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# PERFORMANCE AND SUSTAINABILITY OF VERTICAL CONSTRUCTED WETLAND TO TREAT DOMESTIC WASTEWATER IN RURAL AREAS OF MOROCCO

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**Abstract:** Constructed wetlands (CWs) have been used as a green technology to treat various wastewaters for several decades. This technology can be used to overcome the challenge of wastewater effluent disposal without treatment in rural areas of Morocco. The aim of this study was to evaluate the performance of this system under three hydraulic loading rates.

To do this, a pilot scale of Subsurface-vertical flow constructed wetland system (VFCW) measuring 0.4 m × 0.6 m × 0.78 m (L ×W× H), was designed to treat domestic wastewater from a single household and its performance was investigated. The substrates used in this filter were gravel, iron sawdust and crushed concrete. This system was fed with three hydraulic loading rates: 250 L/m$^2$/day, 350 L/m$^2$/day and 500 L/m$^2$/day, and planted by *Chrosopogon zizanioides* L. The results showed the high removal rates (between 74 - 92 %) for all organic matters, good removal rate for orthophosphate (68±9%) due to the iron and crushed concrete added into the filter, and moderate removal rate for ammonium (47±23%). The effluent quality is in accordance with Moroccan standards. Consequently, VFCW as an efficient, economic, ecological and sustainable wastewater treatment technology can be one of the most appropriate solutions to treat domestic wastewater in rural areas of Morocco.

Keywords: Sustainability, VFCW performance, domestic wastewater, hydraulic loading rates, morocco.

## Introduction

Morocco has made significant efforts to supply rural areas with drinking water and these efforts made reached 95% access rate in 2015 for a rural population of 14.6 million. However, the sanitation issue is left unsolved since the share of households with access to a sewage system is only 2.8% in 2014 (HCP, 2014). Indeed, the high rate of drinking water supply in these areas leads to an increase in the production of wastewater, and the resulting health risks (Latrach *et al.*, 2018). Furthermore, the rural population usually uses traditional autonomous or individual drainage systems (e.g. latrines linked to lost wells) to get rid of black water and discharges gray water directly into nature without treatment (Bouhlal, 2018; Taouraout *et al*., 2019a). These practices still pose a major risk to public health and the environment, exposing many people to infection and dangerous diseases (Sutton *et al*., 2011; United Nations, 2016). The absence of a public sanitation network, the lack of wastewater treatment plants, the absence of environmental control and awareness contribute to the spread of waterborne diseases, the degradation of the landscape and the contamination of surface water and groundwater (HCP, 2015; WHO/ UNICEF, 2017).

The main barriers to access to the sanitation service in rural areas are mainly in terms of investment and operating costs. The lack of financial resources and the high cost of existing

technologies in the sanitation market (intensive systems) are considered among the main reasons for inadequate wastewater treatment in these areas (Taouraout *et al*., 2018).

The treatment of wastewater in small rural communities requires particular attention in the choice of purification technique to be used, as experience has shown, that the technologies initially developed for the urban environment do not prove to be as effective for rural areas (Latrach *et al*., 2018). Constructed wetlands are one of the most biologically productive ecosystems which can effectively treat most constituents found in domestic wastewater (Morvannou *et al*., 2015). A variety of treatment processes then takes place in constructed wetlands, such as filtration, sedimentation, and biological degradation, which together remove the contaminants in domestic wastewater effectively. In general, constructed wetlands require little operation and maintenance when compared with conventional treatment systems. Vertical flow constructed wetlands (VFCWs) have been widely used in recent years for treatment of municipal wastewater, owing to the advantages of good efficiency, low cost and low maintenance (Jia *et al*., 2010; Zurita *et al*., 2012; Zurita & White, 2014), and it is subjectif to intensive research, mainly in Europe, in order to optimize their basic design parameters (Wu*et al*., 2015). It is well documented that this type of wetland is very effective not only for the removal of organic matters but also for nitrification even at a high loading rate in a cold climate (Arias *et al*., 2005; Cooper, 2005; Prochaska *et al*., 2007) because it is intermittently flooded and drained, allowing air to refill the substrate pores within the bed (Prochaska & Zouboulis, 2006) and improving, in this way, the oxygen transfer from the atmosphere to the system. The main benefits of this system were: the lower area demands, lower construction costs, low-energy demand, and less-operational-requirements (Vymazal, 1998; Cooper, 1999). Consequently, it has been proved to be a good and reliable solution for the treatment of domestic wastewater as small onsite treatment systems for single households or small communities (Laber *et al*., 1997; Arias *et al*, 2005; Sklarz et *al*., 2009; Zapater *et al*., 2011; Porst-Boucle & Molle, 2012). The first aim of this study was to evaluate the performance of vertical flow constructed wetland to treat domestic wastewater under three hydraulic loading rates (250 L/m$^2$/day, 350 L/m$^2$/day and 500 L/m$^2$/day) in Moroccan conditions. The second is to study the iron and crushed concrete effect on phosphorus removal.

