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# Treatment of Domestic Wastewater Using two Substrates of Constructed Wetland Planted with Phragmites australis in Arid Regions (Southeast Algeria, Biskra)

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## ABSTRACT

Constructed wetlands (CWs) have been widely recognised for efficiently removing many pollutants from wastewater, making them vital for environmental bioremediation. The substrates used in constructed wetlands are crucial in determining their overall performance, notably their ability to improve nitrogen and phosphorus removal from wastewater. This study aims to investigate the possibility of removing pollutants from wastewater using a pilot scale vertical flow constructed wetland (VFCW) planted with Phragmites australis applied to various substrates, such as gravel and sand in an arid climate in Southeast Algeria. The study involved using four basins, filled with sand and gravel. Two were planted with Phragmites australis and the others were left as a control without vegetation. The efficiency of the filtration systems was evaluated based on various physicochemical and organic parameters.

Results showed that the highest hydraulic retention time is in the 7 days. The removal efficiency values are 84.38% for biological oxygen demand ($DBO_5$), 77.45% for chemical oxygen demand (COD), and 83.30% for total solid matter (TSS) in the planted gravel filter. The planted sand filter had even higher removal efficiency values, with 89.59%, 85.80%, and 86.63% for $DBO_5$, COD, and TSS, respectively. Nitrate concentration increased in all filters due to the complete transformation of ammonium into nitrate. $NO_2^-$, $NH_4^+$, and $PO_4^{3-}$ removal efficiencies were also higher in the planted sand filter 74.45%, 95.43%, and 77.64%, respectively.

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## INTRODUCTION

Developing countries suffer from environmental damage and health risks due to inefficient wastewater treatment (Tang *et al*., 2023). Research on treating domestic wastewater through low-cost, low-energy, and low-maintenance technologies has been a priority in most countries worldwide (Binder *et al*., 2015; Laaffat *et al*., 2016).

In Algeria, the number of wastewater treatment plants (WWTP) available needs to be increased (Zorai *et al*., 2022). Therefore, the majority of domestic wastewater is typically released untreated straight into rivers. This wastewater contains concentrated pollutants that impair the quality of the local aquatic ecosystems (Konnerup *et al*., 2009).

Rural areas or small populations without sewer systems are responsible for discharging wastewater into the environment; it has become necessary to treat this wastewater (García-Avila *et al*., 2019). Unconventional treatments are the most suitable in those areas because they use natural processes, have a low maintenance cost, and avoid chemical treatment (Tahir *et al*., 2016; Zidan *et al*., 2015).

One unconventional treatment in particular, the constructed wetlands (CW), have been increasingly recognised around the world in recent years as natural and economically favorable since they use a combination of plants, microorganisms, and substrates (Mango *et al*., 2017; Orimoloye *et al*., 2018; Talukdar and Pal, 2017; Vymazal, 2011). This classifies them as low-level systems with lower operational and maintenance requirements. CW attempts to mimic the layout and functions of natural wetlands have been widely used to improve water quality (Kyambadde *et al*., 2004). This technique has evolved by adding specific plants and modifying the filtering system.

Climatic conditions can control selecting and designing CWs. For example, hydraulic retention time (HRT) and plant type are essential variables in hyperarid conditions (Vera *et al*., 2016). Vertical Flow Constructed Wetlands (VFCW) are abundant in arid regions. Wastewater is discharged or dosed onto the surface of a planted filter bed. After passing vertically through the filter substrates, treated water is collected in a drainage pipe at the base of the basin (Kadlec and Wallace, 2009).

In any CW, the substrate is a substantial and indispensable part, where the physical, chemical, and biological reactions occur (Nazer *et al*., 2006). Also, it supports plant growth and provides attachments for biofilms, which are essential for removing contaminants.

Sand, gravel, rock, and organic materials like compost are the substrates used in constructed wetlands. These materials are significant because they: (a) support a variety of living things; (b) store a wide range of contaminants; (c) undergo chemical and biological transformations; and (d) the buildup of organic matter in the substrate creates areas for biological reactions and pollutant adsorption in wetlands ( García-Valero *et al*., 2020). Several studies have shown that vegetation is crucial to remove pollutants from wetlands (Caballero-Lajarín *et al*., 2015). Choosing plant species is crucial because the vegetation must withstand the potentially harmful effects of wastewater and its chemical fluctuations and be climatically appropriate to the area.

The common reed, *Phragmites australis*, is a macrophyte that can extract and retain contaminants inside its tissues. According to Vymazal and Březinová (2016), *P. australis* cannot only absorb nutrients and heavy metals but also promote the growth of microorganisms, which boosts the effectiveness of the purification system.

At present, CW technology for wastewater treatment is still limited in developing countries, such as Algeria, and research on it still needs to be improved in the existing literature, especially for arid regions.

The current study investigated the possibility of removing pollutants from wastewater using a pilot scale vertical flow constructed wetland (VFCW) planted with *Phragmites australis* applied to the selected substrates in an arid climate in Southeast Algeria. Several physicochemical parameters were tested to evaluate the purification performance.

## MATERIAL AND METHODS

*Description of the pilot treatment system*

The wastewater used in this study was gathered from the city of Biskra's domestic discharge outfalls (Oued Z'mor). An integrated treatment system utilizing the Vertical Flow Constructed Wetland (VFCW) method was established at the Civil and Hydraulic Engineering Department Station of the University The region of Biskra is located east of Algeria at 34° 48′ N and 05° 44′ E (Figure 1).

