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Optimization of Ceramic Filter for Greywater Treatment by using Horizontal Flow Constructed Wetland

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Abstract. Wetland technology is an effective and sustainable treatment process that relies on a combination of components. Media components, which vary based on the material used, play an important role in this technology. Ceramic-based filters are a natural and versatile water filtration method that can be used in combination with wetland systems to create a simple, low-cost, and efficient wastewater treatment technology. The aim of this study was to assess the performance and efficiency of two experimental scale horizontal flow constructed wetlands (HFCW) as a secondary stage for the treatment of household greywater. This was achieved by examining the untreated and treated greywater characteristics; evaluating the effectiveness of planted wetlands with ceramic addition in removing chemical oxygen demand (COD), biological oxygen demand (BOD5), nutrients, total suspended solids (TSS), and coliforms from the greywater; and monitoring the adaptation and growth of *Bacopa monnieri* L. in the treatment systems. The results showed that both treatment systems significantly improved all the greywater characteristics. The use of ceramic, gravel, and plants in wetlands enhanced the removal efficiency of Mg+2, TDS, and total hardness (TH). A higher treatment efficiency was observed in the ceramic-gravel bed than in the gravel bed.

Keywords. Sustainable, Ceramic filter, Treatment efficiency.

1. Introduction

In response to the global water shortage crisis, sustainable wastewater treatment processes have been gaining attention from scientists with the aim of conserving water and reusing treated water as an alternative water source [1,2]. One successful approach is the reclamation of household greywater in rural areas, which can be recycled for irrigation or cleaning, thus reducing the stress on natural water resources. Constructed wetland (CWs) technology has been widely recommended for wastewater treatment because of its effectiveness, sustainability, thriftiness, and environmental friendliness [3-5]. Greywater includes wastewater that is disposed of from showers, toilets, kitchen sinks, and dishwashers [6], and its components are varied based on the formation sources [7]. For example, wash basins and showers drain water consisting of dead skin, hair, soap, toothpaste, razors, and skin care items. Kitchen wastewater is characterized by high levels of detergents, pH, salts, food particles,

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nitrogen, organic compounds, turbidity, suspended solids, fats, and oils. On the other hand, wastewater from washing machines consists of viruses, dyes, heavy metals, fibres, bleaches, and detergents [8]. It is estimated that greywater covers approximately fifty to 70 present of household discharged water [6]. Therefore, it is considered a good source to provide a valuable quantity of recycled water after treatment [9]. Among all wastewater treatment types, constructed wetland (CWs) technology is widely recommended because of its effectiveness, sustainability, thriftily, and environmental friendliness [10]. CWs are artificially engineered systems that simulate natural wetlands, utilizing a combination of plants, organisms, and soil to treat various types of wastewater, including greywater [11,12]. Among CW configurations, the horizontal flow CW (HFCW) has been found to be the most effective for purifying diverse pollutants [13]. The combination of the main CW components, such as plants and filter media, plays a significant role in wastewater treatment performance [14]. In terms of filter media, the authors confirmed that sand is more efficient than gravel, and a mixture of sand and soil is the best case for removing different contaminants [15]. Recently, other types of media have been used in CWs to improve processing efficiency, such as zeolites, biochar, active carbon, biofilm carriers, and ceramic filters [16,2].

Ceramic wares are also known as filter elements and are used as a mixture of fired clay powder materialized with a special solution of silver that kills bacteria. Disinfection can occur by capturing the pores and disinfecting the silver. When the contaminant is decanted, the tiny pores inside the ceramic pot act as filters, trapping most particles and debris along with larger parasites and bacteria [17]. Ceramic filters have several benefits, including decontamination ability, versatility, low cost, and eco-friendliness, making them a practical choice for rural areas or regions with limited resources.

Bacopa monnieri L. It is a medicinal herbal plant belonging to the family Scrophulariaceae. They are found in wetlands, ponds, and marshes in both light and shaded areas. It has the ability to withstand high temperatures but does not tolerate drought. It is an annual plant with white, non-fragrant flowers. It can reach 10-30 cm in height by forming roots at the nodes. It has many medical applications, as it is used in the production of antioxidants to lower blood pressure, increase brain activity, and others [18].

This study aimed to evaluate the performance and efficiency of two experimental scale HFCWs in treating household greywater, exploring the characteristics of untreated and treated greywater, assessing the efficiency of wetlands with ceramic addition to remove pollutants, and monitoring plant adaptation and growth in treatment systems.