## Materials and Methods

### *Description of the treatment unit*

The pilot-scale system was designed (Figure 1), built to treat domestic wastewater of guardian's household (middle school Razi, Meknes, Morocco). This system began to operate at the beginning of March 2017 and was allowed to stabilize for three months. Our system is a Vertical Follow Constructed Wetland (VFCW) measuring 0.4 m × 0.6 m × 0.78 m (L ×W× H) linked to a feeding tank (100L) used to store prescreened wastewater from the inlet of the household, and it does not include any pretreatment and was exposed to the environmental conditions. This filter was planted by *Chrosopogon zizanioides L.* with a density of 4 plants /m², and these plants are set up with their clod, which facilitates their recovery. According to (Lombard-Latune & Molle, 2017) a density used in VFCW is between 4 and 8 plants / m², depending on the growth rate of the chosen species.

The substrates used in this study were gravel, iron sawdust and crushed concrete (Table 1 & Illustration 1). Crushed concrete and iron sawdust were used in our filter in order to enhance the adsorption of phosphate. According to Guan *et al*., 2015, removal rate of phosphorus is enhanced by using these substrates in Multi-Soil-Layering system. All these materials are abundant and inexpensive in Morocco, constituting a strong point since we are looking for economic and ecological treatment systems that adapt to the Moroccan rural context.

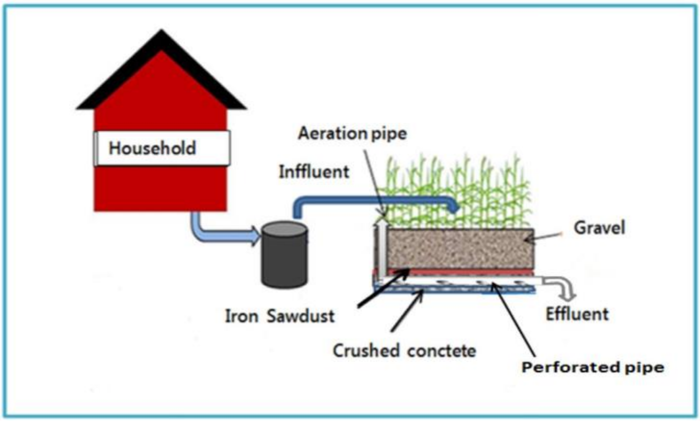


Figure 1: Schematic representation of vertical flow constructed wetlands (VFCW)

Table 1: Nature and quantity of the substrate

| Layer name | Height (cm) | Substrate nature | Diameter |
|---|---|---|---|
| Infiltration layer | 40 | Fine gravel | Ø (2-5 mm) |
| Transition layer | 15 | Medium gravel | Ø (5-10 mm) |
| Iron layer | 1 | Iron sawdust | Ø ≤ 1mm |
| Drainage layer | 15 | Crushed concrete | Ø (20-40 mm) |

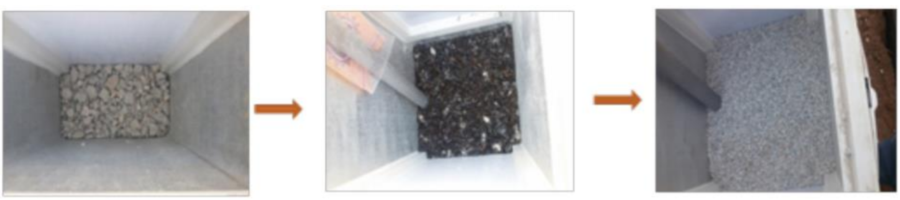


Illustration 1: Substrates used in this study

In order to maintain aerobic conditions into VFCW, passive oxygenation at the bottom of the filter is made using a drainage pipe. This pipe (diameter 50 mm) contains slots (length: ⅓ of pipe circumference, width: greater than 5 mm) for every 10 cm of drainage pipe length (Figure 1). The slots are positioned to allow air to enter via the top of the drainage pipes while treated wastewater is collected at the bottom of the drainage pipe. In order to enhance aeration, we have adopted a cycle of 3.5 wet days followed by 3.5 dry days.

In order to study the impact of the hydraulic load on the treatment performance of the filter according to the season, we applied the three HLRs ($HLR_1$=250 L/m$^2$/day, $HLR_2$=350 L/m$^2$/day and $HLR_3$=500 L/m$^2$/day) for each season (Table 2). Indeed, referring to research work in the same field (Molle *et al.*, 2004, Stefanakis & Tsihrintzis, 2012), these selected hydraulic loads gave a good purification performance and prevented clogging problem into the filter.

