

Article

Assessment of the effectiveness of *Phragmites australis* versus *Typha latifolia* in wastewater treatment through horizontal and vertical flow planted filters in arid environment

Amiri Khaled ^{1 *}, Bekkari Naçouredine ¹, Bouchahm Nora ², Hadjoudj Moussa¹, Benmalek Ahmed ² and Kherifi Wahida ²

¹ Scientific and technical research center for arid areas (CRSTRA), Touggourt, (Algeria); ked_am83@hotmail.fr, bekkarinaceur@gmail.com, mhadjoudj@gmail.com

² Scientific and technical research center for arid areas (CRSTRA), Biskra, (Algeria); bouchahm_nora@yahoo.fr, ahmed.benmalek@yahoo.fr, wahidakherifi@yahoo.fr

* Correspondence: ked_am83@hotmail.fr ORCID: 0000-0003-3140-7586

Received: 14 May 2026
Accepted: 8 July 2026

Citation: Amiri, K.; Bekkari, N.; Bouchahm, N.; Hadjoudj, M.; Benmalek A. & Kherifi W. Assessment of the effectiveness of *Phragmites australis* versus *Typha latifolia* in wastewater treatment through horizontal and vertical flow planted filters in arid environment. *Journal Algérien des Régions Arides* 2026, 19 (2): 1–16.

Publisher's Note: ASJP is an electronic publishing platform for Algerian scientific journals managed by CERIST, that is not responsible for the quality of content posted on ASJP.



Copyright: © 2022 by the CRSTRA. Algerian Journal of Arid Regions is licensed under a Creative Commons Attribution Non Commercial 4.0 (CC BY NC) license.

Abstract: This study compares the wastewater purification capabilities of common reed (*Phragmites australis*) and cattail (*Typha latifolia*) in horizontal (HF-CWs) and vertical (VF-CWs) flow constructed wetlands during four months, and three days of hydraulic retention time (HRT). The analysis focused on the removal of organic matter and nutrient pollutants. Results indicated that *Typha latifolia* excelled in removing total suspended solids (TSS) (92%), biochemical oxygen demand (BOD₅) (88%), ammonium nitrogen (NH₄-N) (69%), total Kjeldahl nitrogen (TKN) (67%), and phosphate (PO₄-P) (98%) in HF-CWs. In contrast, *Phragmites australis* showed superior removal of chemical oxygen demand (COD) (93%) and total phosphorus (TP) (86%). In VF-CWs, *Phragmites australis* outperformed *Typha latifolia* in TSS (23%), BOD₅ (88%), COD (88%), TKN (94%), and TP (90%). Whereas, *Typha latifolia* was more efficient for only NH₄-N (98%) and PO₄-P (93%). Both species exhibited negative nitrate removal efficiency. Overall, both macrophytes are suitable for large-scale constructed wetlands in arid climate.

Keywords: Wastewater, *Phragmites australis*, *Typha latifolia*, HF-CWs, VF-CWs, Physicochemical parameters.

1. Introduction

Discharging untreated domestic wastewater into the environment results in the degradation of water quality and the contamination of groundwater, posing risks to both the environment and human health [1]. Therefore, it is essential to systematically treat this water by implementing appropriate wastewater treatment methods before releasing it into the natural environment [2]. In this regard, various wastewater treatment techniques have been developed; however, many of them, such as the activated sludge process, trickling filter, and membrane bioreactors, are not feasible for use in developing countries [3, 4]. As a result, prioritizing the treatment of domestic wastewater with ecotechnology that requires low costs, minimal energy, and less maintenance is essential for many countries worldwide [5,6]. To this end, constructed wetlands (CWs) are viewed as a practical option for treating polluted effluents [7, 8]. This technology is one of the effective natural treatment systems employed in numerous countries worldwide. CWs are engineered wetlands that incorporate macrophytes, intended to replicate the physical, chemical, and biological processes found in natural wetlands [9]. These processes include sedimentation, filtration, precipitation, sorption, plant uptake, microbial decomposition, and nitrogen transformations [10]. These systems enhance water quality by retaining or transforming various

constituents and have been effectively used to reduce environmental pollution by removing a range of wastewater pollutants, including organic compounds, suspended solids, pathogens, metals, colorants, pesticides, and nutrients [11,12]. The effective operation of CWs relies on the interaction between plants, substrate, and microorganisms, which is influenced by the type of structure and the wastewater treatment employed [13]. CWs are generally classified into the following categories: (1) Free Water Surface (FWS), (2) Vertical Subsurface Flow (VSF-CWs), (3) Horizontal Subsurface Flow (HSF-CWs), and (4) Hybrid Flow Wetlands [14, 15]. Furthermore, subsurface flow-type CWs are commonly utilized for treating domestic wastewater [16]. While Horizontal Subsurface Flow (HSF-CWs) systems are the most prevalent, Vertical Subsurface Flow (VSF-CWs) systems are gaining popularity at present [17]. The presence of macrophytes is a defining characteristic of wetlands, setting CWs apart from unplanted soil filters or lagoons [18, 19]. These plants serve several crucial functions that enhance purification efficiency and extend the operational lifespan of CWs. They significantly contribute to the direct uptake of pollutants from wastewater, while the transformation and mineralization of nutrient and organic pollutants largely rely on the microbial communities associated with their root systems [20]. Choosing plant species for CWs necessitates careful consideration, as the vegetation must be resilient enough to withstand the potential toxic effects of wastewater and its variability [21]. Among the plants frequently used in CWs, common reed (*Phragmites australis*) and cattail (*Typha latifolia*) are classified as emergent aquatic species with a high growth rate [22]. These macrophytes are part of the helophyte group and are distinguished by their highly active root systems, which can withstand harsh conditions even when the above-ground parts of the plants are dry [23]. These two plant species can be valuable assets for restoring eutrophic systems, as they possess a strong ability to degrade nitrogen, phosphorus, and organic matter in wetland environments [2]. They may potentially be utilized for treating saline wastewaters or in CWs located in areas with high evapotranspiration, which raises the salinity of the wastewater [24]. This study aims to compare the purification capabilities of *P. australis* and *T. latifolia* in removing organic matter and nutrient pollutants from wastewater in horizontal flow constructed wetlands (HF-CWs) and vertical flow constructed wetlands (VF-CWs) under identical operational conditions. Additionally, it seeks to identify the most suitable types of CWs for pollutant removal in domestic wastewater in arid climates.

2. Materials and Methods

2.1. Experimental setup

The pilot constructed wetland systems were carried out at the Scientific and Technical Research Center for Arid Regions in Touggourt, located in Southeast Algeria (33°04'37.94"N, 6°02'29.34"E), for the treatment of domestic wastewater. This region experiences an arid climate with summer temperatures exceeding 40°C (in July and August) and an annual rainfall of just 80 mm. For this study, two horizontal flow constructed wetlands (HF-CWs), and two vertical flow constructed wetlands (VF-CWs) were installed (Figure 1). The experiments were monitored for four months (April to July). The HF-CWs were circular, measuring 0.25 m in height and covering an area of 0.28 m². They were filled with coarse gravel (Ø=20 mm) at the inlet and outlet, while the rest consisted of two overlapping layers: fine gravel (Ø=10 mm) and fine sand (Ø=0.2 mm). The VF-CWs were created using cylindrical plastic tanks that were 0.8 m high with a diameter of 0.4 m and a volume of 0.10 m³ each. Each tank featured a valve at the base for bottom water sampling and piezometer tubing (10 mm diameter) to monitor the water level. The substrates for the VF-CWs consisted of two overlapping layers: the lower layer, composed of coarse gravel (Ø=20 mm) and 0.15 m deep for drainage, and the upper layer, consisting of fine sand (Ø=0.2 mm) at a depth of 0.6 m, placed in both systems. The HF-CWs and VF-CWs were planted with reed (*Phragmites australis*) in the first CW and cattail (*Typha latifolia*) in the second CW, at a density of 30 rhizomes per square meter [25]. These plant species are well-suited to the climatic conditions of the region.