2. Materials and Methods

The experimental design and operation involved the use of two types of substrates, namely gravel and ceramic (pottery), obtained from a local laboratory and markets, respectively. The gravel was rinsed with deionized water to remove impurities, while the ceramic was crushed and sifted to obtain ceramic pieces of size 10-20 mm. *Bacopa monnieri* L. was selected as the macrophyte and was collected from a small pond in the Al-Basra governorate and washed with distilled water to remove dust. The greywater used in the study was collected from washing machines, kitchen sinks, and lavatories in different houses in Abu Al-Khaseeb District and was not affected by black water.

Two experimental-scale HFCWs were operated using rectangular plastic basins placed under semi-natural conditions in the yard of a house in Abu Al-Khaseeb District. Both basins received the same quantity of 25 liters of greywater, with the first basin consisting of gravel as the medium and the second basin consisting of a mixture of gravel and ceramic. The wetland basins were filled and drained every five days, and a contact time of five days was recommended for the best reduction of TSS, TDS, TU, BOD_5, COD, NH_3, NO_3, and PO_4. Table 1 summarizes the properties and descriptions of the experimental wetlands.

Samples were collected at regular intervals from the outlet water of each filter and from raw greywater for subsequent analyses. The volume of each sample was three liters, and standard methods were used for most of the analyses, including pH, temperature, TDS, EC, TU, TSS, BOD_5, COD, DO, reactive nitrate (NO_3), and orthophosphate (PO_4) measurements using various instruments, such as pH meters, turbidity meters, spectrophotometry, and oxi Top. Additionally, Total hardness and magnesium and calcium levels were determined using the Titremetric Method (APHA 2005).

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The pollutant reduction efficiency and porosity were calculated using Equations 1 and 2, respectively [2]. Fecal and total coliforms were calculated using APHA [19]. method, and bacterial colonies were counted using Equation 3.

$$R = ((Ic - Oc)/Ic) \times 100\% \quad (1)$$

$$\text{Porosity} = ((Vt\text{-}Vs)/Vt) \text{ x } 100\% \quad (2)$$

$$Colonies\ forming\ unit \frac{(CFU)}{100}\ mL = Rd \times 100 \times \frac{n}{FS} \quad (3)$$

where Ic is the inlet concentration, Oc is the outlet concentration, Vt is the total volume, Vs is the volume of the solids, *CFU is the* colony forming unit, Rd; Reciprocal dilution, *n is* the number of colonies in the plate, *and FS is the* filter sample size.

2.1. Experimental Set Up

Data analysis was performed using Microsoft Excel, while statistical analyses, including the Shapiro-Wilk test, t-test, and Mann-Whitney U test, were performed using IBM SPSS Statistics version 22. The Shapiro-Wilk test was used to check data normality, and the t-test and Mann-Whitney U test were used to identify significant differences between filters for parametric and non-parametric data.

3. Results and Discussion

The raw greywater characteristics for the period between 4/10/2022 and 26/12/2022 are presented in Table 2. The physicochemical parameters of treated water reflect the biological activities that occur in wetland systems to improve treatment performance [2].

The mean temperature values for treated water during the study period were lower than the corresponding values for untreated water [20,21]. The pH level affects bacterial growth and activities when the pH of water is within the range of 4 to 9.5 [22,2].

The outflow values of TU, TDS, and TSS for the filters were lower than those for raw water (Tables 2 and 3). The profiles of the raw and treated water characteristics in terms of the TU, TDS, and TSS are shown in the figures. 2d, e, and f). TSS removal was due to TSS trapping and the high porosity of the substrates in the filters [23,24]. The mean outflow values of TU, TDS, and TSS for the gravel-ceramic bed were lower than those for the gravel bed. Tung et al. [25] and Guo et al. [16]confirmed the same outcome. No difference (p > 0.05) was observed between the two filters in terms of TU (p = 0.199, t-test) and TSS (p = 0.106, T- test), but there was a significant difference (p <0.05) in TDS (p =0.078, Mann-Whitney U test). This means that the ceramic did not significantly affect these parameters. All TSS outflow values for the treated water ranged from sound to acceptable [26]. In contrast, TDS records extended from poor to unacceptable water quality.

The outflow electrical conductivity values were lower than the inflow values, which is attributed to the presence of plants in both treatment systems [27,28].