Table 2: Hydraulic load rates applied and the corresponding doses used in this study

| | Month | HLR (Liters/m$^2$/day) | Liters/0.24m$^2$/day |
|---|---|---|---|
| Summer | June | HRL1=250 | 60 |
| | July | HRL2=350 | 84 |
| | August | HRL3=500 | 120 |
| Fall | September | HRL1=250 | 60 |
| | October | HRL2=350 | 84 |
| | November | HRL3=500 | 120 |
| Winter | December | HRL1=250 | 60 |
| | January | HRL2=350 | 84 |
| | February | HRL3=500 | 120 |
| Spring | March | HRL1=250 | 60 |
| | April | HRL2=350 | 84 |
| | May | HRL3=500 | 120 |

### *Climate of the Study Area*

Meknes has a continental climate and the weather is under the influence of the Atlas Mountains. Summer months can be quite warm because of the warm air coming from the Sahara. The average temperature in summer is above 30 degrees Celsius (°C). In winter months the average temperature is about 15 degrees Celsius during the day, however during the nights it can be extremely cold at times (Hamdani, 2015).

### *Measurement of Water Quality Parameters*

After the stabilization period (three months), Samples from the influent and effluent were collected at almost the same time every month, using plastic bottles. Samples were analyzed for different water quality parameters using the methods recommended by Rodier (2009) standards. For physicochemical parameters, pH, temperature (T), electrical conductivity (EC) and Dissolved Oxygen (DO) were measured in situ using a multi-parameter probe type PCE-PHD1 and turbidity by Turbidity meter (HI 93703 HANNA instrument). The other parameters were measured into Laboratory of Natural Resources Management and Development Team, Health and Environment (Faculty of Science Meknes). Biochemical oxygen demand measured in a 5-day test ($BOD_5$) was determined by the BOD Sensor (VELP SCIENTIFICA), and chemical oxygen demand (COD) was analysed according to the dichromate open reflux method. Total suspended solids (TSS) concentration was determined by the filtration method, ammonium ($NH_4^+$) concentration by the indophenol method, nitrate ($NO_3^-$) concentration by the diazotization method and orthophosphate ($PO_4^{3-}$) concentration by the molybdate and ascorbic acid method.

### *Data analysis*

Statistical analyses of the collected data were carried out using software: Microsoft Excel 2010, SPSS 20 (Analysis of variance test (ANOVA)). In this study, the objective of the ANOVA test is to investigate whether there is a significant difference between the characteristics of the sample before and after treatment with a significance level (p) of 0.05 ($p < 0.05$ ) and the effect of hydraulic load rates on the performance of VFCW.

## Results and discussion

### *Trend of Temperatures, pH, DO and EC*

The average values of influent and effluent water temperatures were 20.3±6.1°C and 20.3±6.4°C, respectively. The highest temperatures (inflow: 29.0°C, outflow: 28.6°C) were reached in July–August, and the lowest values (inflow: 11.6°C, outflow: 12.4°C) were recorded in March. The Dissolved oxygen content in raw and treated water averaged 1.2±0.5 mg/L and 4.5±1.6 mg/L, respectively. This parameter reached the highest value in December (7.1 mg/L in outflow) and the lowest value in May (1.2 mg/L in outflow). This parameter presented an inverse variation with temperature (Figure 2) and this can be explained by the combined effects of lower solubility of DO and greater $BOD_5$ in the wetland system at higher temperatures (Coveney *et al.*, 2002). Indeed, the rate of oxygen consumption into the filter is affected by a number of variables: temperature, pH, the presence of certain kinds of microorganisms, and the type of organic and inorganic material in the water (APHA, 1992). Furthermore, the DO values decrease as the values of the hydraulic load rate (HLR) increase. The average values of DO for the three tested HLRs ($HLR_1$, $HLR_2$ *et* $HLR_3$) were 4.82±2.5, 4±1.3 and 3.08±1.1mg/L, respectively (Figure 2). Indeed, when HLR increases, the amount of organic matter increases too, thus, the microorganisms used more oxygen in order to decompose it (APHA, 1992).

The pH values of the treated water are between 7 and 8 units (Figure 3), indicating best conditions in the treatment system during the study period; the averages of this parameter in influent and effluent were 7.0±0.6 and 7.6±0.2, respectively. This parameter is a fundamental factor for the quality of the water, exerting a great influence on the aquatic system because it is a fundamental parameter in many chemical reactions in living organisms. The pH of the effluent reached the highest value in September (7.98) and the lowest in February (7.07) (Figure 3).