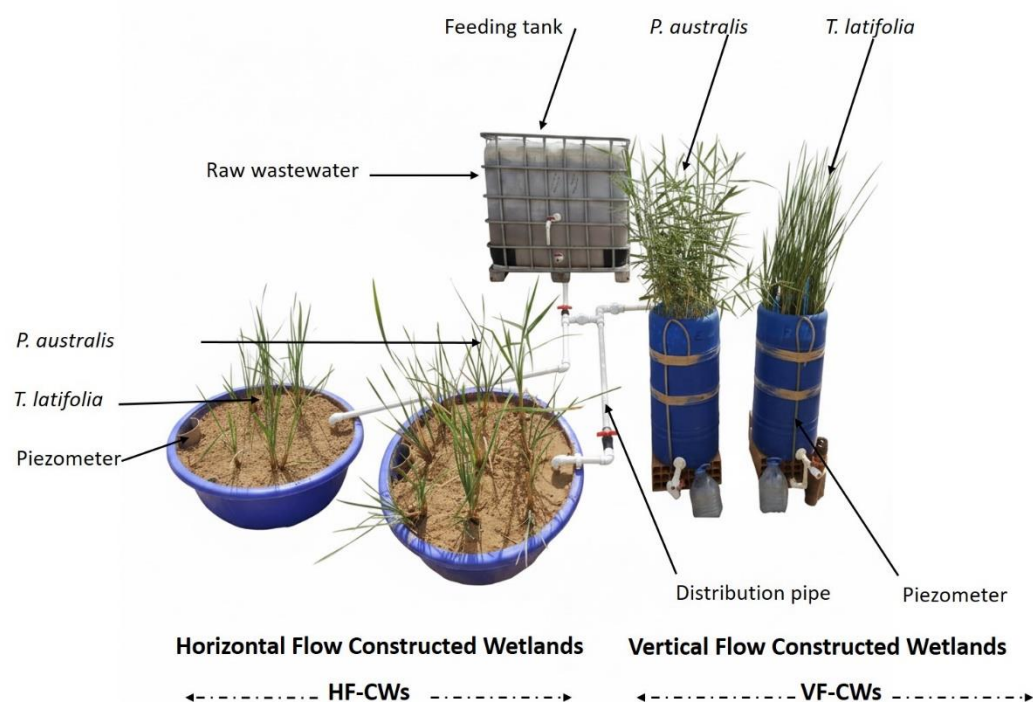


Figure 1. Pilot-scale of wastewater treatment systems using HF-CWs and VF-CWs.

2.2. Samples collection and analytical methods

During the experimental period, one liter of wastewater samples were collected from all inlet and outlet points of the constructed wetlands (CWs) at 9:00 AM after a hydraulic retention time (HRT) of 3 days. Sampling occurred once a week for the horizontal flow constructed wetlands (HF-CWs) and twice a week for the vertical flow constructed wetlands (VF-CWs), using opaque glass bottles. The collected samples were promptly transported to the CRSTRA (Scientific and Technical Research Center for Arid Areas) laboratory for immediate analysis of the following parameters: Total suspended solids (TSS), Biological oxygen demand (BOD₅), Chemical oxygen demand (COD), Nitrate nitrogen (NO₃-N), Ammonium nitrogen (NH₄-N), Total Kjeldahl nitrogen (TKN), Orthophosphate phosphorus (PO₄-P), and Total phosphorus (TP). In situ measurements were taken for pH, Electrical conductivity (EC), and Temperature. A total of 17 samples were analyzed for HF-CWs, while 35 samples were analyzed for VF-CWs, following approved standard methods [26]. Treatment efficiency was assessed using the average influent and effluent concentrations of the key water quality parameters. The pollutant removal efficiencies were calculated using the following equation:

$$R \% = \frac{(C_0 - C_1)}{C_0} \times 100 \quad \dots\dots\dots (1)$$

Where, C_0 was inflow pollutant concentration (mg/l). C_1 was Outflow pollutant concentration (mg/l) and R was pollutant removal efficiency.

2.3. Statistical analysis

In this study, the effectiveness of wastewater treatment in vertical flow constructed wetlands (VF-CWs) and horizontal flow constructed wetlands (HF-CWs) planted with *P. australis* and *T. latifolia* was statistically assessed by comparing the mean values of various physicochemical parameters under identical operating conditions using SPSS statistical software (version 15). One-way analysis of variance (ANOVA) was employed to identify significant statistical differences ($p < 0.05$) in the wastewater treatment performance of

each system between *P. australis* and *T. latifolia*. A post hoc LSD test was conducted to pinpoint the differences among the means.

3. Results

3.1. Performance and removal efficiencies

The treatment performance of the influents and effluents from two configurations of vertical and horizontal flow constructed wetlands, both planted with the same species (*P. australis* and *T. latifolia*), was evaluated, focusing specifically on the physicochemical parameters. Tables 1 and 2 display the results of the physicochemical characterization of the wastewater influent and effluent over the four-month experimental period (with a total of 17 samples for HF-CWs and 35 samples for VF-CWs).

Table 1: Characteristics of wastewater influents used in the horizontal (n=17) and vertical flow (n=35) constructed wetlands during four months of the experimental period.

Parameters	Units	HF-CWs	VF-CWs
Temperature	°C	29.74 ± 4.28 ^(a) (20.80-37.00) ^(b)	28.61 ± 4.78 (21.20-37.60)
pH	-	7.73 ± 0.19 (7.39-8.10)	7.60 ± 0.16 (7.60-8.24)
Electrical Conductivity (EC)	ms/cm	7.96 ± 1.45 (6.93-12.12)	9.84 ± 2.90 (5.00-17.88)
Total Suspended Solid (TSS)	mg/l	398.53 ± 284.57 (20.00-1261.25)	49.83 ± 67.88 (1.25-325.00)
Biochemical Oxygen Demand (BOD ₅)	mg/l	334.70 ± 90.29 (170.00-490.00)	71.41 ± 26.00 (50.00-140.00)
Chemical Oxygen Demand (COD)	mg/l	1024.94 ± 227.29 (660.00-1365.00)	324.43 ± 201.55 (76.00-864.00)
Nitrate Nitrogen (NO ₃ -N)	mg/l	1.097 ± 0.368 (0.298-1.794)	0.492 ± 0.405 (0.028-1.637)
Ammonia Nitrogen (NH ₄ -N)	mg/l	126.264 ± 29.859 (70.000-162.400)	50.852 ± 12.219 (39.200- 89.600)
Total Kjeldahl Nitrogen (TKN)	mg/l	174.412 ± 48.293 (96.60-295.40)	57.462 ± 17.824 (32.20-110.60)
Phosphate Phosphorous (PO ₄ -P)	mg/l	5.785 ± 1.726 (2.181-7.991)	2.244 ± 1.249 (0.879-7.320)
Total Phosphorus (TP)	mg/l	7.015 ± 2.395 (3.022-12.880)	2.464 ± 1.231 (1.256-7.426)

^(a) Mean ± Standard deviation; ^(b) Min-Max; n: number of samples

Table 2: Average concentration of the effluents water quality parameters along HF-CWs (n=17) and VF-CWs (n=35).

Parameters	HF-CWs		VF-CWs	
	Ph	Ty	Ph	Ty
T (°C)	27.38±3.73 ^(a) (19.9-34) ^(b)	26.95±3.57 (20.6-32.3)	27.68 ±4.34 (19.3-36.5)	28.03±4.17 (19.8-36.8)
pH	7.30±0.09 (7.13-7.46)	7.13±0.11 (6.9-7.31)	7.66±0.28 (7.28-8.57)	7.56±2.24 (7.32-8.72)
CE (ms/cm)	29.34±8.26 (17.96-40.2)	22.46±4.37 (16.18-27.7)	14.38±4.21 (7.76-24.1)	16.67±6.38 (8.82-28.3)
TSS (mg/l)	125.44±45.12 (58.75-222.5)	71.83±28.53 (11.25-123.75)	38.30±13.94 (16.25-71)	38.70±29.85 (1.25-118.75)
BOD ₅ (mg/l)	46.47±49.24 (10-230)	41.33±20.99 (20-90)	11.39±3.75 (7-20)	13.64±5.84 (6-30)

COD (mg/l)	69.70±41.83 (20-133)	91.41±33.97 (19-130)	38.46±25.63 (6-102)	53.70±28.16 (8-132)
NO ₃ -N (mg/l)	1.633±0.830 (0.198-2.716)	1.960±0.660 (0.638-2.773)	0.627±0.880 (0.072-5.38)	0.854±0.574 (0.06-2.778)
NH ₄ -N (mg/l)	72.305±48.849 (1.4-162.4)	38.705±23.300 (1.4-85.4)	2.008±0.742 (0.7-3)	1.100±0.914 (0-3)
TKN (mg/l)	89.317±51.821 (2.8-168)	57.800±43.597 (4.2-169.4)	3.352±1.144 (1.4-7)	3.964±4.563 (0.47-25.20)
PO ₄ -P (mg/l)	0.287±0.315 (0.011-0.917)	0.125±0.130 (0-0.464)	0.250±0.252 (0.105-1.55)	0.166±0.102 (0.03-0.56)
TP (mg/l)	1.002±1.856 (0.054-7.967)	1.806±2.892 (0.01-7.804)	0.250±0.121 (0.143-0.658)	0.301±0.209 (0.039-0.704)

(^a) Mean ± Standard deviation; (^b) Min-Max; n: number of samples; Ph: *P. australis* CWs; Ty: *T. latifolia* CW

Table 3: Performance of *P. australis* and *T. latifolia* in wastewater treatment by horizontal and vertical flow CW systems from literature.