The constructed wetland was comprised of four basins, each measuring 36 cm in length (depth), with vertical flow, and equipped with plastic taps at the bottom to discharge water and a 2 cm diameter PVC tube for aeration. Each basin had three superimposed layers of washed materials of different particle sizes. The top layer, made up of 12 cm thick gravel and sand, was planted and encouraged plant growth and the development of microorganisms; this is a crucial component of water treatment. Two basins were planted with *Phragmites australis*, while the other two were left unplanted as controls. Two basins were filled with sand, and the rest with fine gravel. In order to facilitate *P. australis*'s adaptability and growth, irrigation water was used to plant it two months before the experiment's start. Figure 2 provides a detailed illustration of the constructed wetland.

*Strategy of wetland management and sampling*

The system was operated during the experiments with two different hydraulic retention times (HRT) - 3 days and 7 days. Both HRTs were tested in four Vertical Flow Constructed Wetland (VFCW) cells, each undergoing three filling and emptying cycles. Wastewater samples were collected from the inlet of each cell during filling and served as control samples. Meanwhile,

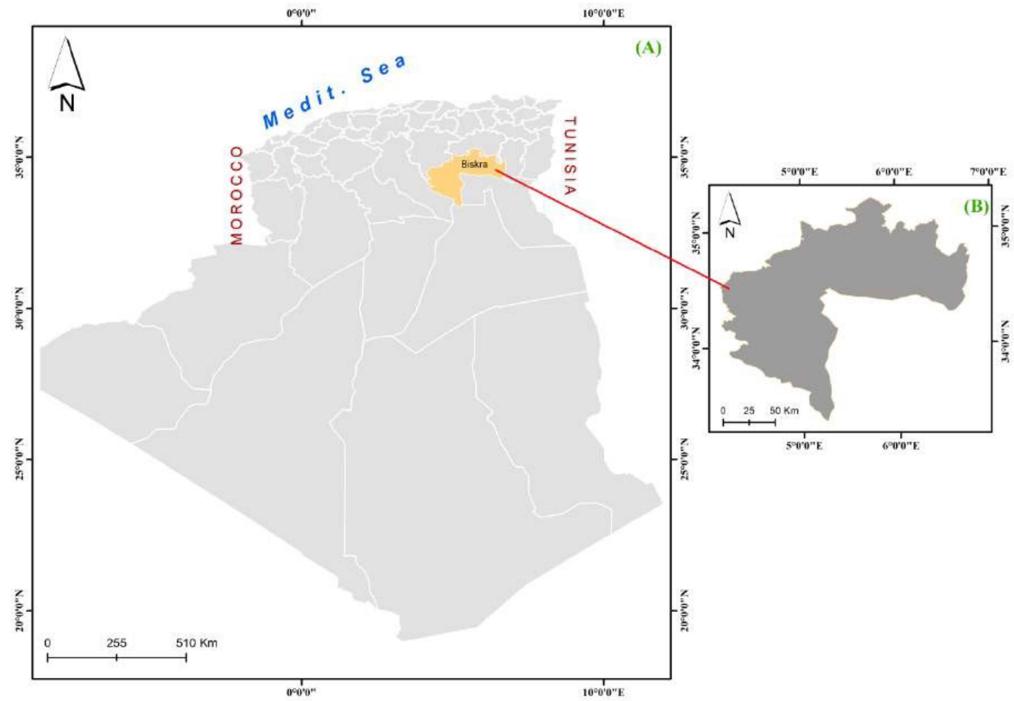
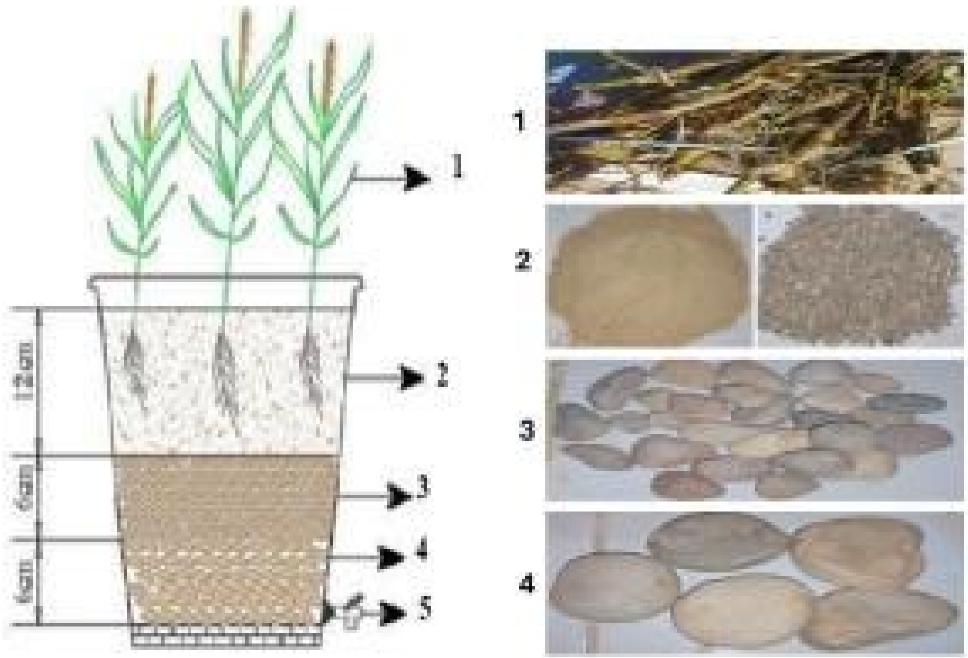



**Fig. 1.** Study location

the other wastewater samples were collected from the outlet of each cell during emptying.