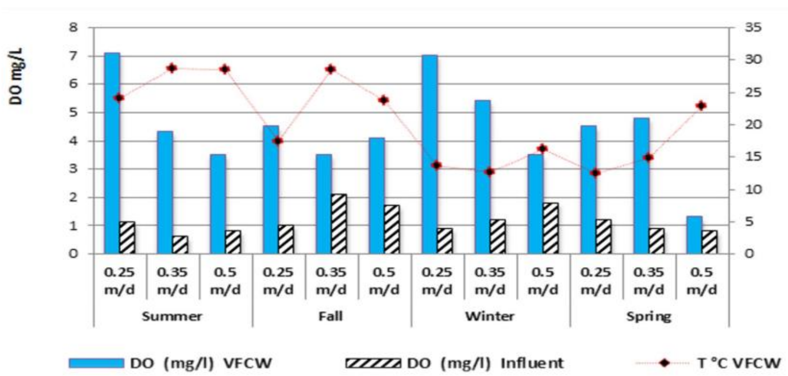


Figure 2: Trend of DO and temperature according to HLR and season (0.25 m/d = 250 Liters/m$^2$/day, 0.35 m/d = 350 Liters/m$^2$/day and 0.5 m/d = 500 Liters/m$^2$/day)

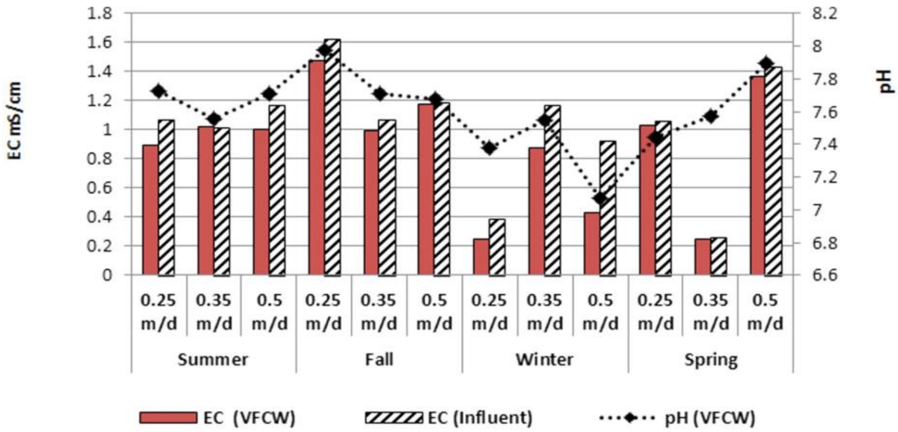


Figure 3: Trend of EC and pH according to HLR and season (0.25 m/d = 250 Liters/m$^2$/day, 0.35 m/d = 350 Liters/m$^2$/day and 0.5 m/d = 500 Liters/m$^2$/day)

The average electrical conductivity of the treated wastewater (1.06±0.3 mS/cm) was slightly decreased as compared to the values for the influent (1.03±0.38 mS/cm) during the study period, except at the end of winter when the outflow EC values were lower than those of influent. The fluctuation of the electrical conductivity during the study period was mainly related to the variation of the organic and hydraulic loading rate of domestic wastewater used each month.

### *Reduction of $BOD_5$, COD, and TSS*

The concentrations of $BOD_5$, COD, and TSS in the inlet and outlet during the study period according to the hydraulic loading rates are shown in figures 4 to 6. The averages of their concentrations in the influent were 186.7±42.9 mg/L, 386.8±84.1 mg/L and 371±102.7 mg/L, and those of the effluent were 40.3±25.3 mg/L, 80±47.9 mg/L and 61.3±42.6 mg/L, respectively. In influent, the fluctuation of the concentrations of $BOD_5$, COD, and TSS during the study period is mainly related to the variation of the organic and hydraulic loading rates used for each month. For the effluent, the trends of these parameters during the study period follow the same trends of those in influent except in winter and spring. This can explain by the temperature effect (Taylor *et al.*, 2011; Stefanakis & Tsihrintzis, 2012).