Plant	Type of CWs	Location	Removal efficiency (%)								Reference
			TSS	BOD ₅	COD	NO ₃ -N	NH ₄ -N	TKN	PO ₄ -P	TP	
<i>P. australis</i>	VF-CW	Egypt	75	84	75	-	32	-	-	22	[33]
<i>P. australis</i>	VF-CW	Ecuador	63	75	65	-90	71	-	-	49	[42]
<i>P. australis</i>	HF-CW	Italy	-	-	82	58	74	-	-	61	[46]
<i>P. australis</i>	HF-CW	Canada	94	-	90	79	92	-	-	92	[47]
<i>P. australis</i>	HF-CW	Iran	49-71	-	68-72	40-70	-	-	-	-	[48]
<i>T. latifolia</i>	HF-CW	Italy	64	72	76	-	50	52	-	48	[13]
<i>T. angustifolia</i>	HF-CW	Spain	-	-	-	-	-	10	-	78	[29]
<i>T. latifolia</i>	HF-CW	Turkey	-	-	85-88	53	95-97	-	-	95-97	[30]
<i>T. latifolia</i>	HF-CW	Spain	92	97	81	73	40	-	-	-	[39]
<i>T. latifolia</i>	VF-CW	Turkey	74	-	81	-73	60	-	48	-	[45]
<i>T. latifolia</i>	HF-CW	Brazil	-	-	76	-316	25	25	-	69	[49]

3.1.1. Variation of pH and electrical conductivity

pH:

The pH of the influent during the monitoring period ranged from 7.39 to 8.10 and from 7.60 to 8.24 with an average of 7.73 ± 0.19 and 7.60 ± 0.16 for HF-CWs and VF-CWs respectively. The average pH values shown in (Table 2) indicate a slight decrease of the pH in the effluent of HF-CWs, whereas in the VF-CWs, the average pH was at almost steady for inlets and outlets of both species. These values are found in the standard interval (6.5 to 8.5), where the optimum pH for plant development is considered to be from 3.0 to 8.5 for *T. latifolia* and from 3.7 to 8.0 for *P. australis* [27]. According to the one-way ANOVA test, a statistically significant difference in pH values between species of macrophytes for HF-CWs were observed ($p < 0.05$), indicating that pH levels were significantly affected by vegetation type used in this type of experiment. These results are consistent with the results found by [28], which show that the presence of plants in constructed wetlands is responsible for slightly modifying the pH conditions in the rhizosphere.

Electrical conductivity (EC)

During the study period, the electrical conductivity (EC) of the influent was between 6.93 and 12.12 ms/cm for the HF-CWs and between 5.00 and 17.88 ms/cm for the VF-CWs

(Table 1). Electrical conductivity of the effluent samples obtained from both wetland configurations was higher than that of the influent during the experiment period (Table 2). This can be partly attributed to the mineralization of the organics, dissolution of the bed granules and to the high evaporation values [29]. For the outlet of the 1st experiment (HF-CWs), a considerably increase in EC values was observed at both sampling points (HF - Ph, HF -Ty), where the average EC value was higher in CW-Ph than in CW-Ty. Concerning the 2nd experiment (VF-CWs), EC showed also a considerably increase but at a lower value than the first experience, where the average EC value was higher in VF -Ty than in VF -Ph. There are no significant statistical differences determined between VF-Ph and VF-Ty ($p > 0.05$). This result suggests that the effect of vegetation type on the EC purification process may not be important in VF-CWs. The increase of EC value determined at the effluents of both experiments; probably due to evapotranspiration process associated with significant water loss [30]. The EC values of the inflow and outflow of both experiments were greater than the threshold of 3.0 ms/cm, which can led to a negative impact on soil structure and the adsorption capability of macrophytes concerning required water and nutrients [31].

3.1.2. Organic matters and TSS removal

Total suspended solid (TSS)

In this study, The HF-CWs has received a large amount of suspended solids at the entrance (Figure 2a), and the TSS inflow concentrations were generally low in VF-CWs as shown in the Figure 2b. The mean TSS value in the influent wastewater was 398.53 and 49.83 mg/l for HF-CWs and VF-CWs respectively (Table 1). The average outlet concentrations were 125.44 mg/l for HF-Ph, 71.83 mg/l for HF-Ty, 38 mg/l for VF-Ph and VF-Ty (Table 2). In the elimination of TSS, according to the statistical analysis, there is no significant difference between the primary treatment and wastewater treatment by VF-CWs ($p > 0.05$), while in the HF-CWs, One-way ANOVA showed a significant different between influent and both effluents ($p < 0.05$). Regarding the signification between effluent TSS concentrations in the same experiment, not significant was detected in both experiments. These results clearly show that the TSS removal performance is not affected by plants type. As shown in Figure 5, HF-CWs provided the highest removal of TSS (Ph: 68%, Ty: 82%) compared to VF-CWs (Ph: 23%, Ty: 22%), which exhibited low removal efficiency due to the decrease of the concentration in the influent throughout the experiment. The HF-CW planted with *T. latifolia* showed the best behavior with respect to TSS removal when compared to HF-CW planted with *P. australis*. Several studies [13, 27] indicated that the decrease in TSS in CWs is mainly due to physical processes (sedimentation, filtration and adsorption). [32] reported that filtration occurs by particle impact in the roots and stems of macrophytes or in gravel particles in subsurface flow systems. [33] and [34] reported also that the voids and media grain structure in gravel has remarkable impact on suspended solids and trapping during the flow path.

Chemical oxygen demand (COD)

As shown in the Table 1, the average COD influent concentration was extremely high (1024.94 mg/l) in HF-CWs compared to VF-CWs (324.43 mg/l), whereas, effluent mean concentrations for different tested wetlands were 68.64 mg/l for HF-Ph, 91.41 mg/l for HF-Ty, 38.46 mg/l for VF-Ph and 53.70 mg/l for VF-Ty (Table 2). Therefore, the average COD removal efficiencies were 93.20%, 91.08%, 88.16% and 83.66% for HF-Ph, HF-Ty, VF-Ph and VF-Ty respectively. According to the analysis of variance (ANOVA), significant differences ($p < 0.05$) appeared between the influent and effluents water concentrations, but no significant differences between species were observed in both experiments ($p > 0.05$). The monthly removal efficiencies of COD for both effluents of HF-CWs and VF-CWs were over 80% and 70% respectively. The highest average COD removal rate was measured at HF-Ph (95.65%) in June (Figure 2b), and at VF-Ph (94.33%) in April (Figure 2b). This indicate that the wetlands were able to substantially decrease the level of wastewater effluent COD. As a result, the HF-CW system exhibited higher COD removals than the VF-CW systems, which may be caused by the low influent organic loading rate in the VF-CWs. Furthermore, CWs planted with *P. australis* were significantly more effective in removing

COD compared to the CWs beds planted with *T. latifolia* (Figure 5a). According to previous studies, the main mechanisms of removal of COD in CWs are mainly due to physical processes (sedimentation and filtration) [35], and biological decomposition processes by various microorganisms under aerobic, facultative and anaerobic conditions [29, 36]. [37] report that the substrate usually could influence contaminants removal performance by affecting both physicochemical and microbial processes.