The removal rate of total suspended solids (TSS) was slightly higher in filter A2 (79.59%) than in A1 (79.40%), and the reduction in both filters was attributed to mechanical filtration and plant root growth [29,30]. The removal of total dissolved solids (TDS) and total organic matter (TU) was lower in A1 than in A2, with a significant difference in the mean TDS removal (p = 0.00, Mann-Whitney U test). The removal of electrical conductivity (EC) was lower in filter A2 than in A1, but there were no significant differences between the two filters (p=0.372, Mann-Whitney U test) (Fig.3a).

The outflow Dissolved oxygen concentrations were ranged between 5.3 and 8.4 mg/L, confirming high nitrification and limited denitrification processes. The outflow DO values were significantly higher than those of the inflow water (Tables 2 and 3, Fig. 2g). This is due to the shallow depth of the designed wetland, which allows oxygen in the system to be affected by atmospheric diffusion and consequently enhances the concentration of DO in the treated water [31]. The presence of aquatic plants also increased the concentration of DO in the system. The DO values were significantly higher ($p \leq 0.05$) in A2 than in A1 (p = 0.005, t-test). This reflects the impact of the ceramic, which reduces the bio-requirements for oxygen and ammonia. As a result of the activity of microorganisms and their

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ability to remove pollutants, they consume dissolved oxygen but are compensated through the process of photosynthesis by plants, which are highly active in A2 [32].

The outflow COD and BOD_5 records were less than those of raw water, which is attributed to the breakdown of organic matter in both filters [25,33]. The study also found that the removal of chemical oxygen demand (COD) was due to organic matter decomposition in wetland systems, and the average reduction efficiency of COD was slightly higher in A2 (86.61%) than in A1 (84.33%), with no significant difference between the two filters ($p = 0.290$, Mann-Whitney U test). The ratio of biological oxygen demand (BOD_5) to COD was within the range of the lowest biodegradability [34]. The mean BOD_5 removal rate was higher in filter A1 (56.49%) than in filter A2 (55.92%), but there were no significant differences between the two filters ($p = 0.927$, t-test) (Fig.3b).

The outflow ammonia values were noticeably lower than the inflow values, which is attributed to the presence of an aerobic environment in both filters (high DO level) [31]. The outflow NO_3 values were somewhat less than those of the inflow water, and the mean PO_4 records of the treated water were lower than those of the inflow water [35,13].

In terms of nitrogen and phosphorus removal, the study found that the mean removal efficiency of ammonia (NH_3) was very high in both filters, with no significant differences between them ($p > 0.05$), and the mean nitrate (NO_3) removal efficiency was very low in both filters, with no significant differences ($p = 0.254$, Mann-Whitney U test). The reduction in phosphate (PO_4) was slightly higher in A2 (55.16%) than in A1 (52.10%), with no significant differences between the two filters ($p = 0.694$, Mann-Whitney U test) (Fig.3c).

Calcium and magnesium concentrations decreased in treated water, which is attributed to their absorption by plants [35,36]. The total hardness (TH) values of the treated water of A2 were significantly lower than those of A1, confirming the impact of ceramic on the TH reduction rate [36]. Ceramic is a beneficial adsorbent material that enhances the removal rates of calcium and magnesium, with significant differences in the mean magnesium removal rates ($p = 0.046$, t-test) between the two filters (Fig.3d).

The study observed a reduction in fecal coliform concentrations in both filters, with lower values in A2 than in A1, and no significant difference in total coliform concentrations between the two filters (Fig.4). Finally, the study found that the plants grew well during the experiment period in both treatment systems36,37, 38, 39 ,40,24 ,20, 33, 41,25,42).

Table 1. Treatment systems details.

Details	A1	A2
Length (cm)	26	26
Width (cm)	85	85
Depth (cm)	45	45
Influent volume (liter)	25	25
HRT (days)	5	5
Water depth (cm)	35	35
Porosity (%)	29	29
Vegetation	*Bacopa monnieri* L.	*Bacopa monnieri* L.
Ceramic weight (kg)	-	42
Gravel weight (kg)	85	43
Size of gravel /sides	40-80 mm	40-80 mm
Bottom layer (10 cm depth)	Gravel 10-20 mm	Gravel 10-20 mm
Middle layer (15 cm depth)	Gravel 10-20 mm	ceramic 10-20 mm
Top layer (15 cm depth)	Gravel 5-10 mm	Gravel 5-10 mm

