z) were 4.3, 6.2 and 6.5 mg/L^{-1} respectively with removal efficiency of 69%, 60% and 64% respectively. The average influent and effluent concentrations were 18.3 and 5.7 mg/L^{-1} with the average removal efficiency of 69% at the average temperature of 11.6°C as shown in Table 9. In this study, the results in the warm season were similar as well in cold season. The effect of temperature and HRT in warm periods were not seen probably of similar performance carried by the plants, however, in cold periods, the temperature and HRT effects were not seen due to a low temperature below 15°C [26,27]. Simoes et al. [35] indicated average RE for Ammonium of 76.7 %, Oliveira et al. [36] in his study of 4 HSSF-CWs showed average RE for Ammonium ranging between 4% and 51% while Albuquerque and Morecos do Monte et al. [37] indicated average removal efficiency for Ammonium of 78.8. These results are lower than in this study that shows the average removal efficiency for ammonium during warm periods is 82%. The removal efficiency of ammonium in cold seasons are lower compared to removal efficiency in warmer seasons probably due to a small area of the bed considering the design system of HSSF-CWs that gives lower HRT; also the contact time for wastewater and biofilms responsible for the removal of nitrogen was inadequate. Also, the high flow rate of water to the wetland bed during raining season contributes to the less performance of the system. In this study, the wetland ammonia went through multiple ways to remove the majority of ammonium through the matrix surrounding the plants' root and nitrification microorganism transform into nitrate. There is a possibility to remove a small amount of ammonium by direct evaporation.

Table 8. The concentrations of influent, effluent and removal efficiency of (NH_4^+N) in the first round of experimental operations

Months	Temp.	HRT	Inf. A,B & C	Eff. A	Eff. B	Eff. C
	°C	days	Mg/L	Mg/L	Mg/L	Mg/L
July	23.71	2	23	5.4 (77 %)	5.5 (76%)	4.6 (80%)
August	25.45	2	32	5.4 (83%)	5.7 (82%)	5 (84%)
September	30.96	3	27.3	5.1 (78%)	4.8(79%)	4.6 (81%)

Here, HRT=hydraulic retention time, Inf=influent, Eff=effluent, A=capsicum annuum, B=allium sativum, C=apium graveolens.

Table 9. The concentrations of influent, effluent and removal efficiency of (NH_4^+N) in the second round of experimental operations

Months	Temp.	HRT	Inf. X, Y & C	Eff. X	Eff. Y	Eff. Z
	°C	days	Mg/L	Mg/L	Mg/L	Mg/L
January	9	2	14	4.6 (67 %)	4.4 (68%)	4.3 (69%)
February	11	3	22.6	6.4 (72%)	5.5 (76%)	6.2 (60%)
March	15	2	18.3	5.8 (68%)	6.8 (61%)	6.5 (64%)

Here, HRT= hydraulic retention time, Inf=influent, Eff=effluent, X=spinancia oleracea, Y=apium graveolens, Z=cilantro.