For the first hydraulic retention time experiment, which had an HRT of 3 days, we filled the VFCW cells on day 1 and emptied them on day 3 for the first cycle. For the second cycle, we refilled the cells on day 3 after emptying them on the first cycle and emptying them again on day 6. Finally, for the third cycle, we filled the cells on day 6 and emptied them on day 9. After finishing the HRT= 3 experiments, we cleaned the cells using irrigation water before starting the HRT= 7 experiment. The same process was followed for the HRT= 7 experiment as was done for the HRT=3 experiment. The wet zone ran for 30 days, with cleaning carried out in the middle. This indicates that the system was not saturated during the experimental period. However, if we had run the wetland for a longer time, we would have assessed its saturation.

Considering the three HRT treatment cycles, 48 samples were collected for each HRT (Table 1), with 24 samples at the inlet and 24 samples at the outlet. We placed each sample in 500 ml sterilized plastic bottles, labeled them, and immediately cooled them to 4°C.




1. Phragmite Australis
2. Planted layer (fine gravel or sand)
3. Intermediate layer
4. Drainage layer
5. Tap

**Fig. 2.** (a) Sectional view of the wetland and composition, and (b) different layers used in the wetland.

**Table 1.** Sampling strategy for wastewater. Samples taken for the two hydraulic retention times (HRT).

| | **HRT= 3 days** | | | | | | | | **HRT= 7 days** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **I3 (Control)** | | | | **O3** | | | | **I7 (Control)** | | | | **O7** | | | |
| | **Cell 1** | **Cell 2** | **Cell 3** | **Cell 4** | **Cell 1** | **Cell 2** | **Cell 3** | **Cell 4** | **Cell 1** | **Cell 2** | **Cell 3** | **Cell 4** | **Cell 1** | **Cell 2** | **Cell 3** | **Cell 4** |
| **cycle I** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **cycle II** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **cycle III** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **TOTAL** | | 12 | | | | 12 | | | | 12 | | | | 12 | | |

*Analytical methods*

The temperature (T°), pH, electrical conductivity (EC), salinity, and total dissolved solids (TDS) were measured using a portable multimeter model HI9829. Total solid matter (TSS) was quantified using the standard method for testing water and wastewater (NF T90-105). Biological oxygen demand ($BOD_5$) was measured using the 5-day. BOD was tested with OxiTop head gas sensors (OxiTop ® WTW box). COD was measured using the dichromate method under ISO guideline 6060 (ISO 1989). $NH_4^+$ was measured manually by spectrometry in compliance with ISO 7150 (ISO 1984). $NO_3^-$ was measured using the method described in ISO 7150 (ISO 1984) and $NO_2^-$ was measured using the ISO 6777 (ISO 1984) guideline method. Finally, $PO_4^{3-}$ was measured using the ISO 6878 method (ISO 2004).

The pollutant removal efficiency (RE) was calculated as below:

$$RE\left(\%\right)=\frac{\left(Cinf-\ Ceff\right)}{Cinf}100 \tag{1}$$

Where RE is the removal efficiency (%), Cinf the influent concentrations, and Ceff effluent concentrations (mg/L). (Kadlec and Wallace, 2008).

Data analysis was carried out using Microsoft Excel for statistical analysis, quantification, and trend evaluation. Curve and trend plotting was also done using Excel.

## RESULTS AND DISCUSSION

*Variation of T°, pH*

Table 2 shows the average values of the environmental parameters' influent and effluent concentrations parameters (T° and pH) in influent wastewater and experimental wetland units. The mean temperature in the gravel and sand filters from the bare (unplanted) and planted marks the values 20.13±0.06, 20.17±0.06, 20.00±0.00, and 20.13±0.06°C for HRT=3 days, 20.83±0.06, 20.27±0.46, 20.70±0.00, and 20.8±0.14°C for HRT=7 days, respectively, as shown in figure 3(a).

The effluent had an initial mean temperature of 28.55±0.56 °C. After the wastewater treatment, a decrease in the temperature was observed around 20 °C (ambient temperature) for all the systems; similar outcomes were noted by Zorai *et al*. (2022). This temperature suits microbial activity and efficient nutrient removal (Kadlec and Knight, 1996; El Fanssi *et al*., 2019). There was no significant difference in water temperature between the planted substrates and the control, between the two HRT times ($P > 0.0001$). However, in contrast, the initial mean pH of the wastewater before the experiments was 8.03±0.24. After the wastewater treatment, the pH values of planted gravel 6.79±0.15, and planted sand 6.34±0.02 were lower than those of the unplanted control 6.98±0.15 and 6.75±0.02 HRT=7 days, 7.4±0.05, 7.36±0.01, 7.51±0.09, and 7.38±0.01 for HRT=3 days, as demonstrated in Figure 3(b), same outcomes were noted) by Sharma and Sinha (2016). Similarly, there was no significant difference between the pH of planted and unplanted substrates ($P > 0.0001$). A slight decrease in pH occurred due to the metabolism of phosphates and nitrogen compounds and the production of volatile acid produced by acid-forming bacteria, which break down organic matter (Kim *et al*., 2016; Sandri and Reis, 2021).