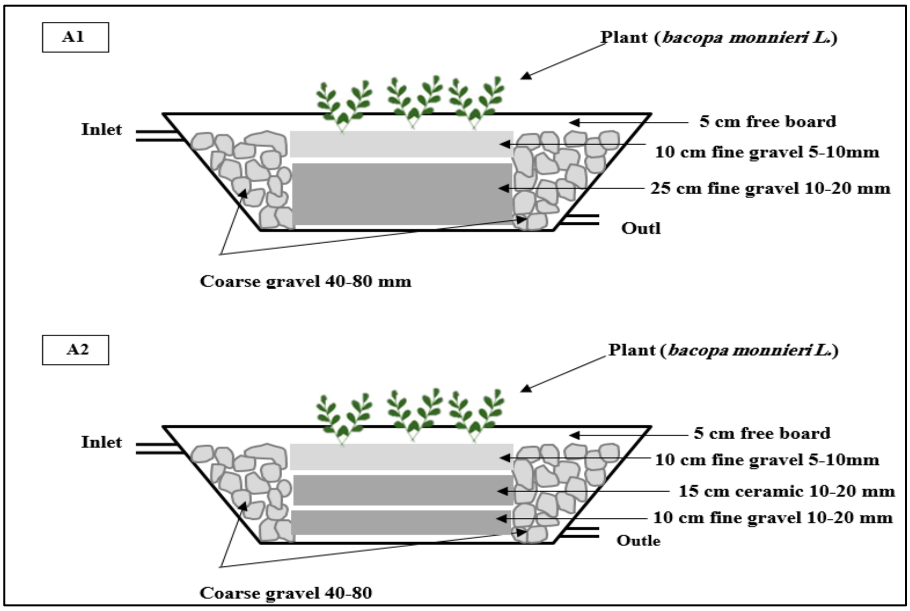

Figure 1. Schematic diagram of the experimental setup.

Table 2. Characteristics of the raw greywater (Note: readings number is 15).

Parameter (unit)	Average	Standard deviation	Maximum	Minimum
Temp. (°C)	27.5	2.0	30.9	24.3
pH	9.6	0.8	11.3	8.4
EC (mS/cm)	2.9	1.7	6.2	1.1
TU (NTU)	284.1	138.5	648.0	105.0
TDS (mg/L)	2070.7	828.4	3212.0	766.0
TSS (mg/L)	558.5	434.2	1420.0	140.0
DO (mg/L)	5.0	0.8	6.0	3.1
BOD_5 (mg/L)	288.0	48.9	400.0	200.0
COD (mg/L)	1313.4	270.0	1646.0	876.0
NO_3 (mg/L)	46.2	7.6	63.1	36.6
NH_3 (mg/L)	1238.0	202.3	1652.0	866.0
PO_4 (mg/L)	12.5	3.0	20.0	8.1
Total hardness (mg/L)	1011.26	310.81	1700.00	600.0
Ca^{+2}(mg/L)	250.6	73.7	416.8	160.3
Mg^{+2}(mg/L)	184.8	60.8	329.3	87.4

Table 3. Treated water characteristics (Note: number of readings, 15).

Parameter	Filter	Average	Standard deviation	Maximum	Minimum
Temp (^{o}C)	A1	25.7	2.6	30.9	22.6
	A2	24.4	2.7	28.7	20.7
pH	A1	9.1	0.4	9.9	8.3
	A2	9.1	0.3	9.5	8.1
EC (mS/cm)	A1	1.7	1.2	4.1	0.4
	A2	1.7	1.2	4.2	0.3
TDS (mg/L)	A1	1105.3	426.8	1642.0	423.0
	A2	898.2	373.8	1449.0	329.0
TSS (mg/L)	A1	71.8	14.2	93.0	33.0
	A2	63.1	13.4	86.7	44.0
TU(NTU)	A1	53.1	13.6	77.1	21.2
	A2	44.2	21.5	95.5	16.3
DO(mg/L)	A1	6.9	0.9	8.4	5.3
	A2	6.9	0.9	8.4	5.3
BOD_5 (mg/L)	A1	124.0	51.7	260.0	20.0
	A2	125.3	49.8	260.0	20.0