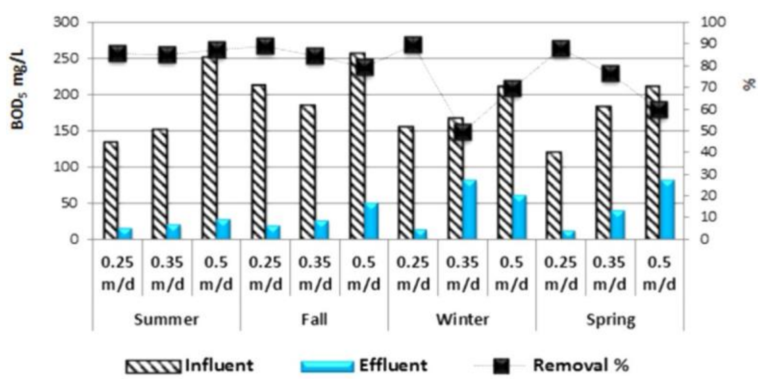


Figure 4: Trend of $BOD_5$ concentrations during the study period according to HLR and season (0.25 m/d = 250 Liters/m$^2$/day, 0.35 m/d = 350 Liters/m$^2$/day and 0.5 m/d = 500 Liters/m$^2$/day)

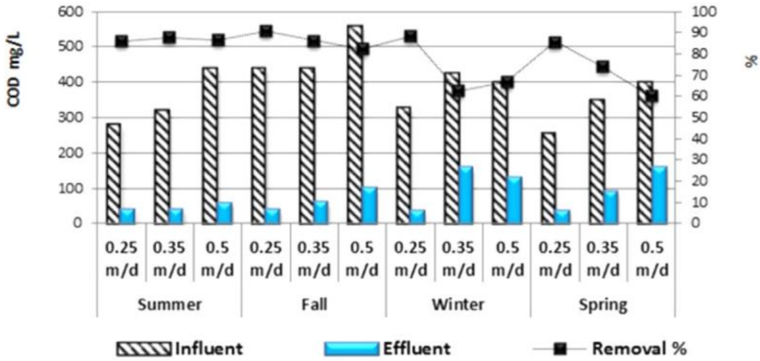


Figure 5: Trend of COD concentrations during the study period according to HLR and season (0.25 m/d = 250 Liters/m$^2$/day, 0.35 m/d = 350 Liters/m$^2$/day and 0.5 m/d = 500 Liters/m$^2$/day)

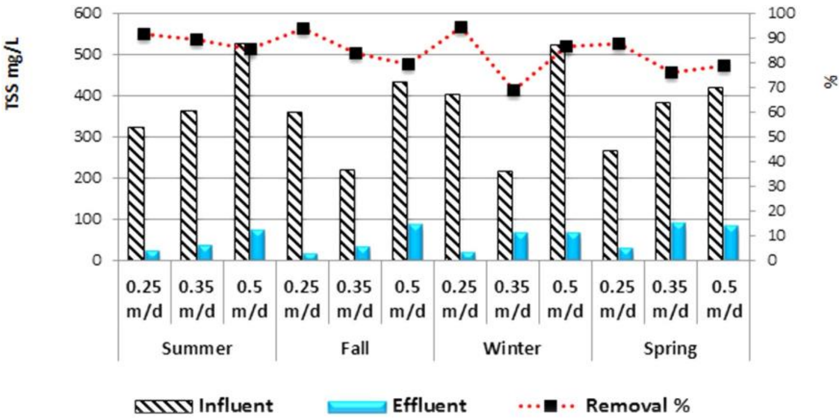


Figure 6: Trend of TSS concentrations during the study period according to HLR and season (0.25 m/d = 250 Liters/m$^2$/day, 0.35 m/d = 350 Liters/m$^2$/day and 0.5 m/d = 500 Liters/m$^2$/day)

The ANOVA test shows that there is a significant difference between the $BOD_5$, COD and TSS average concentrations in influent and effluent at $p < 0.05$ (Table 3).

Table 3: ANOVA test of treatment (influent and VFCW)

| Variable | (I) Treatment | (J) Treatment | Difference (I-J) | Signification (p) |
|---|---|---|---|---|
| $BOD_5$ (mg/L) | Influent | VFCW | 146.342* | .000 |
| COD (mg/L) | Influent | VFCW | 306.725* | .000 |
| TSS (mg/L) | Influent | VFCW | 310.000* | .000 |
| $P0_{43-}$(mg/L) | Influent | VFCW | 2.290* | .001 |
| $NH_{4+}$(mg/L) | Influent | VFCW | 9.248* | .000 |
| $NO_{3-}$(mg/L) | Influent | VFCW | -9.250-* | .000 |