Biochemical oxygen demand (BOD₅)

Throughout the study period, the BOD₅ concentration variations of both CWs in each experiment are shown in Table 1 and 2. The mean influent water concentrations were around 335 and 71mg/l for HF-CWs and VF-CWs respectively. Whereas, effluent mean concentrations for each tested wetlands were 46.47mg/l for HF-Ph, 41.33 mg/l for HF-Ty, 11.39 mg/l for VF-Ph and 13.64mg/l for VF-Ty (Table 2). Consequently, the mean BOD₅ removal efficiencies were almost similar in all CWs and over 80%, as follows: 88.91%, 87.7%, 88.43% and 86.15% for HF-Ph, HF-Ty, VF-Ph and VF-Ty respectively (Figure 5a). According to the statistical analysis, it was significantly different ($p < 0.05$) between influent and effluents water concentrations. In contrast, no significant differences between species were observed in both experiments ($p > 0.05$). The monthly BOD₅ removal efficiency in the present study was observed to be 72 to 92% for HF-Ph, 84 to 91% for HF-Ty, 73 to 95% for VF-Ph and 71 to 95% for VF-Ty. Therefore, both experiments indicate that CWs can have good ability to reduce BOD₅ concentration during the treatment process. According to previous studies, the reduction of BOD₅ concentration in wetlands could be due to physical processes (sedimentation and filtration of colloid organics) [29, 38] and to aerobic and anaerobic microbial biodegradation processes supported by macrophytes transferring oxygen to the water within the rhizosphere [09, 39, 40]. Furthermore, the abatement of BOD₅ in VF-CWs might be due to the low strength of domestic wastewater used [41].

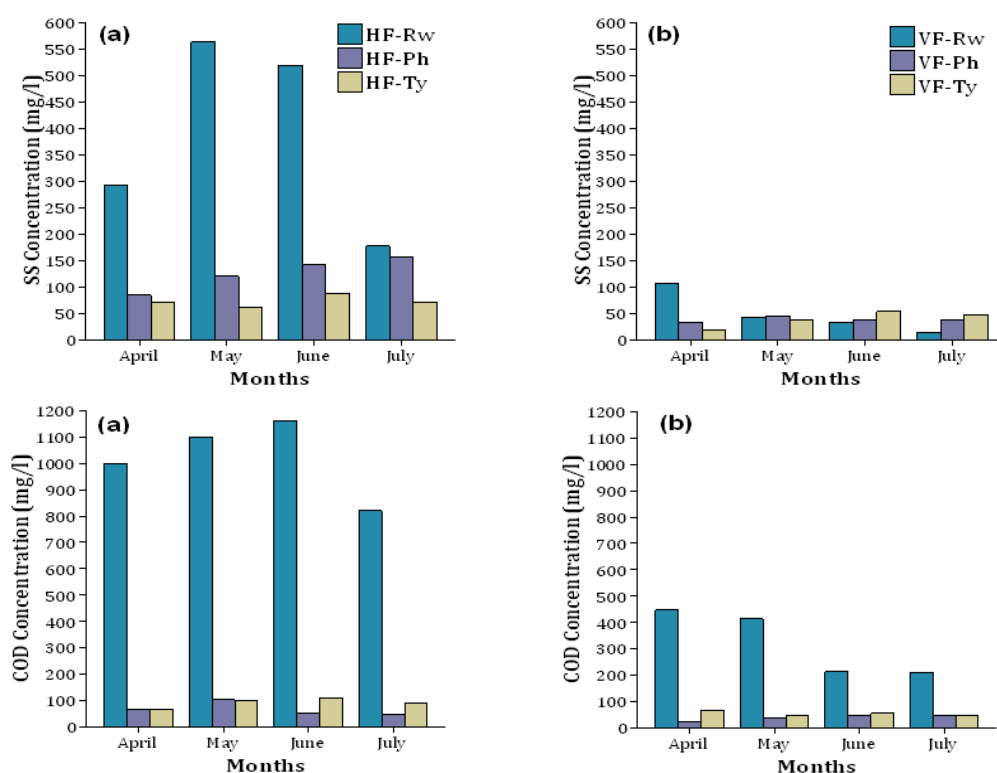


Figure 2. Monthly variation of pollutant concentrations in HF-CWs and VF-CWs for SS, COD and BOD₅.

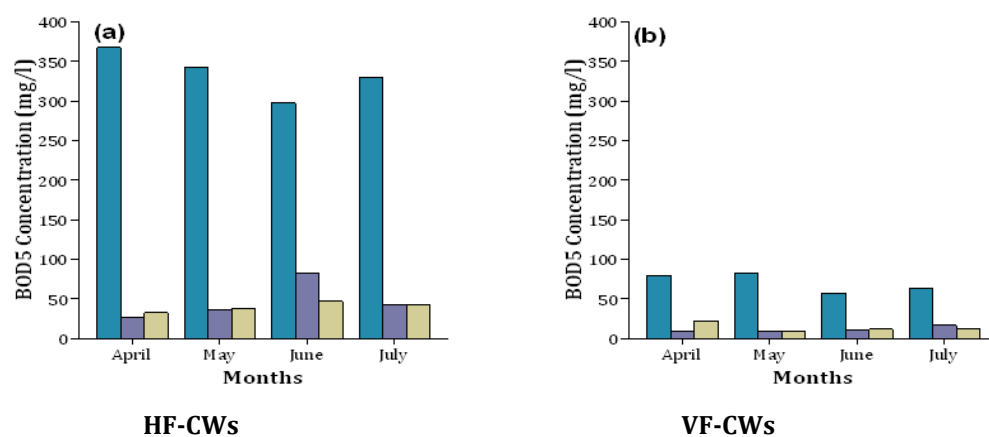


Figure 2. Monthly variation of pollutant concentrations in HF-CWs and VF-CWs for SS, COD and BOD₅.

3.1.3. Nutrients removal

Nitrate Nitrogen ($\text{NO}_3\text{-N}$)

As shown in the Table 1, the averages nitrate concentration ($\text{NO}_3\text{-N}$) obtained at sampling influents were low (1.097 ± 0.368 mg/l for HF-CWs and 0.492 ± 0.405 mg/l for VF-CWs). Whereas, the effluent concentrations were mildly higher than the influent concentration for both experiments (Table 2, Figure 3. a, b). A slight increase in $\text{NO}_3\text{-N}$ values observed in the effluent of HF-CWs and VF-CWs produced negative removal efficiencies (Figure. 5b). These results could be due mainly to conversion of ammonium to nitrate via nitrification process [42], with absence of denitrification reaction [43]. It has been shown that an important limiting factor in this conversion (nitrification) in CWs is the presence of oxygen produced from plant roots to wetland inhibiting microbial denitrification [30] which is the most dominant process in nitrogen removal only under anaerobic and anoxic conditions with presence of an organic matter [33]. According to results obtained from this study, both experiments did not remove nitrates, probably due also to the predominance of anaerobic conditions in CWs. The negative elimination of nitrate was also found by some authors in literature ([44] for HF-Ty); ([42], [34] for VF-Ph) and ([45] for VF-Ty) (Table 3).

Ammonia Nitrogen ($\text{NH}_4^+\text{-N}$)

As presented in Table 1, high ammonium ($\text{NH}_4\text{-N}$) influent concentrations were detected in HF-CWs (126.26 ± 29.86 mg/l) compared to the VF-CWs (50.85 ± 12.22 mg/l). Data effluents (Table 2) showed that ammonia concentrations decreased to be 72.30 mg/l for HF-Ph, 38.70 mg/l for HF-Ty, 2.01 mg/l for VF-Ph and 1.10 mg/l for VF-Ty. These values respectively represent a reduction to 42.73%, 69.35%, 96.05% and 97.84% (Figure 5). In this case, it was significantly different ($p < 0.05$) between the primary treatment and the water treatment with wetlands, whereas no significant differences in the $\text{NH}_4\text{-N}$ concentrations were found between the two plant species in VF-CWs ($p > 0.05$). In the present study, the removal rate of $\text{NH}_4^+\text{-N}$ was higher in VF-CWs than in the HF-CWs. However, the CW-Ty systems performed better on $\text{NH}_4\text{-N}$ removal than the CW-Ph system in both experiments. The low rate of $\text{NH}_4\text{-N}$ removal in HF-CWs could be explained by a low nitrification rate caused by an incomplete transformation of ammoniacal nitrogen into nitrites and nitrates. Whereas, the high removal efficiency of $\text{NH}_4\text{-N}$ observed in VF-CWs could be due mainly to higher rate of nitrification which happened in the presence of oxygen provided by vegetation during photosynthesis. These results confirm that the VF-CWs have been used mainly for the treatment of domestic wastewater, due to their greater capacity of nitrification [09]. In addition, several studies indicated that plant species could influence the $\text{NH}_4\text{-N}$ removal [49, 50]. Furthermore, [40] have pointed out plant uptake and nitrification process are the main responsible factors for Ammonia-N removal.