Parameter	Filter	Average	Standard deviation	Maximum	Minimum
COD (mg/L)	A1	204.5	54.1	268.0	99.0
	A2	180.9	66.8	275.0	92.0
NO_3 (mg/L)	A1	34.6	8.0	51.4	24.5
	A2	35.2	8.0	51.6	24.7
NH_3 (mg/L)	A1	8.1	0.9	10.1	6.8
	A2	11.0	1.1	14.3	9.2
PO_4 (mg/L)	A1	5.5	0.8	6.9	4.4
	A2	5.2	0.9	6.4	3.5
Total hardness(mg/L)	A1	699.6	286.9	1320.0	380.0
	A2	629.9	280.6	1240.0	360.0
Ca^{+2} (mg/L)	A1	166.9	54.6	272.5	104.2
	A2	157.8	71.2	312.6	88.2
Mg^{+2}(mg/L)	A1	128.1	54.2	235.1	67.0
	A2	113.4	49.1	219.5	64.1

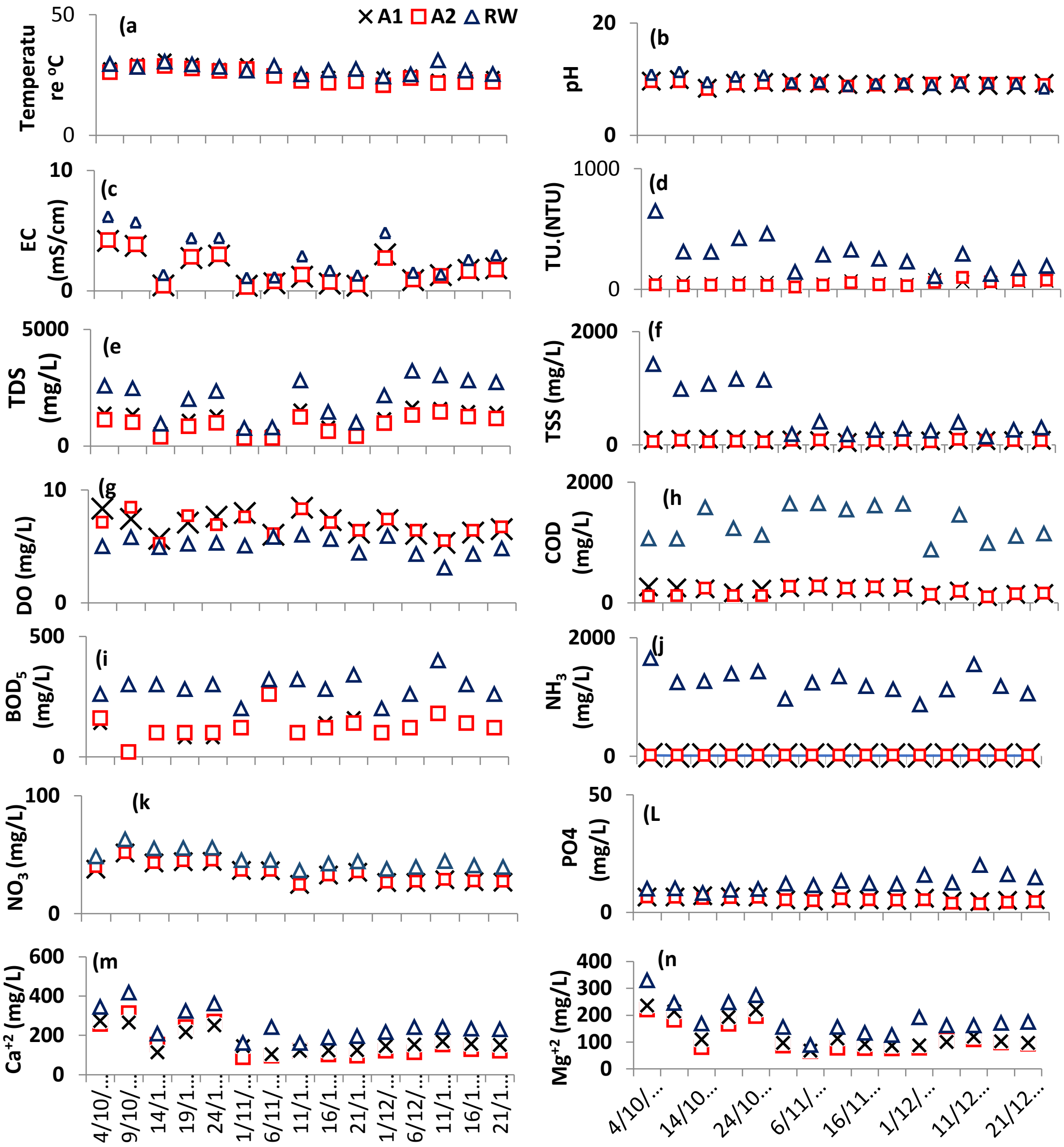

Figure 2. Outflow-water characteristics during the study period (RW: raw wastewater; A1: treated water from plant + gravel filter; A2: treated water from plants+ ceramic+ gravel filter).