*Variation in EC, salinity*

Figure 4(a) shows the variation in EC of the planted system and the unplanted control. The EC is 4.37 mS/cm in wastewater and 5.04±0.04, 4.84±0.03, 6.05±0.04, and 5.53±0.02 mS/cm for HRT=3 days, 5.64±0.22, 5.47±0.02, 6.82+0.06, and 6.11±0.04 mS/cm for HRT=7 days, at gravel and sand filters bare and planted respectively. The increases in EC are related to evapotranspiration, which concentrates effluent further (Abissy and Mandi, 1999), as well as

**Table 2.** Influent and effluent wastewater characterization (mean ± standard deviation)

| | Parameters | Unit | Influent | Effluent gravel planted with P. Australis | Effluent sand planted with P. Australis | Effluent gravel unplanted | Effluent sand unplanted |
|---|---|---|---|---|---|---|---|
| **HRT=3days** | T | °C | 28,55±0,56 | 20,17±0,06 | 20,13±0,06 | 20,13±0,06 | 20,00±0,00 |
| | pH | | 8,03±0,24 | 7,4±0,05 | 7,36±0,01 | 7,51±0,09 | 7,38±0,01 |
| | EC | mS/cm | 4,275±0,37 | 4,84±0,03 | 5,53±0,02 | 5,04±0,04 | 6,05±0,04 |
| | Salinity | mg/l | 2,62±0,17 | 4,33±0,02 | 4,67±0,02 | 3,44±0,02 | 3,83±0,02 |
| | TSS | mg/l | 274,33±12,01 | 152,82±1,62 | 138,27±1,15 | 181,78±1,87 | 164,59±1,38 |
| | COD | mg/l | 314,68±26,74 | 142,31±3,35 | 133,85±3,39 | 169,44±0,00 | 145,73±1,38 |
| | $BOD_5$ | mg/l | 234,66±11,84 | 96,49±0,68 | 85,30±1,02 | 131,68±2,10 | 105,35±9,02 |
| | $NH_4^+$ | mg/l | 64,68±0,53 | 20,83±3,10 | 14,90±0,56 | 24,15±1,88 | 19,50±0,92 |
| | $NO_2^-$ | mg/l | 0,6±0,00 | 0,36±0,01 | 0,34±0,00 | 0,44±0,05 | 0,40±0,01 |
| | $NO_3^-$ | mg/l | 8,18±0,49 | 10,43±0,45 | 9,57±0,20 | 19,75±0,59 | 17,34±0,77 |
| | $PO_4^{3-}$ | mg/l | 14,16±0,31 | 10,49±0,52 | 9,11±0,58 | 12,10±1,13 | 10,73±0,21 |
| **HRT=7days** | T | °C | 28,55±0,56 | 20,27±0,46 | 20,80±0,14 | 20,83±0,06 | 20,70±0,00 |
| | pH | | 8,04±0,24 | 6,79±0,15 | 6,34±0,02 | 6,98±0,13 | 6,75±0,06 |
| | EC | mS/cm | 4,37±0,38 | 5,74±0,02 | 6,11±0,04 | 5,64±0,22 | 6,86±0,06 |
| | Salinity | mg/l | 2,62±0,17 | 6,67±0,03 | 6,87±0,08 | 4,41±0,04 | 4,97±0,04 |
| | TSS | mg/l | 274,33±11,83 | 45,67±1,26 | 36,56±0,81 | 81,86±3,51 | 66,18±0,33 |
| | COD | mg/l | 314,69±26,35 | 70,96±2,42 | 44,68±1,05 | 105,47±5,20 | 83,50±1,63 |
| | $BOD_5$ | mg/l | 234,67±11,67 | 36,46±1,05 | 24,30±1,34 | 61,21±2,18 | 47,00±1,62 |
| | $NH_4^+$ | mg/l | 64,68±0,52 | 4,17±0,12 | 2,96±0,04 | 22,02±1,71 | 16,40±0,61 |
| | $NO_2^-$ | mg/l | 0,6±0,00 | 0,19±0,00 | 0,15±0,00 | 0,46±0,01 | 0,37±0,01 |
| | $NO_3^-$ | mg/l | 8,18±0,49 | 45,41±0,84 | 34,87±1,65 | 62,96±1,85 | 51,85±1,55 |
| | $PO_4^{3-}$ | mg/l | 14,17±0,31 | 2,75±0,19 | 3,17±0,01 | 5,71±0,63 | 7,78±0,23 |

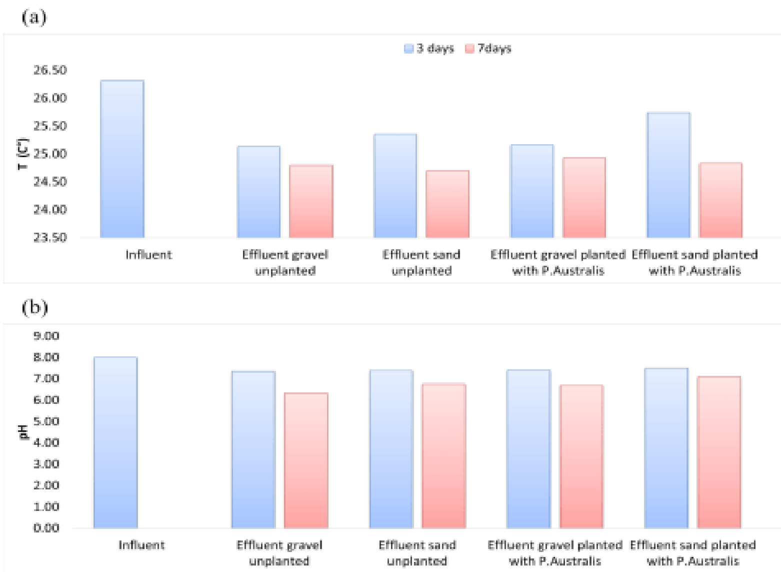



**Fig. 3.** (a) Water temperature, (b) pH, in the influent, unplanted substrates, and the substrates planted with P.Australis

substrate movement through plant roots (Stefanakis *et al*., 2009). The increase in all units could be due to the evapotranspiration of plants and the phenomenon of the dissolution of salts (Chen *et al*., 2017). Nerveless, compared to gravel filters, sand filters have a greater EC. The density of roots in the lower zone is the primary component contributing to an increase in EC (Abissy and Mandi, 1999). The salinity of the water at the inlet of the systems was 2.62±0.17 mg/L. This salinity increased significantly at the outlet of the systems. It increased from 4.41±0.04 mg/L for gravel filter to 6.67±0.03 and 6.87±0.08 mg/L for planted gravel filter, for planted sand filter and 4.97±0.04 mg/L, for sand filter, respectively for HRT=7 days (Figure 4(b)). According to these findings, treated wastewater from both planted and unplanted systems has a higher salt content than raw wastewater. Because of the arid climate, there is a higher conductivity, which indicates excessive salinity. These circumstances result in extremely high evaporation, which concentrates soil solution (Gouaidia *et al*., 2012).