Total Kjeldahl nitrogen (TKN)

Total Kjeldahl nitrogen (TKN) is the sum of organic nitrogen and ammoniacal nitrogen in the chemical analysis of wastewater. As shown in Table 1, means TKN concentrations were respectively around 174 mg/l and 57 mg/l at the inlet of HF-CWs and VF-CWs. Whereas the Table 2 showed a reduction of TKN concentrations to be around 89 mg/l for HF-Ph, 57 mg/l for HF-Ty and 3 mg/l for VF-Ph and VF-Ty. According to the statistical analysis, there was significant difference ($p < 0.05$) between the influent and wastewater effluents, and between two plant species in HF-CWs, while no significant differences ($p > 0.05$) were reported between TKN concentration in VF-Ph and VF-Ty. Consequently, the average TKN removal efficiencies were 66.86%, 48.79%, 93.10% and 94.17% for HF-Ty, HF-Ph, VF-Ty and VF-Ph respectively. The TKN removal rates obtained in the HF-CWs were lower than those in the VF-CWs. In addition, the behavior of *P. australis* and *T. latifolia* followed a similar pattern in removing of TKN and reached close values in VF-CWs. Whereas, *T. latifolia* performed better than *P. australis* in HF-CWs. Depending on Figure 5b, the TKN removal efficiency in the effluents was approximately similar to the removal of $\text{NH}_4^+\text{-N}$ in both experiments, indicating that the removal of TKN followed the same $\text{NH}_4^+\text{-N}$ removal process. The high TKN removal efficiencies during this study can be due mainly to high reduction of organic nitrogen and ammonia nitrogen which are the main component of TKN [51].

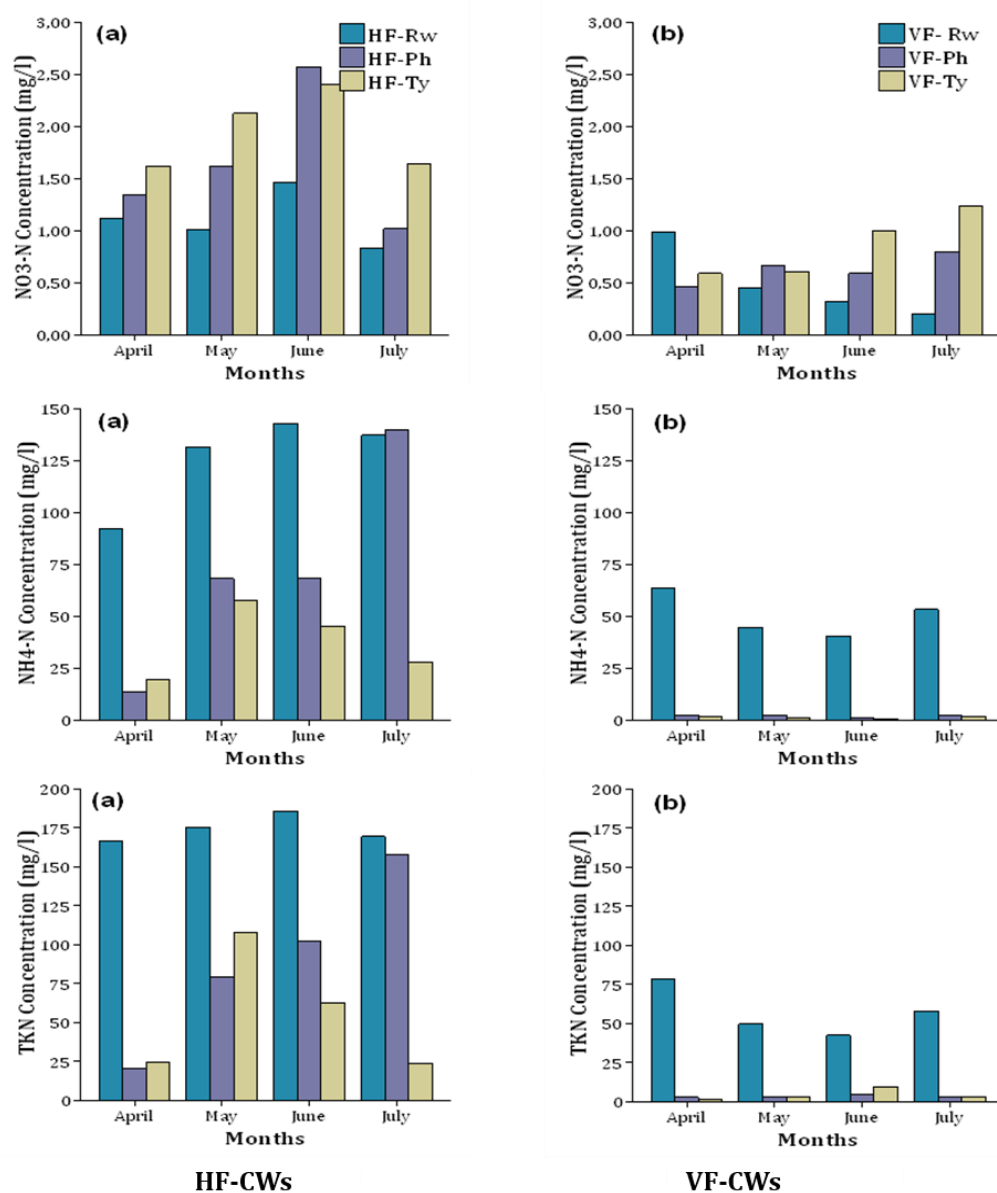


Figure 3. Monthly variation of pollutant concentrations in HF-CWs and VF-CWs for NO₃-N, NH₄-N and TKN.

Phosphate Phosphorous ($PO_4^{3-}P$)

The mean $PO_4^{3-}P$ content in the influents for the whole period was 5.785 ± 1.726 mg/l for HF-CWs and 2.244 ± 1.249 mg/l for VF-CWs (Table 1), whereas the average $PO_4^{3-}P$ concentrations in the effluents decreased to a low concentration close to zero in both experiments (Table 2), which means a removal efficiency of over 97%, 95%, 92% and 88% for HF-Ty, HF-Ph, VF-Ty and VF-Ph respectively. According to the statistical analysis, there was a significant difference ($p < 0.05$) between the influents and effluents water concentrations. On the contrary, no significant differences between plants were marked in effluents ($p > 0.05$). In this study, the HF-CWs were more efficient in $PO_4^{3-}P$ removal compared to the VF-CWs which is possibly, due to the low concentration of influent in VF-CWs comparing with HF-CWs. In contrast, *Typha* beds performed better than *Phragmite* beds in both experiments. The high removal efficiency in these two experiments may be explained by physical (sedimentation) and chemical (adsorption) process and plant and microorganism uptake at high pH of 9–11 [52]. [53] pointed out plant uptake has minimum role in phosphate removal, and as the pH values were not high enough to trigger precipitation, therefore, the main phosphate removal process in these systems may be via bacterial activity.

Total phosphorus

The average influent concentrations of total phosphorus in HF-CWs and VF-CWs were 7.015 ± 2.395 mg/l and 2.464 ± 1.231 mg/l respectively (Table 1). Through the study period, all effluents showed a reduction of TP concentration in both experiments, where the average removal efficiencies were 74% for HF-Ty, 86% for HF-Ph, 88% for VF-Ty and 90% for VF-Ph. According to one-way ANOVA statistical analysis, there was significant difference between influent and effluents concentrations in both experiments ($p < 0.05$). In contrast, no significant differences were found between *Phragmite* and *Typha* CWs in each experiment ($p > 0.05$). These findings showed that VF-CWs were more efficient than HF-CWs in removing TP. Moreover, the CWs planted with *P. australis* performed better than CWs planted with *T. latifolia*. [30] pointed out that phosphorus removal performance of CWs could vary with plant species which is used for vegetation purpose, and thus selection of plant could be crucial for phosphorus removal efficiency. According to previous studies, phosphorus removal in constructed wetlands occurs through a combination of several processes such as substrate adsorption, precipitation, uptake by the aquatic plant [54]. [55] and [56] reported that adsorption and precipitation within substrates play the largest role in the phosphorus removal process. In addition, [57] reported that the use of gravel as substrates in CWs systems increased the removal of phosphorus. However, some research studies pointed out plant assimilation and absorption contribute in a small portion to phosphorus removal in CWs [58].