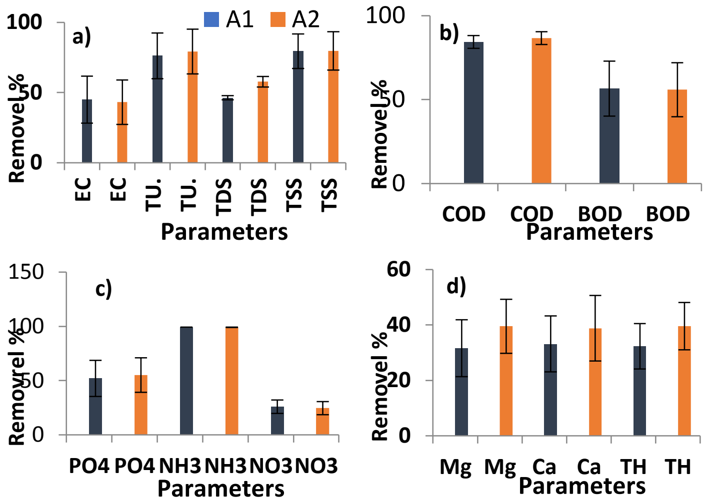

Figure 3. Mean removal efficiency of treatment filters (A1: treated water by plant + gravel filter; A2: treated water by plants+ ceramic+ gravel filter).

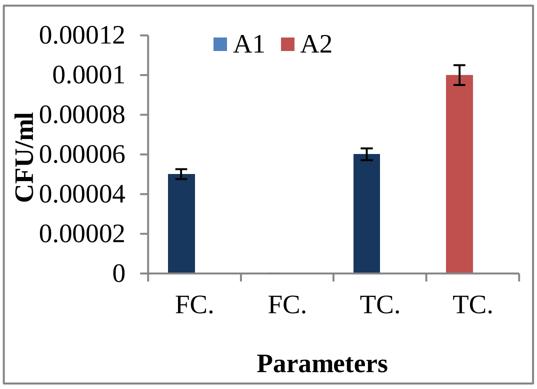

Figure 4. Fecal and total coliform bacterial concentrations. (A1: treated water by plant + gravel filter; A2: treated water by plants+ ceramic+ gravel filter).

Conclusions

The text above describes a study on a designed horizontal flow constructed wetland (HFCW) in Basra City. The study found that both treatment systems enhanced the graywater characteristics. The gravel-ceramic bed achieved higher COD removal rates, but lower BOD_5 removal rates compared to the gravel bed. Both filters achieved high NH3 and low NO_3 removal rates. The reduction in PO_4 was slightly greater in the ceramic gravel bed. The ceramic-gravel bed had higher removal rates for Ca^{+2}, Mg^{+2}, TDS, TU, and EC compared to the gravel bed. Both filters reduced fecal coliform concentrations, with zero fecal coliform in the ceramic-gravel filter. The plants grew well and remained green during the experiment period.

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References

[1] Abunaser SG and Abdelhay A 2020 Performance of a novel vertical flow constructed wetland for greywater treatment in rural areas in Jordan EnvironmentalTechnology 1-11 https://doiorg/101080/0959333020201841832

[2] Zaboon B H Al-Abbawy D A and Yaseen D A 2022 Improving Wastewater Reclamation Using Constructed Wetlands by Artificial Plastic Biofilm Carriers Journal of Ecological Engineering 23 11 241-253DOI: https://doiorg/1012911/22998993/153459

[3] Juan Y K Chen Y and Lin J M 2016 Greywater reuse system design and economic analysis for residential buildings in Taiwan Water Vol 8 11 546 https://doiorg/103390/w8110546

[4] Al-Nabhan E A M and Al-Abbawy D A 2021 Improving Wastewater Quality By Using Ceratophyllum Demersum L In IOP Conference Series: Earth and Environmental Science 910 1 p012086 IOP Publishing https://doiorg/101088/1755-1315/910/1/0120861

[5] Abdelhay A and Abunaser S G 2021 Modeling and economic analysis of greywater treatment in rural areas in Jordan using a novel vertical-flow constructed wetland Environmental Management 67 3 477-488 https://doiorg/101007/s00267-020-01349-7