*TSS removal*

The mean influent concentration of TSS was 274.33±11.83 mg/L, which decreased significantly ($P > 0.0001$) to mean concentrations of 181.78±1.87, 152.82±1.62, 164.59±1.38, and 138.27±1.15 mg/L for HRT=3 days, 81.86±3.51, 45.67±01.26, 66.18±00.33, and 36.56±00.81 mg/L for HRT=7 days in gravel and sand filters bare and planted, respectively (Figure 5(a)).

The planted gravel and sand systems had a mean TSS removal of 83.3 and 86.63%, respectively. In the unplanted system, TSS removal efficiencies were 70.07 and 81.92% (Figure 5(a)). That is comparable to the removals reported by Abdelhakeem *et al*. (2016); Zorai *et al*. (2022). Moreover, according to the findings of Sirianuntapiboon and Jitvimolnimit (2007) and Marín-Muñiz *et al*. (2020), there are no appreciable differences between planted and non-planted systems ($P > 0.0001$). In addition, the convergence of TSS removal values in unplanted and planted cells is due to interception, filtration, and decantation, which represent the processes of TSS removal (Ciria *et al*., 2005). Temperature changes are not influenced by the removal of TSS (Kadlec and Wallace, 2009; Avila *et al*., 2019).

The last result is less than that of other studies. Al-Saad *et al*. 2021 reported that TSS removal

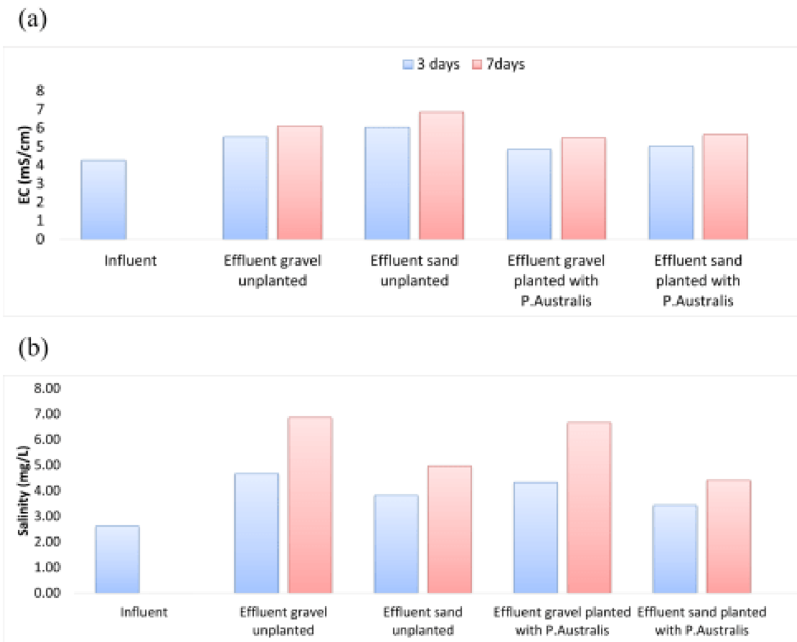



**Fig. 4.** (a) EC, (b) Salinity, in the influent, unplanted substrates, and the substrates planted with P.Australis

efficiency was about 97%. In addition, Bensmina-Mimeche *et al*. (2013) reported a TSS removal efficiency of around 95%. According to Zhang *et al*. (2019), the two main removal procedures for CW were sedimentation and filtration.

COD removal

The COD concentration of the influent was 314.69±26.35 mg/L. According to Figure 5(b), the average effluent concentrations for gravel and sand filters bare and planted were 169.44±0.00, 142.31±3.35, 145.73±1.38, and 133.85±3.39 mg/L for HRT=3 days, 105.47±5.20, 70.96±2.42, 83.50±1.63, and 44.68±1.05 mg/L for HRT=7 days, respectively. Results obtained during VFCWs operation showed high levels of COD removal in both planted and unplanted cells (Table 3). COD removal efficiencies differed significantly ($P < 0.0001$) between planted substrate types and the unplanted control in both HRTs. The result is similar to that obtained by Abdelhakeem *et al*. (2016).