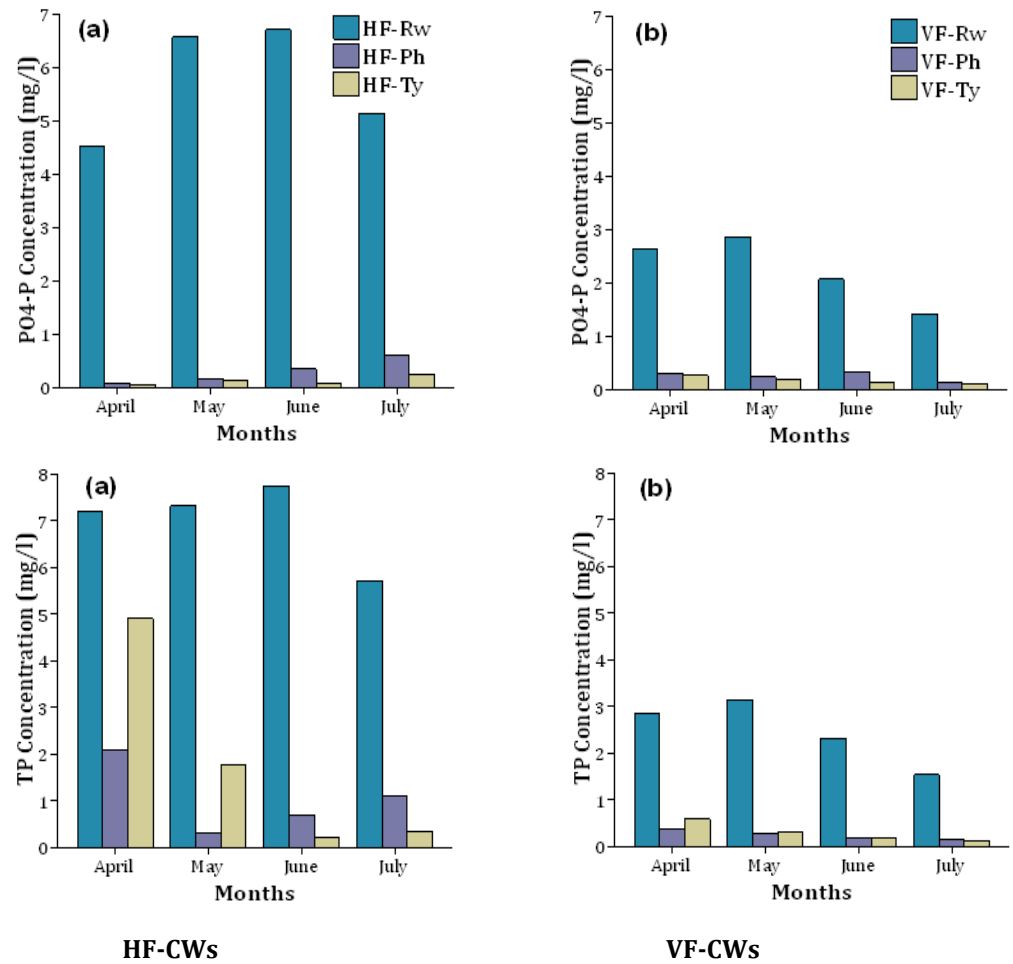


Figure 4. Monthly variation of pollutant concentrations in HF-CWs and VF-CWs for PO₄-P and TP.

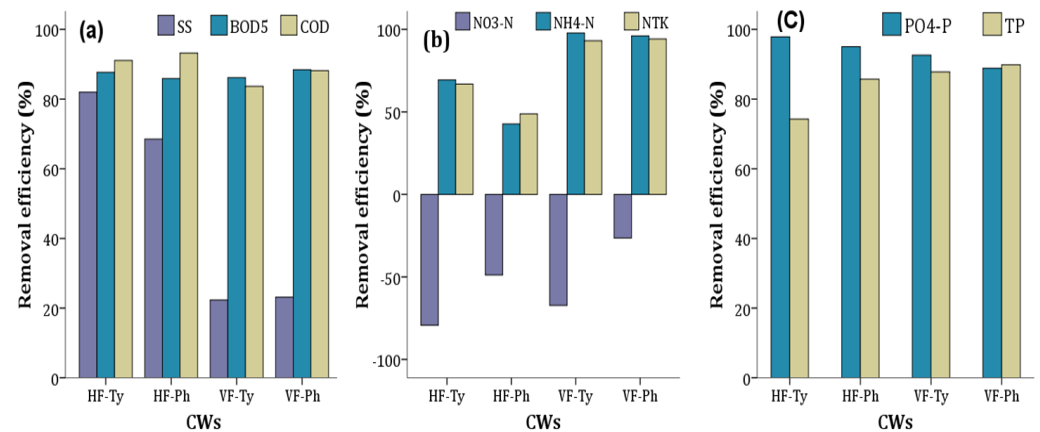


Figure 5. Removal efficiency of *P. australis* and *T. latifolia* in HF-CWs and VF-CWs for (a): TSS, BOD₅ and COD. (b): NO₃-N, NH₄-N and TKN. (c): PO₄-P and TP

4. Conclusions

The primary objective of this research was to conduct a comparative analysis of the effectiveness of *Phragmites australis* and *Typha latifolia* in the treatment of wastewater

within horizontal and vertical flow constructed wetlands in arid area. Below is a summary of the key conclusions derived from this study:

- HF-CWs exhibited superior removal of TSS compared to VF-CWs. Specifically, the HF-CW containing *T. latifolia* demonstrated the most effective TSS removal, outpacing the HF-CW planted with *P. australis*.
- HF-CW system demonstrated greater COD removal compared to the VF-CW systems. Additionally, CWs with *P. australis* showed significantly better COD removal efficiency than those planted with *T. latifolia*.
- BOD₅ removal efficiencies were largely comparable across all CWs. Both experiments demonstrated that CWs are effective at reducing BOD₅ concentrations during treatment. However, *T. latifolia* proved slightly more effective than *P. australis* in the HF-CW system, while the opposite was true in the VF-CW system.
- Neither species was effective at removing nitrates in either the HF-CW or VF-CW systems.
- Removal rate of NH₄⁺-N was greater in VF-CWs compared to HF-CWs. However, the CW-Ty systems outperformed the CW-Ph systems in NH₄⁺-N removal in both experiments.
- TKN removal rates were lower in HF-CWs than in VF-CWs. *P. australis* and *T. latifolia* exhibited similar TKN removal patterns and achieved comparable values in VF-CWs, while *T. latifolia* was more effective than *P. australis* in HF-CWs.
- HF-CWs were more effective at removing PO₄³⁻-P than VF-CWs, whereas *Typha* beds outperformed *Phragmites* beds in both experiments.
- VF-CWs showed greater efficiency than HF-CWs in removing total phosphorus (TP), and CWs planted with *P. australis* were more effective than those with *T. latifolia*.

Overall, when comparing the performance of *P. australis* and *T. latifolia*, the removal efficiencies indicated that *T. latifolia* was more effective in removing TSS, BOD₅, NH₄-N, TKN, and PO₄-P, while *P. australis* excelled only in the removal of COD and TP in HF-CWs. In VF-CWs, *P. australis* was found to be more efficient than *T. latifolia* for removing TSS, BOD₅, COD, TKN, and TP from wastewater. Conversely, *T. latifolia* was less effective in all other water quality parameters, except for NH₄-N and PO₄-P. These findings suggest that both *P. australis* and *T. latifolia* could be suitable macrophyte species for large-scale constructed wetlands.