[6] Laaffat J Aziz F Ouazzani N and Mandi L 2016 Biotechnological approach of greywater treatment and reuse for landscape irrigation in small communities Saudi journal of biological sciences 26 1 83-90 https://doiorg/101016/jsjbs201701006

[7] Spychala M Niec J Zawadzki P Matz R Nguyen TH2019 Removal of volatile solids from greywater using sand filters Appl Sci 770 2–13 https://doiorg/103390/app9040770

[8] Couto EAD Calijuri ML Assemany PP Santiago AF Lopes LS 2015 Greywater treatment in airports using anaerobic filter followed by UV disinfection: an efficient and low cost alternative J Clean Prod 106 372–379

[9] Chrispim M C and Nolasco M A 2017 'Greywater treatment using a moving bed biofilm reactor at a university campus in Brazil' Journal of Cleaner Production Elsevier Ltd 142 290296 https://doiorg/101016/jjclepro201607162

[10] Gizinska-Górna M Czekała W Józwiakowski K Lewicki A Dach J Marzec M Pytka A Janczak D Kowalczyk-Jusko A Listosz A 2016 The possibility of using plants from hybrid constructed wetland wastewater treatment plant for energy purposes Ecol Eng 95 534541

[11] Yaseen D A Scholz M 2016 Shallow pond systems planted with Lemna minor treating azo dyes Ecological engineering 94 295305 http://dxdoiorg/101016/jecoleng201605081

[12] Yaseen D A Scholz M 2018 Treatment of synthetic textile wastewater containing dye mixtures with microcosms Environmental Science and Pollution Research 25 1980-1997 https://doiorg/101007/s11356-017-0633-7

[13] Shukla R Gupta D Singh G and Mishra V K 2021 Performance of horizontal flow constructed wetland for secondary treatment of domestic wastewater in a remote tribal area of Central India Sustainable Environment Research 31 1 110 https://doiorg/101186/s42834-021-00087-7

[14] Shaikh I N and Ahammed M M 2020 Quantity and quality characteristics of greywater: a review Journal of environmental management 261 110266 https://doiorg/101016/jjenvman2020110266

[15] Priya S G and Brighu U 2013 Comparison of different types of media for nutrient removal efficiency in vertical upflow constructed wetlands International Journal of Environmental Engineering and Management 4 5 https://doiorg/101186/s42834-021-00087-7

[16] Guo X Cui X Li H and Xiong B 2021 Purifying effect of biochar-zeolite constructed wetlands on arsenic-containing biogas slurry in large-scale pig farms Journal of Cleaner Production 279 123579 https://doiorg/101016/jjclepro2020123579

[17] Bulta A L and Micheal G A W 2019 Evaluation of the efficiency of ceramic filters for water treatment in Kambata Tabaro zone southern Ethiopia Environmental Systems Research 8 1 115 https://doiorg/101186/s40068-018-0129-6

[18] Al-Nabhan E A 2023 Water hyssop as bioaccumulator for remediation of Lead Nickel and Iron Marsh bulletin 17 1 30-39

[19] APHA 2005 Standard methods for the examination of water and wastewater 21st edn American Public Health Association APHA American Water Works Association and Water and Environment Federation Washington DC

[20] Kadlec RH Wallace SD 2008 Treatment wetlands Boca Raton Florida: CRC Press https://doiorg/101201/9781420012514

[21] Chyan JM Senoro DB Lin CJ Chen PJ Chen IM 2013 A novel biofilm carrier for pollutant removal in a constructed wetland based on waste rubber tire chips International Biodeterioration & Biodegradation 85 638645 https://doiorg/101016/jibiod201304010