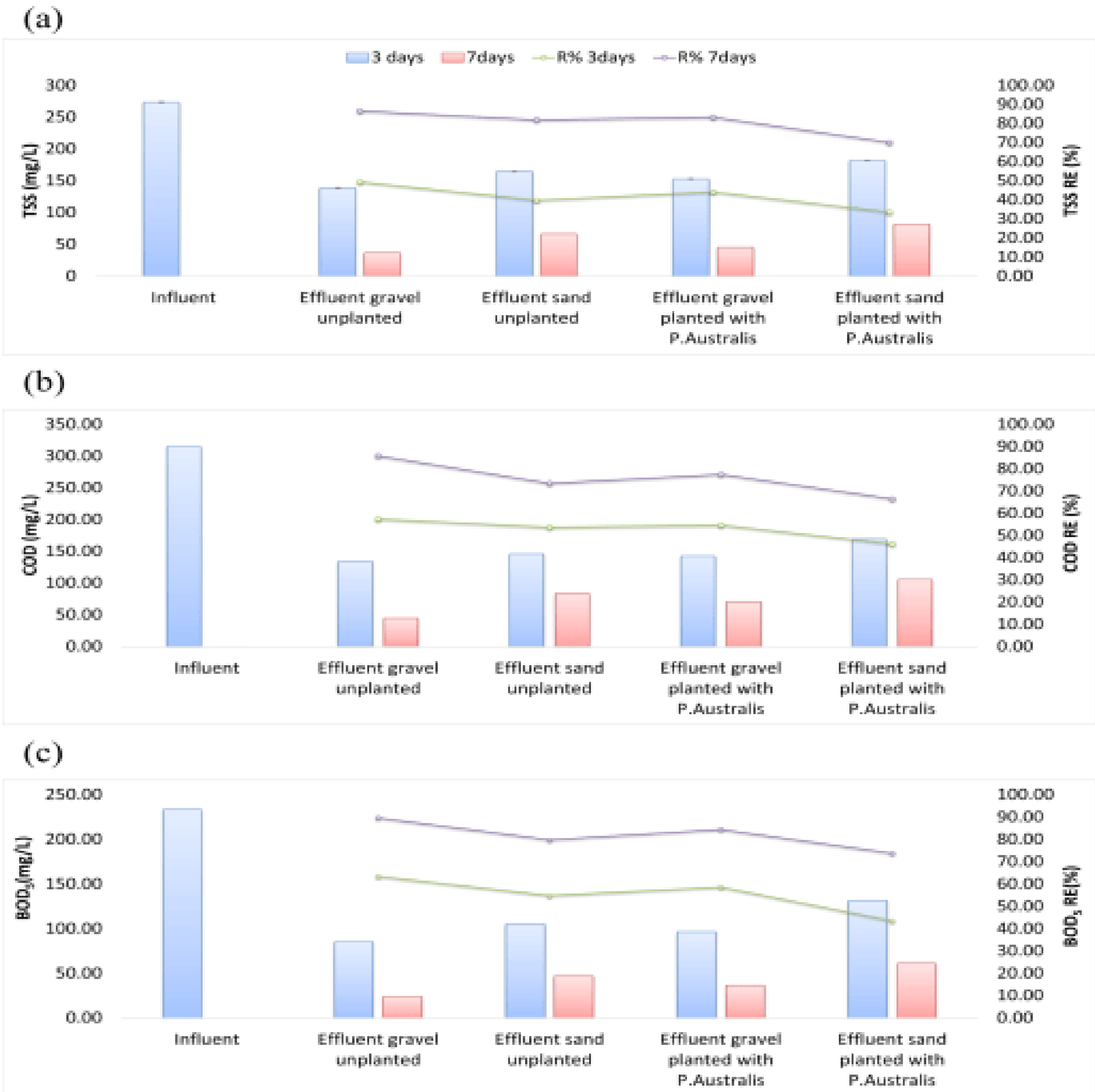



**Fig. 5.** Organic matter concentration and RE% of (a) TSS, (b) COD, and $BOD_5$, in the influent, unplanted substrates, and the substrates planted with P.Australis

The highest removal efficiencies recorded for COD were at HRT=7 days for bare gravel, bare sand, planted gravel, and planted sand cells were 66.49, 73.47, 77.45, and 85.8%, respectively (Figure 5(b)). This result is comparable to the COD removal in (85%) recorded by He *et al*. (2002), 88% by Abou-Elela *et al*. (2012) in Egypt, and 80% by Kabboura *et al*. (2022). The organic matter decreases with the longer HRT (Wang *et al*., 2018; Rani and Pohekar, 2021), where microbial degradation plays a meaningful role in COD degradation (Xu and Cui. 2019). There was significant convergence in the mean percentages of COD decrease. In the unplanted control, deposited organic matter is quickly removed by sedimentation and filtration, leading to higher removal of COD than biodegradability; in the planted filters, organic compounds are broken down by heterogeneous microorganisms into aerobic and anaerobic states based on the concentration of oxygen (Aslam *et al*., 2007).

*BOD removal*

More significant reductions were observed for $BOD_5$. The mean $BOD_5$ concentration in the influent was 233.39±15.02 mg/L, and the mean effluent $BOD_5$ concentrations for the gravel and sand filters bare and planted were 131.68±2.10, 96.49±0.68, 105.35±9.02, and 85.30±1.02 mg/L for HRT=3 days, 61.21±02.18, 36.46±01.05, 47.00±01.62, and 24.3±01.34 mg/L for HRT=7 days, respectively (Table 3 and Figure 5(c)). This might be the result of plants imitating the microbial assemblages, wetland vegetation, and soils that naturally treat water to improve its quality. The organic load is eliminated by simple filtration in addition to the biological processes due to bacterial flora and a 95% removal rate of BOD. These results indicate that the elimination of organic compounds expressed by $BOD_5$ is produced without plant intervention and carried out by physical processes and microbial decomposition (De Lille *et al*., 2020). The outcomes demonstrated that the planted substrate basin and the unplanted control at both HRTs had significantly different $BOD_5$ removal capacities ($P < 0.0001$). According to performance, the overall removal efficiency was as follows: planted sand (89.59%), bare sand (79.86%), planted gravel (84.38%), and bare gravel (73.77%). This results are confirmed by Vera *et al*. (2013); García-Avila *et al*. (2019); Al-Saad *et al*. (2021); Qomariyah *et al*. (2022).