References

1. Kalipci, E. (2011). Investigation of decontamination effect of *Phragmites australis* for Konya domestic wastewater treatment. *Journal of Medicinal Plants Research*, 5(29), 6571-6577.
2. Kantawanichkul, S., Kladprasert, S., & Brix, H. (2009). Treatment of high-strength wastewater in tropical vertical flow constructed wetlands planted with *Typha angustifolia* and *Cyperus involucratus*. *Ecological engineering*, 35(2), 238-247. <https://doi.org/10.1016/j.ecoleng.2008.06.002>
3. Ghasemi, S. M., Mohseni-Bandpei, A., Ghaderpoori, M., Fakhri, Y., Keramati, H., Taghavi, M., & Karimyan, K. (2017). Application of modified maize hull for removal of Cu (II) ions from aqueous solutions. *Environment protection engineering*, 43(4). <https://doi.org/10.5277/epe170408>
4. Massoudinejad, M., Ghaderpoori, M., & Azari, M. R. (2015). The removal of COD and color from textile industry by chlorine hypochlorite. *Int. J. Adv. Sci. Technol*, 76, 35-42. <http://dx.doi.org/10.14257/ijast.2015.76.05>
5. Binder, W., Göttle, A., & Shuhuai, D. (2015). Ecological restoration of small water courses, experiences from Germany and from projects in Beijing. *International Soil and Water Conservation Research*, 3(2), 141-153. <https://doi.org/10.1016/j.iswcr.2015.04.004>.
6. Laaffat, J., Aziz, F., Ouazzani, N., & Mandi, L. (2017). Biotechnological approach of greywater treatment and reuse for landscape irrigation in small communities. *Saudi journal of biological sciences*, 26(1), 83-90. <https://doi.org/10.1016/j.sjbs.2017.01.006>
7. Di Luca, G. A., Maine, M. A., Mufarrije, M. M., Hadad, H. R., Pedro, M. D. C., Sánchez, G. C., & Caffaratti, S. E. (2017). Phosphorus distribution pattern in sediments of natural and constructed wetlands. *Ecological Engineering*, 108, 227-233. <https://doi.org/10.1016/j.ecoleng.2017.08.038>
8. Irwin, N. B., Irwin, E. G., Martin, J. F., & Aracena, P. (2018). Constructed wetlands for water quality improvements: Benefit transfer analysis from Ohio. *Journal of environmental management*, 206, 1063-1071. <https://doi.org/10.1016/j.jenvman.2017.10.050>
9. Stefanakis, A., Akratos, C. S., & Tsihrintzis, V. A. (2014). Vertical flow constructed wetlands: eco-engineering systems for wastewater and sludge treatment. *Newnes*. <https://doi.org/10.1016/C2012-0-01288-4>
10. Fu, X., Wu, X., Zhou, S., Chen, Y., Chen, M., & Chen, R. (2018). A constructed wetland system for rural household sewage treatment in subtropical regions. *Water*, 10(6), 716. <https://doi.org/10.3390/w10060716>
11. Amiri, K., Bekkari, N. E., Debbakh, A. E., Chaib, W., & Kherifi, W. (2022a). Urban wastewater treatment by pilot-scale vertical subsurface flow constructed wetland planted with *Typha latifolia* and *Phragmites australis* under arid climate. *Water, Air, & Soil Pollution*, 233(8), 345. <https://doi.org/10.1007/s11270-022-05802-7>.
12. Hansen, A. M., Kraus, T. E., Bachand, S. M., Horwath, W. R., & Bachand, P. A. (2018). Wetlands receiving water treated with coagulants improve water quality by removing dissolved organic carbon and disinfection byproduct precursors. *Science of the Total Environment*, 622, 603-613. <https://doi.org/10.1016/j.scitotenv.2017.11.205>
13. Leto, C., Tuttolomondo, T., La Bella, S., Leone, R., & Licata, M. (2013). Effects of plant species in a horizontal subsurface flow constructed wetland—phytoremediation of treated urban wastewater with *Cyperus alternifolius* L. and *Typha latifolia* L. in the West of Sicily (Italy). *Ecological engineering*, 61, 282-291. <https://doi.org/10.1016/j.ecoleng.2013.09.014>
14. Odinga, C. A., Swalaha, F. M., Otieno, F. A. O., Ranjith, K. R., & Bux, F. (2013). Investigating the efficiency of constructed wetlands in the removal of heavy metals and enteric pathogens from wastewater. *Environmental Technology Reviews*, vol.2(1), pp.1-16.
15. Wu, H., Zhang, J., Ngo, H. H., Guo, W., Hu, Z., Liang, S., ... & Liu, H. (2015). A review on the sustainability of constructed wetlands for wastewater treatment: design and operation. *Bioresource technology*, vol.175, pp.594-601.
16. Vymazal, J. (2009). The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. *Ecological engineering*, vol.35 (1), pp.1-17.

17. Ebrahimi, A., Taheri, E., Ehrampoush, M. H., Nasiri, S., Jalali, F., Soltani, R., & Fatehizadeh, A. (2013). Efficiency of constructed wetland vegetated with *Cyperus alternifolius* applied for municipal wastewater treatment. *Journal of Environmental and Public Health*.
18. Amiri, K., Bekkari, N. E., Débbakh, A. E., Chaib, W., & Kherifi, W. (2022b). The efficiency of household sewage treatment by Wastewater garden technique in arid regions, case of WWG of Temacine, Algeria. *Journal Algérien des Régions Arides*, 14(2), 18-31.
19. Vymazal, J. (2013a). Emergent plants used in free water surface constructed wetlands: a review. *Ecological engineering*, 61, 582-592. <https://doi.org/10.1016/j.ecoleng.2013.06.023>
20. Li, Y., Zhu, G., Ng, W. J., & Tan, S. K. (2014). A review on removing pharmaceutical contaminants from wastewater by constructed wetlands: design, performance and mechanism. *Science of the Total Environment*, 468, 908-932. <https://doi.org/10.1016/j.scitotenv.2013.09.018>
21. Maine, M. A., Sune, N., Hadad, H., Sánchez, G., & Bonetto, C. (2009). Influence of vegetation on the removal of heavy metals and nutrients in a constructed wetland. *Journal of environmental management*, 90(1), 355-363. <https://doi.org/10.1016/j.jenvman.2007.10.004>
22. Gaballah, M. S., Abdelwahab, O., Barakat, K. M., & Aboagye, D. (2020). A novel horizontal subsurface flow constructed wetland planted with *Typha angustifolia* for treatment of polluted water. *Environmental Science and Pollution Research*, 27, 28449-28462. <https://doi.org/10.1007/s11356-020-08669-5>
23. Bekkari, N. E., Amiri, K., & Hadjoudj, M. (2022). Performance of pilot scale constructed wetland as ecological practice for domestic wastewater treatment in an arid climate–Algeria. *Water Science & Technology*, 86(4), 787-799. <https://doi.org/10.2166/wst.2022.242>
24. Vymazal, J. (2013b). The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: a review of a recent development. *Water research*, 47(14), 4795-4811. <https://doi.org/10.1016/j.watres.2013.05.029>
25. Borin, M., Milani, M., Salvato, M., & Toscano, A. (2011). Evaluation of *Phragmites australis* (Cav.) Trin. evapotranspiration in northern and southern Italy. *Ecological Engineering*, 37(5), 721-728. <https://doi.org/10.1016/j.ecoleng.2010.05.003>
26. APHA (American Public Health Association) (2005). Standard Methods for the Examination of Water and Wastewater (21st ed.). Washington, DC: American Public Health Association.
27. USEPA, N. (2000). Constructed wetlands treatment of municipal wastewaters. United States Environmental Protection Agency, EPA/625/R-99/010, Cincinnati, Ohio, USA.
28. Hussein, A., & Scholz, M. (2017). Dye wastewater treatment by vertical-flow constructed wetlands. *Ecological engineering*, 101, 28-38. <https://doi.org/10.1016/j.ecoleng.2017.01.016>
29. Bakhshoodeh, R., Alavi, N., Majlesi, M., & Paydary, P. (2017). Compost leachate treatment by a pilot-scale subsurface horizontal flow constructed wetland. *Ecological Engineering*, 105, 7-14. <https://doi.org/10.1016/j.ecoleng.2017.04.058>
30. Saz, Ç., Türe, C., Türker, O. C., & Yakar, A. (2018). Effect of vegetation type on treatment performance and bioelectric production of constructed wetland modules combined with microbial fuel cell (CW-MFC) treating synthetic wastewater. *Environmental Science and Pollution Research*, 25, 8777-8792. <https://doi.org/10.1007/s11356-018-1208-y>
31. Ayers, R. S., & Westcot, D. W. (1985). Water quality for agriculture (Vol. 29, p. 174). Rome: Food and Agriculture Organization of the United Nations.
32. Priya, E. S., & Selvan, P. S. (2017). Water hyacinth (*Eichhornia crassipes*)—An efficient and economic adsorbent for textile effluent treatment—A review. *Arabian Journal of Chemistry*, 10, S3548-S3558. <https://doi.org/10.1016/j.arabjc.2014.03.002>
33. Abdelhakeem, S. G., Aboulroos, S. A., & Kamel, M. M. (2016). Performance of a vertical subsurface flow constructed wetland under different operational conditions. *Journal of Advanced Research*, 7(5), 803-814. <https://doi.org/10.1016/j.jare.2015.12.002>
34. Tsihrintzis, V. A. (2017). The use of vertical flow constructed wetlands in wastewater treatment. *Water resources management*, 31(10), 3245-3270. <https://doi.org/10.1007/s11269-017-1710-x>