* Significant difference at $p < 0.05$

**I**: concentration of a specified variable in Influent **J**: concentration of a specified variable in Effluent

The main treatment performance results showed the following average removal rates: 79%, 80% and 83% for $BOD_5$, COD and TSS, respectively. The results obtained by our pilot unit were higher than those reported by Molle *et al*. (2008) in terms of COD and TSS reduction, which are 68% and 74%, respectively. Morvannou *et al*. (2015) and Paing *et al*. (2015) achieved similar results. The high removal rates of these pollutants ($BOD_5$, COD and TSS) in this study indicate the importance of physical (filtration, sedimentation), chemical (adsorption, precipitation) and biological (biodegradation, plant assimilation) mechanisms occurring in our VFCW filter. Therefore, it can be stated that *Chrosopogon zizanioides L.* used in this wetland system, associated to the roots adsorbed biomass which is of particular importance in the removal of biodegradable organic content (Noyes, 1994), play an important role in the treatment process. It is also reported that the major organic matters part are removed in the first 10-20 cm of the VFCW bed, since the top layer is dominated by aerobic conditions and contains high microbial density (Tietz *et al*., 2008; Kadlec & Wallace, 2009; Stefanakis & Tsihrintzis, 2012). Moreover, Ye *et al*. (2012) investigated the vertical DO profile within a VFCW bed and observed a high DO concentration in the upper part followed by a reduction with depth. They also reported that atmospheric oxygen is the main oxygen source for the bed, while most of it is consumed within the first centimeter of the bed. Similar results were reported by Morari & Giardini (2009) that investigated the performance of two pilot-scale VFCWs (without a pretreatment stage) in municipal wastewater treatment. In addition, Abou-Elela & Hellal, (2012) reported the following results (88%, 90%, 92%, 53%, and 57% for COD, $BOD_5$, TSS, TKN, and $NH_4$-N, respectively) for a full-scale VFCW system in Egypt. The overall good performance of VFCWs was also reported by Vera *et al*. (2013) for a system in the Canary Islands (80% and 75% for COD and $BOD_5$ and 90% for TSS). However, Molle *et al*. (2005) presented an overview of the two-staged French system performance with removal rates above 90% for COD, 94% for TSS, and 85% for TKN, while the respective values for the first treatment stage were79%, 86%, and 58%.

The performance of our filter to remove organic matter pollution is affected by the hydraulic loading rate applied and season. Indeed, the average removal rates in the study period under the three hydraulic loading rates tested ( HLR1, HLR2 and HLR3) were 88%, 74% and 74% respectively (for $BOD_5$), 88%, 77% and 75%, respectively (for DCO) and 92%, 80% and 79%, respectively (for TSS) (Table 4).

In general, when the HLR increased, the filter performance decreased during the study period. This is because the retention time of the wastewater within the system increased as the HLR decreased, thus providing the system with sufficient time to adsorb, react, and remove the organic pollutants from the wastewater and consequently enhancing the removal efficiency (Masunaga et *al*., 2007; Taouraout et *al*., 2019b). According to Breen, (1997) and Ghosh & Gopal, (2010), the hydraulic residence time (HRT) appears to be a crucial parameter for the system performance, since it determines the contact time between the wastewater and the root zone.

Table 4: Average removal rates of organic matter and nutrient pollution according to HLRs during the study period

| | Removal rate % | | | | |
|---|---|---|---|---|---|
| | **$BOD_5$** | **COD** | **TSS** | **$NH_{4+}$** | **$PO_{43-}$** |
| HLR1 | 88.1 ± 1.5 | 87.7 ± 2.2 | 92.2 ± 2.8 | 50.1 ± 18.4 | 71.8 ± 8.3 |
| HLR2 | 73.8 ± 14.4 | 77.4 ± 10.2 | 79.8 ± 7.8 | 54.5 ±15.5 | 64.6 ± 7.4 |
| HLR3 | 74.2 ±10.3 | 74.9 ±9.6 | 79.2 ± 8.7 | 44.8 ± 13.6 | 68.6 ± 8.6 |

(HLR1 = 250 Liters/$m^2$/day, HLR2 = 350 Liters/$m^2$/day and HLR3= 500 Liters/$m^2$/day)

Contrary to what was mentioned above, the removal efficiency of our filter in winter (according to the HLRs applied) did not follow the logical findings since the VFCW showed high efficiency in removing the organic matters with HLR3= 500 L/m$^2$/day (applied in February with 70%) than HLR2= 350 L/m$^2$/day (applied in January with 50%) (Table 5 and Figure 7). This can be explained by the temperature effect on VFCW performance since the water temperature recorded in February (16°C) was greater than that recorded in January (12°C) (Figure 2). This result is confirmed by other authors like Langergraber *et al*. (2007) who tested the performance of three experimental VFCW units in Austria under different organic loads with temperature variations and they reported that the $BOD_5$ and COD removal efficiencies in all VFCW units were higher with the temperatures greater than 12°C than those with temperatures less than 12°C.