*Nitrogen removal*

Figure 6(a) shows that both planted cells successfully eliminated $NH_4^+$. The planted sand filter attained an average removal efficiency of 95.43%, which was its highest level. In the planted gravel unit, average removal efficiency reached 93.55%. Removal is adequate and is higher than that reported by other authors Tang *et al*. (2023); Al-Saad *et al*. (2021); García-Avila *et al*. (2019); Abdelhakeem *et al*. (2016). $NH_4^+$ removal showed a significant difference

**Table 3.** Pollution removal efficiency (%)

| Parameters | gravel planted$_3$ (%) | gravel planted$_7$ (%) | sand planted$_3$ (%) | sand planted $_7$ (%) | gravel unplanted$_3$ (%) | gravel unplanted$_7$ (%) | sand unplanted$_3$ (%) | sand unplanted$_7$ (%) |
|---|---|---|---|---|---|---|---|---|
| TSS | 44,12 | 83,3 | 49,44 | 86,63 | 33,54 | 70,07 | 39,82 | 81,92 |
| COD | 54,78 | 77,45 | 57,47 | 85,8 | 46,16 | 66,49 | 53,69 | 73,47 |
| $BOD_5$ | 58,66 | 84,38 | 63,45 | 89,59 | 43,58 | 73,77 | 54,86 | 79,86 |
| $NH_4^+$ | 67,79 | 93,55 | 76,96 | 95,43 | 62,66 | 65,95 | 69,85 | 74,65 |
| $NO_2^-$ | 39,49 | 68,64 | 43,81 | 74,45 | 27,32 | 23,06 | 33,02 | 39,27 |
| $NO_3^-$ | -27,41 | -454,95 | -16,99 | -326,07 | -141,34 | -669,41 | -111,89 | -533,56 |
| $PO_4^{3-}$ | 25,97 | 80,59 | 35,68 | 77,64 | 14,61 | 59,7 | 24,25 | 45,12 |

between the planted substrate types and the unplanted control ($P < 0.0001$), while there was no difference between the two HRTs ($P > 0.0001$). These results are similar to those obtained by Abdelhakeem *et al*. (2016); Bohorquez *et al*. (2017); Barco and Borin (2017); Guerrouf and Seghairi (2022). The obtained results show the existence of nitrification in planted VFCWs, which is confirmed by the decrease in $NH_4^+$ concentrations and the elimination of $NO_2^-$ in the system: planted gravel (68.64%) and planted sand (74.45%) for HRT=7 days (Figure 6 (a) and (b)), and by the increase in $NO_3^-$ concentration in the treated effluent from 8.18 to 19.75, 10.43, 17.34, and 9.57 mg/L in the gravel and sand filters bare and planted, respectively. The high ammonium reduction rates due to the nitrification by nitrified bacteria attached to the substrate and root (Tanveer, 2020), the nitrate concentration in the effluent of all planted and unplanted systems increased (Figure 6(c)). The concentration of $NO_3^-$ in the effluent of the VFCW seeded with the two substrates increased slightly, producing negative removal percentages. These low results for $NO_3^-$ elimination reflect the absence of favorable conditions for their elimination by