[22] Qian W Ma B Li X Zhang Q and Peng Y 2019 Long-term effect of pH on denitrification: High pH benefits achieving partial-denitrification Bioresource Technology 278 444449.
[23] Zidan ARA El-Gamal MM Rashed AA Eid MAAEH 2015 Wastewater treatment in horizontal subsurface flow constructed wetlands using different media setup stage Water Science 29 1 26–35 https://doiorg/101016/jwsj201502003
[24] Hdidou M Necibi M C Labille J El Hajjaji S Dhiba D Chehbouni A and Roche N 2021 Potential use of constructed wetland systems for rural sanitation and wastewater reuse in agriculture in the Moroccan context Energies 151 p156 https://doiorg/103390/en15010156
[25] Tung T X Xu D Zhang Y Zhou Q Wang X Pan Y and Wu Z 2019 Effective Purification in Constructed Wetlands Using Strontium-Doped TiO 2 Coated on Porous Ceramic Filter Media Polish Journal of Environmental Studies 28 6 DOI: https://doiorg/1015244/pjoes/99243
[26] Zamora S Marín-Muñíz JL Nakase-Rodríguez C Fernández-Lambert G Sandoval L2019 Wastewater treatment by constructed wetland eco-technology: Influence of mineral and plastic materials as filter media and tropical ornamental plants Water 11 11 p 2344 https://doiorg/103390/w11112344
[27] Lastiri-Hernández M A Álvarez-Bernal D Cruz-Cárdenas G Silva-García J T Conde-Barajas E and Oregel-Zamudio E 2023 Potential of Epipremnum aureum and Bacopa monnieri L Wettst for Saline Phytoremediation in Artificial Wetlands Water 15 1p 194 https://doiorg/103390/w15010194
[28] Yaseen DA Scholz M 2017 Comparison of experimental ponds for the treatment of dye wastewater under controlled and semi-natural conditions Environmental Science and Pollution Research 24 19 1603116040 https://doiorg/101007/s11356-017-9245-5
[29] Tsang E 2015 Effectiveness of Wastewater Treatment for Selected Contaminants Using Constructed Wetlands in Mediterranean Climates https://repositoryusfcaedu/capstone/128
[30] Gupta P Ann T W and Lee S M 2016 Use of biochar to enhance constructed wetland performance in wastewater reclamation Environmental Engineering Research 21 1 36-44.
[31] Wang W Ding Y Ullman J L Ambrose R F Wang Y Song X and Zhao Z 2016 Nitrogen removal performance in planted and unplanted horizontal subsurface flow constructed wetlands treating different influent COD/N ratios Environmental Science and Pollution Research 23 9 9012-9018 https://doiorg/101007/s11356-016-6115-5
[32] Paul D and Hall S G2021 Biochar and Zeolite as Alternative Biofilter Media for Denitrification of Aquaculture Effluents Water 13 19 2703 https://doiorg/103390/w13192703
[33] Mohamed R M S R Ahmad M S L Bakar S A Musa S and Kassim A H M 2019 Ceramic Tile Waste for Treating Laundry Greywater Pertanika Journal of Science & Technology 27 3
[34] Zhang B Ning D Yang Y Van Nostrand JD Zhou J Wen X 2020 Biodegradability of wastewater determines microbial assembly mechanisms in full-scale wastewater treatment plants Water Research 169 p 115276 https://doiorg/101016/jwatres2019115276
[35] Kozak C Schirmer W N Gomes S and da Fonseca A F 2014 verifying the efficacy in removing nutrients using wastewater treatment stations by constructed wetlands Recursos Hídricos 35 1
[36] Chaukura N Chiworeso R Gwenzi W Motsa M M Munzeiwa W Moyo W and Nkambule T T 2020 A new generation low-cost biochar-clay composite 'biscuit'ceramic filter for point-of-use water treatment Applied Clay Science 185 105409 https://doiorg/101016/jclay2019105409
[37] Wand H Vacca G Kuschk P Kruger M Kastner M 2007 Removal of bacteria by filtration in planted and non-planted sand columns Water Research 41 1 159–167 https://doiorg/101016/jwatres200608024
[38] Vymazal J 2005 Removal of enteric bacteria in constructed treatment wetlands with emergent macro-phytes: A review Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering 40 6–7 1355–1367 https://doiorg/101081/ESE-200055851
[39] Vymazal J 2007 Removal of nutrients in various types of constructed wetlands Science of the total environment 3 801–3 48–65 https://doiorg/101016/jscitotenv200609014
[40] Andreo-Martínez P; García-Martínez N; Quesada-Medina J; Almela L 2017Domestic wastewaters reuse reclaimed by an improved horizontal subsurface-flow constructed wetland: A case study in the southeast of Spain Bioresour Technol 233 236–246 https://doiorg/101016/jbiortech201702123
[41] Oliveira GA Colares GS Lutterbeck CA Dell'Osbel N Machado ÊL Rodrigues LR 2021 Floating treatment wetlands in domestic wastewater treatment as a decentralized sanitation alternative Science of the Total Environment 773 145609 https://doiorg/101007/s11356-021-17395-5
[42] Zhang L Zhao J Cui N Dai Y Kong L Wu J Cheng S 2016 Enhancing the water purification efficiency of a floating treatment wetland using a biofilm carrier Environmental Science and Pollution Research 23 8 74377443 https://doiorg/101007/s11356-015-5873-9.