On the other hand, the efficiency (per cent removal by mass) of the VFCW to remove organic matters according to season is shown in Table 5 and Figure 7. This filter showed a high performance removing the $BOD_5$ and COD in summer (86%) and in fall (85%) but a low performance in winter (71%) and spring (73%) due to the low temperatures recorded in these months (Table 5 and Figure 2) (Taylor *et al.*, 2011; Stefanakis and Tsihrintzis, 2012). However, this filter showed a good performance to eliminate TSS for all seasons with 89±3%, 86.1±7.6%, 83.5±13% and 75±11% for summer, fall, winter and spring, respectively. According to Taylor *et al.*, (2011), Stefanakis and Tsihrintzis, (2012), the effects of season and temperature on organic matter removal efficiency in the CWs were reported with the worst performance occurring usually during winter. In a continental Mediterranean climate region, Garfi *et al*. (2012) observed that $BOD_5$ removal efficiency followed seasonal trends which ranged from 96.2% in summer to 65% in winter. The authors also observed dependence of pollutant removal efficiency on season is more emphasised in

Table 5: Removal of organic matter and nutrient pollution according to the seasons and HLRs during the study period

| | | | Removal rates % | | | | |
|---|---|---|---|---|---|---|---|
| | | | **BOD** | **COD** | **TSS** | $NH_{4+}$ | $PO_{43-}$ |
| Summer | June | HLR1 | 85.9 | 85.7 | 91.7 | 28.0 | 84.4 |
| | July | HLR2 | 85 | 87.5 | 89.4 | 35.6 | 55.8 |
| | Aug. | HLR3 | 87.6 | 86.4 | 85.8 | 31.9 | 80.3 |
| | | Means±SD | 86.2 ± 1.3 | 86.5 ± 0.9 | 89 ± 3 | 31.9 ± 3.8 | 73.5 ± 15.4 |
| Fall | Sept. | HLR1 | 89.4 | 90.9 | 94.4 | 38.4 | 71.7 |
| | Oct. | HLR2 | 84.3 | 86.1 | 84.3 | 44.4 | 61.1 |
| | Nov. | HLR3 | 79.5 | 82.1 | 79.5 | 33.6 | 56.2 |
| | | Means±SD | 84.4 ± 5 | 86.4 ± 4.4 | 86.1 ± 7.6 | 38.8 ± 5.4 | 63 ± 7.9 |
| Winter | Dec. | HLR1 | 89.5 | 88.5 | 94.7 | 58.2 | 70.0 |
| | January | HLR2 | 49.6 | 62.4 | 69 | 62.8 | 65.8 |
| | Feb. | HLR3 | 69.8 | 66.9 | 86.7 | 65.7 | 67.3 |
| | | Means±SD | 69.6 ± 20 | 72.6 ± 14 | 83.5 ± 13.2 | 62.2 ± 3.8 | 67.7 ± 2.1 |
| Spring | March | HLR1 | 87.8 | 85.5 | 86.5 | 75.9 | 61.0 |
| | April | HLR2 | 76.3 | 73.7 | 75.3 | 75.4 | 75.8 |
| | May | HLR3 | 60 | 61 | 61.5 | 47.9 | 70.5 |
| | | Means±SD | 74.7 ± 14 | 73.1±12.8 | 74.7 ± 11 | 66.4 ± 16 | 69.1 ± 7.5 |

(HLR1 = 250 Liters/m$^2$/day, HLR2 = 350 Liters/m$^2$/day and HLR3= 500 Liters/m$^2$/day)