35. Carballeira, T., Ruiz, I., & Soto, M. (2016). Effect of plants and surface loading rate on the treatment efficiency of shallow subsurface constructed wetlands. *Ecological Engineering*, vol.90, pp.203-214.
36. Barco, A., & Borin, M. (2017). Treatment performance and macrophytes growth in a restored hybrid constructed wetland for municipal wastewater treatment. *Ecological Engineering*, 107, 160-171. <https://doi.org/10.1016/j.ecoleng.2017.07.004>
37. Xu, G., Li, Y., Hou, W., Wang, S., & Kong, F. (2021). Effects of substrate type on enhancing pollutant removal performance and reducing greenhouse gas emission in vertical subsurface flow constructed wetland. *Journal of Environmental Management*, 280, 111674. <https://doi.org/10.1016/j.jenvman.2020.111674>
38. Merino-Solís, M. L., Villegas, E., De Anda, J., & López-López, A. (2015). The effect of the hydraulic retention time on the performance of an ecological wastewater treatment system: an anaerobic filter with a constructed wetland. *Water*, 7(3), 1149-1163. <https://doi.org/10.3390/w7031149>
39. Ciria, M. P., Solano, M. L., & Soriano, P. (2005). Role of macrophyte *Typha latifolia* in a constructed wetland for wastewater treatment and assessment of its potential as a biomass fuel. *Biosystems Engineering*, 92(4), 535-544. <https://doi.org/10.1016/j.biosystemseng.2005.08.007>
40. Sricoth, T., Meeinkuirt, W., Pichtel, J., Taeprayoon, P., & Saengwilai, P. (2018). Synergistic phytoremediation of wastewater by two aquatic plants (*Typha angustifolia* and *Eichhornia crassipes*) and potential as biomass fuel. *Environmental Science and Pollution Research*, 25, 5344-5358. <https://doi.org/10.1007/s11356-017-0813-5>
41. Klomjek, P., & Nitisoravut, S. (2005). Constructed treatment wetland: a study of eight plant species under saline conditions. *Chemosphere*, 58(5), 585-593. <https://doi.org/10.1016/j.chemosphere.2004.08.073>
42. García-Ávila, F., Patiño-Chávez, J., Zhinín-Chimbo, F., Donoso-Moscoso, S., del Pino, L. F., & Avilés-Añazco, A. (2019). Performance of *Phragmites Australis* and *Cyperus Papyrus* in the treatment of municipal wastewater by vertical flow subsurface constructed wetlands. *International Soil and Water Conservation Research*, 7(3), 286-296. <https://doi.org/10.1016/j.iswcr.2019.04.001>
43. Maltais-Landry, G., Maranger, R., Brisson, J., & Chazarenc, F. (2009). Nitrogen transformations and retention in planted and artificially aerated constructed wetlands. *Water research*, 43(2), 535-545. <https://doi.org/10.1016/j.watres.2008.10.040>
44. da Costa, J. F., Martins, W. L. P., Seidl, M., & Von Sperling, M. (2015). Role of vegetation (*Typha latifolia*) on nutrient removal in a horizontal subsurface-flow constructed wetland treating UASB reactor-trickling filter effluent. *Water Science and Technology*, 71(7), 1004-1010. <https://doi.org/10.2166/wst.2015.055>
45. Yalçuk, A., & Ugurlu, A. (2020). Treatment of landfill leachate with laboratory scale vertical flow constructed wetlands: plant growth modeling. *International journal of phytoremediation*, 22(2), 157-166. <https://doi.org/10.1080/15226514.2019.1652562>
46. Borin, M., Politeo, M., & De Stefani, G. (2013). Performance of a hybrid constructed wetland treating piggery wastewater. *Ecological Engineering*, 51, 229-236. <https://doi.org/10.1016/j.ecoleng.2012.12.064>
47. Rodríguez, M., & Brisson, J. (2015). Pollutant removal efficiency of native versus exotic common reed (*Phragmites australis*) in North American treatment wetlands. *Ecological engineering*, 74, 364-370. <https://doi.org/10.1016/j.ecoleng.2014.11.005>
48. Saharimoghaddam, N., Massoudinejad, M., & Ghaderpoori, M. (2019). Removal of pollutants (COD, TSS, and NO₃⁻) from textile effluent using *Gambusia* fish and *Phragmites australis* in constructed wetlands. *Environmental geochemistry and health*, 41, 1433-1444
49. Wang, P., Zhang, H., Zuo, J., Zhao, D., Zou, X., Zhu, Z., ... & An, S. (2016). A hardy plant facilitates nitrogen removal via microbial communities in subsurface flow constructed wetlands in winter. *Scientific reports*, 6(1), 1-11. <https://doi.org/10.1038/srep33600>
50. Wu, M. (2014). Potential of *Typha* as plant candidates for sludge treatment Wetlands. *GSTF Journal of BioSciences (JBio)*, 3, 1-9. <https://doi.org/10.7603/s40835-014-0001-z>
51. Hua, Y., Peng, L., Zhang, S., Heal, K. V., Zhao, J., & Zhu, D. (2017). Effects of plants and temperature on nitrogen removal and microbiology in pilot-scale horizontal subsurface flow constructed wetlands treating domestic wastewater. *Ecological Engineering*, 108, 70-77. <https://doi.org/10.1016/j.ecoleng.2017.08.007>

52. Mujtaba, G., Rizwan, M., & Lee, K. (2017). Removal of nutrients and COD from wastewater using symbiotic co-culture of bacterium *Pseudomonas putida* and immobilized microalga *Chlorella vulgaris*. *Journal of Industrial and Engineering Chemistry*, 49, 145-151. <https://doi.org/10.1016/j.jiec.2017.01.021>
53. Sakadevan, K., & Bavor, H. J. (1998). Phosphate adsorption characteristics of soils, slags and zeolite to be used as substrates in constructed wetland systems. *Water Research*, 32(2), 393-399. [https://doi.org/10.1016/S0043-1354\(97\)00271-6](https://doi.org/10.1016/S0043-1354(97)00271-6)
54. Lu, S. G., Bai, S. Q., Zhu, L., & Shan, H. D. (2009). Removal mechanism of phosphate from aqueous solution by fly ash. *Journal of Hazardous Materials*, 161(1), 95-101. <https://doi.org/10.1016/j.jhazmat.2008.02.123>
55. Feizi, M., & Jalali, M. (2016). Sorption of aquatic phosphorus onto native and chemically-modified plant residues: modeling the isotherm and kinetics of sorption process. *Desalination and Water Treatment*, 57(7), 3085-3097. <https://doi.org/10.1080/19443994.2014.981226>
56. Vohla, C., Kõiv, M., Bavor, H. J., Chazarenc, F., & Mander, Ü. (2011). Filter materials for phosphorus removal from wastewater in treatment wetlands—A review. *Ecological engineering*, 37(1), 70-89. <https://doi.org/10.1016/j.ecoleng.2009.08.003>
57. Vera, I., Araya, F., Andrés, E., Sáez, K., & Vidal, G. (2014). Enhanced phosphorus removal from sewage in mesocosm-scale constructed wetland using zeolite as medium and artificial aeration. *Environmental Technology*, 35(13), 1639-1649. <https://doi.org/10.1080/09593330.2013.877984>
58. Liang, Y., Zhu, H., Bañuelos, G., Yan, B., Shutes, B., Cheng, X., & Chen, X. (2017). Removal of nutrients in saline wastewater using constructed wetlands: Plant species, influent loads and salinity levels as influencing factors. *Chemosphere*, 187, 52-61. <https://doi.org/10.1016/j.chemosphere.2017.08.087>