3.4. Total Phosphorous (TP) Removal

The concentrations of influent of total phosphorous in the first round of experimental operations were 2.3, 3.1 and 2.8 mg/L^{-1} and effluents of (plant A were 0.2, 0.2 and 0.3 mg/L^{-1} respectively with removal efficiency of 91%, 94%, and 89% respectively. The average influent and effluents were 2.7 and 0.2 mg/L^{-1} and the average removal efficiency of 93% at the average temperature of 27°C. Effluents of (plant B) were 0.1, 0.2 and 0.2 mg/L^{-1} respectively with the removal efficiency of 95%, 94% and 93% respectively. The average influent and effluents were 2.7 and 0.16 mg/L^{-1} and the average removal efficiency of 94.1% at the average temperature of 27°C. Effluents (plants C) were 0.2, 0.1 and 0.2 mg/L^{-1} respectively with removal efficiency of 91%, 97% and 93 % respectively. The average influent and effluents were 2.7 and 0.16 mg/L^{-1} and the average removal efficiency of 94.1% at the average temperature of 27°C as illustrated in Table 10. In the second round of experimental operations, the concentrations of influent were 1.2, 1.4 and 1.2 mg/L^{-1} and effluent of (plants X) were 0.2, 0.18 and 0.18 respectively with removal efficiency of 83%, 87%, and 85% respectively. The average influent and effluent concentrations were 1.3 and 0.17 mg/L^{-1} with average removal efficiency of 87% at the average temperature of 11.6°C. Effluents of (plant Y) were 0.2, 0.2 and 0.17 with removal efficiency of 83%, 85% and 86% respectively. The average influent and effluent concentrations were 1.3 and 0.19 mg/L^{-1} with average removal efficiency of 85% at the average temperature of 11.6°C. Effluents in (plants Z) were 0.1, 0.19 and 0.18 respectively with removal efficiency of 83%, 86% and 85% respectively. The average influent and effluent concentrations were 1.3 and 0.16 mg/L^{-1} with average removal efficiency of 87% at the average temperature of 11.6°C as shown in Table 11. The TP removal efficiency in a constructed wetland in summer was higher than in winter. In this study, the results of the removal efficiency of TP by different plants in warm periods were similar as well as in cold periods. The different removal efficiency of TP in HSSF-CWs conducted by different authors ranges between 26% to 94% [29,35,36,37,38] which is in agreement with this study which is 94.3%. Vera et al. [33] indicated that a maximum mean RE for TP was 58% which is lower compared to this study. In the cold seasons, Akratos and Tsihrintzi et al. [26] indicated that the mean TP removal efficiency at the temperature below 15°C is 41.8% while above the temperature of 15°C is 70.1% which is lower than in this study 86.3%. The TP removal efficiency involved both biotic (uptake by vegetation, periphyton and microns, and burial; adsorption and precipitation. It also involved the exchange of soil and overlying water column process [20,39]. All these processes were favored by long retention time [40,41]. The seasonal variations in phosphorous removal could be explained by the fact that during winter the litter and microbial biomass were decomposed, and the phosphorous virus is released from the precipitation resulting into phosphorous solubilization in water [42]. In cold climate, phosphorus removal is indirectly affected by oxygen availability which influenced redox levels, and regression depicts low total phosphorus removal efficiency.

Table 10. The concentrations of influent, effluent and removal efficiency of (TP) in the first round of experimental operations

Months	Temp.	HRT	Inf. A,B & C	Eff. A	Eff. B	Eff. C
	°C	days	Mg/L	Mg/L	Mg/L	Mg/L
July	23.71	2	2.3	0.2 (91 %)	0.1 (95%)	0.2 (91%)
August	25.45	2	3.1	0.2 (94%)	0.2 (94%)	0.1 (97%)
September	30.96	3	2.8	0.3 (89%)	0.2 (93%)	0.2 (93%)

Here, HRT=hydraulic retention time, Inf=influent, Eff=effluent, A=capsicum annuum, B=allium sativum, C=apium graveolens.

Table 11. The concentrations of influent, effluent and removal efficiency of (TP) in the second round of experimental operations

Months	Temp.	HRT	Inf. X,Y & C	Eff. X	Eff. Y	Eff. Z
	°C	days	Mg/L	Mg/L	Mg/L	Mg/L
January	9	2	1.2	0.2 (83 %)	0.2 (83%)	0.1 (83%)
February	11	3	1.4	0.18 (87%)	0.2 (85%)	0.19 (86%)
March	15	2	1.2	0.18 (85%)	0.17 (86%)	0.18 (85%)

Here, HRT= hydraulic retention time, Inf=influent, Eff=effluent, X=spinancia oleracea, Y=apium graveolens, Z=cilantro.

4. Conclusions

The results indicated that the HSSF-CWs systems are more useful for nutrient removal of TN, NO_3^-N, NH_4^+N, and TP especially in warmer seasons than in cold periods. The temperature was high in the summer period that gives a better nutrient removal than in winter period. A three day HRT was of the best performance, especially in TN removal. All the vegetative plants almost performed similarly in nutrient removal under HRT of two and three days with the best performance revealed in summer

The HSSF-WC successfully achieved average removal efficiencies (RE)concentrations for plants A, B & C in summer were 77.2%, 77.2%, 81.4% & 93% for TN, $NO^{3-}N$, $NH^{4+}N$ & TP. Whereas in the winter season the RE were 67.6%, 65%, 69.4% & 86.6% for TN, $NO^{3-}N$, $NH^{4+}N$ & TP for plants X, Y, & Z respectively. The organic matter and nutrient concentrations in the effluent from the system were lower than class (1), A regulated value for Chinese National standard (GB18918-2002). The HSSF-CWs are energy saving, cost-intensive technology and an alternative for rural regions of the developing countries in treating wastewater.

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