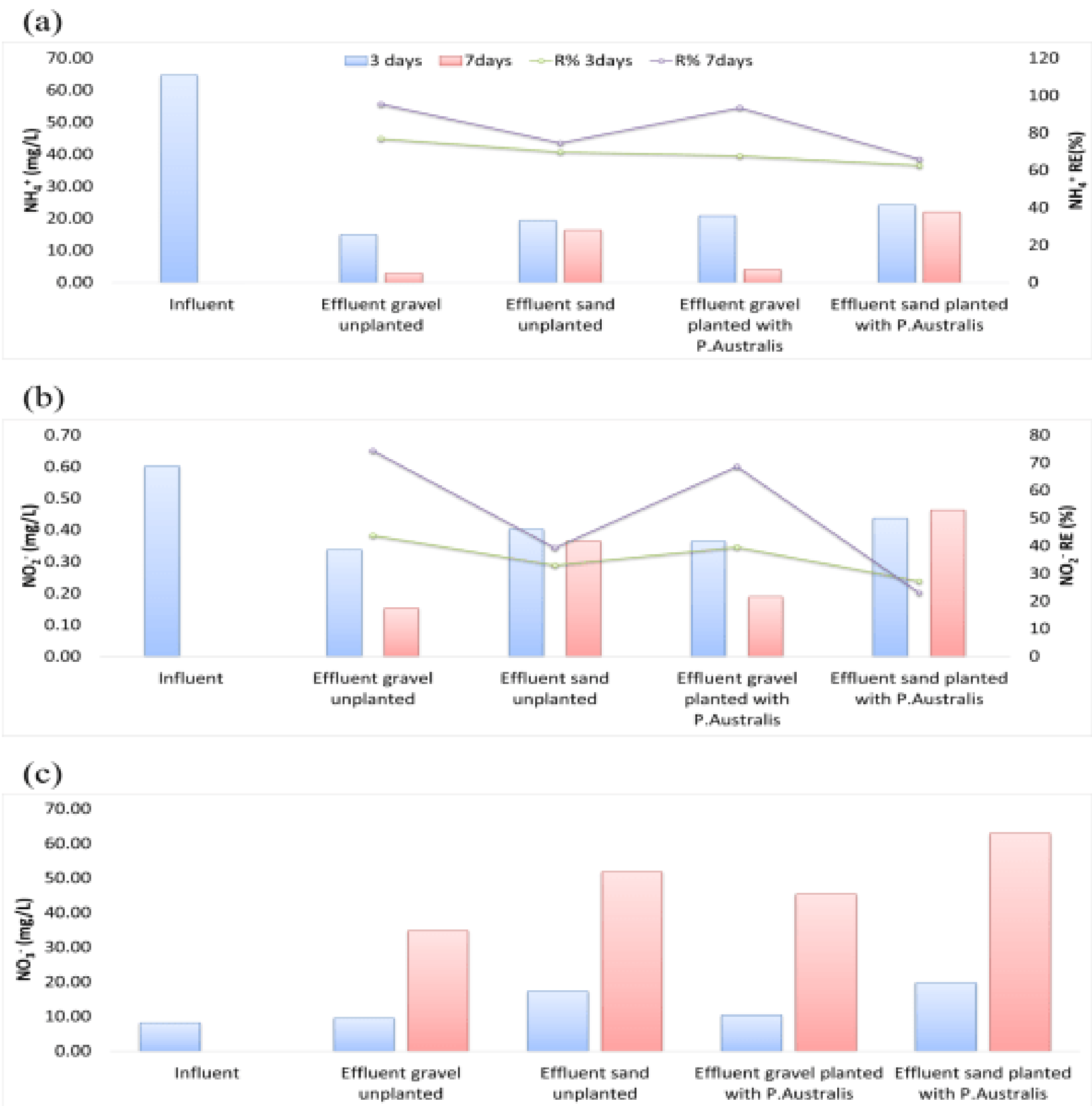



**Fig. 6.** Nutrients concentration and RE (%), (a) $NH_4^+$, (b) $NO_2^-$ , and (c) $NO_3^-$ , in the influent, unplanted substrates, and the substrates planted with P.Australis

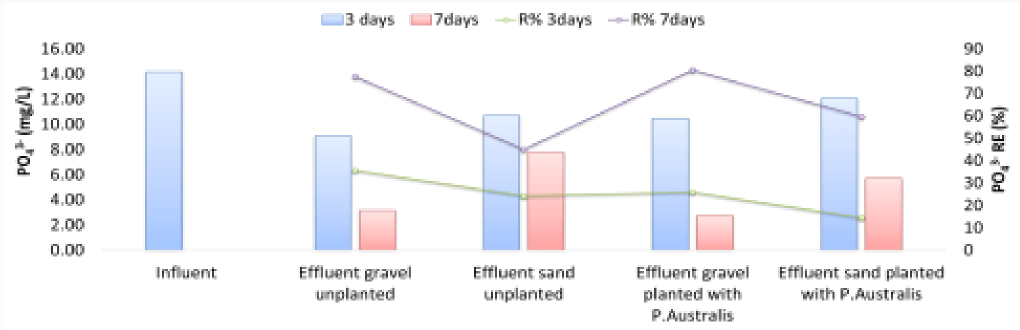



**Fig. 7.** Phosphorous concentration $PO_4^{3-}$, and $PO_4^{3-}$ RE(%), in the influent, unplanted substrates, and the substrates planted with P.Australis

the well-aerated VFCW wetland. Nitrates are eliminated by reducing them to nitrogen gas due to the denitrification process. These results are consistent with those obtained by Vymazal (2010) and Stefanakis *et al*. (2014), who found that constructed vertical flow wetlands successfully eliminate ammonia, but very limited denitrification occurs. The VFCW offers reasonable oxygen requirements for the nitrification of $NH_4^+$ but unfavorable conditions for the denitrification of $NO_3^-$. Negative efficiencies were registered in the elimination of $NO_3^-$. Tsihrintzis (2017) also reported this. The system did not remove nitrates because anaerobic conditions predominated in some system areas.

*Phosphorus removal*

The variation of orthophosphate is depicted in Figure 7. A decrease in $PO_4^{3-}$ concentration from 14.17±0.31 mg/L for the inlet to 12.10±1.13, 10.49±0.52, 10.73±0.21, and 9.11±0.58 mg/L for HRT= 3 days, 5.71±0.63, 2.75±0.19, 7.78±0.23, and 3.17±0.01 mg/L for HRT= 7 days for gravel and sand filters bare and planted, respectively. The purification yield in cultivated gravel and sand basins recorded at HRT= 7 days was 80.59% and 77.64%, respectively, and 59.70% and 45.11% in unplanted gravel and sand control (Figure 7). The same result was reported by Tang *et al*. (2023); Fai *et al*. (2021). Statistical analysis showed that there was a significant difference between gravel and sand substrates when wastewater was treated with both HRTs.

The planted VFCWs and unplanted control results were confirmed by Zhang *et al*. (2007); García-Valero *et al*. (2020). The substrate constitutes the primary component of phosphorus storage and plays a crucial role in the overall phosphorus retention in CWs. Several studies have reported that the substrate accounts for over 50% of phosphorus removal, compared to other components such as water, perennial plants, and macrophytes (Lai, 2014; Wang *et al*., 2018).

## CONCLUSION

In this research, the possibility of removing pollutants from wastewater was investigated using a pilot scale vertical flow constructed wetland (VFCW) planted with *Phragmites australis* applied to various substrates such as gravel and sand in an arid climate in Southeast Algeria.

The tested plant species grew well in both substrates and their presence significantly improved pollutant removal in the CW and showed tolerance to wastewater. TSS, $BOD_5$, and $NH_4^+$ removal is a slow process that needs more time, and it is shown on the HRT on the 7$^{th}$ day.

The removal efficiency values were 84.38% for $BOD_5$, 77.45% for COD, and 83.30% for TSS in the planted gravel filter. The planted sand filter had even higher removal efficiency values, with 89.59%, 85.80%, and 86.63% for $BOD_5$, COD, and TSS, respectively. Nitrate concentration increased in all filters due to the complete transformation of ammonium into nitrate. $NO_2^-$, $NH_4^+$, and $PO_4^{3-}$ removal efficiencies were high in the planted sand filter 74.45%, 95.43%, and 77.64%, respectively.

However, treatment with gravel and sand substrates was evaluated as having the best removal performance for pollution parameters, but the combination with other substrate types should be tested.

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## CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

## LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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