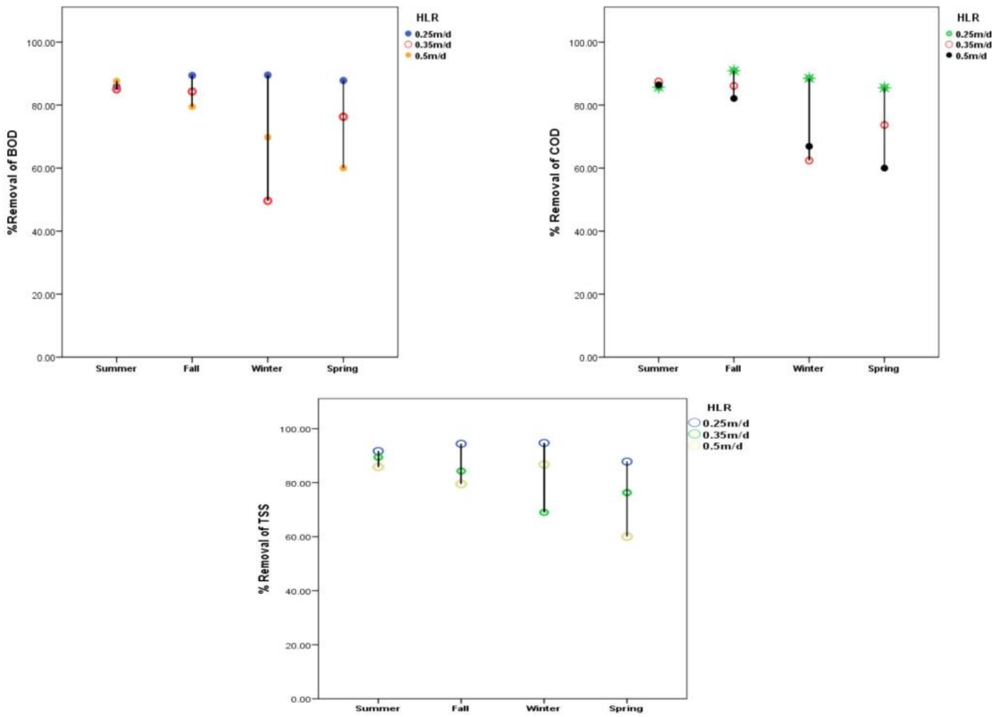


Figure 7: Performance of VFCW to remove organic matters according to HLR and season (0.25 m/d = 250 Liters/m$^2$/day, 0.35 m/d = 350 Liters/m$^2$/day and 0.5 m/d = 500 Liters/m$^2$/day)

regions that the with a continental climate than in areas with Mediterranean climate due to more severe winters in the continental regions.

Despite the performance difference shown between the three HLRs in this study, the ANOVA test did not show any significant difference of the removal performance of $BOD_5$, COD and TSS according to these HLRs (Table 6).

Table 6: ANOVA test of organic pollutions according to HLRs

| Variable | (I) HLR | (J) HLR | Difference (I-J) | Signification (p) |
|---|---|---|---|---|
| BOD5 mg/L | 0.25m/d | 0.35m/d | -26.62500- | 0.239 |
| | | 0.5m/d | -39.70000- | 0.066 |
| | 0.35m/d | 0.5m/d | -13.07500- | 0.678 |
| COD mg/L | 0.25m/d | 0.35m/d | -49.50000- | 0.255 |
| | | 0.5m/d | -74.32500- | 0.071 |
| | 0.35m/d | 0.5m/d | -24.82500- | 0.680 |
| TSS mg/L | 0.25m/d | 0.35m/d | -32.75000- | 0.361 |
| | | 0.5m/d | -75.25000-* | **0.022** |
| | 0.35m/d | 0.5m/d | -42.50000- | 0.201 |

* Significant difference at $p < 0.05$
**I** and **J**: concentration of a specified variable at different HLRs (**I-J**): the difference between the concentrations of a specified variable under HLR (I) and HLR (J) (0.25 m/d = 250 Liters/m$^2$/day, 0.35 m/d = 350 Liters/m$^2$/day and 0.5 m/d = 500 Liters/m$^2$/day)

***Ammonia Removal and Nitrate Transformation***

The average concentrations of the ammonia and nitrate concentrations in VFCW were 10.6±5 mg/L and 14.1±5.3 mg/L, respectively; while those of influent were 19.8±5.4 mg/L and 4.9±2.7 mg/L, respectively (Figure 8). Therefore, the decrease of ammonium concentration and the increase of nitrates in the VFCW indicate that the nitrification was effective due to aerobic conditions. The higher nitrification capacity of the VFCW can be attributed to increased oxygen transfer from the atmosphere to the beds (Brix, 1997; Stefanakis & Tsihrintzis, 2012). Moreover, in an intermittently fed vertical flow system, oxygenation of the matrix is high compared to other wetland systems, favouring nitrification processes (Abou-Elela & Hellal, 2012). The ANOVA test shows that there is a significant difference between the concentrations of $NH_4^+$ and $NO_3^-$ in the VFCW and the influent at $p < 0.05$ (Table 3).

Figure 8, Figure 9 and Table 5 show ammonia removal during the study period, according to the hydraulic load rates (HLRs) and season. These figures and table indicate that the $NH_4^+$ removal performance has reached the highest values in winter and spring with 62.2 ± 3.8% and 66.4 ± 16%, respectively. In these seasons, the water temperatures recorded the values between 12°C and 16.5°C, and the dissolved oxygen reached the highest values (Figure 2), while when the water temperature was above 17.5°C, the DO decrease and the nitrification were affected. This indicated that there is dependence between the removal rate of the ammonium, water temperature and dissolved oxygen values. This finding has been demonstrated by Langergraber *et al*. (2007) which tested three experimental VFCW units in Austria under different organic loads and correlated the performance of the beds with the temperature variations. They reported that the removal of ammonium was high with temperatures above 12°C and low with temperature under 12°C, indicating the dependence of the removal rate on temperature variations.

Langergraber *et al.* (2008a, 2008b) investigated a two-stage VFCW system with intermittent loading and they reported similar efficiency to a single-stage system for organic matter and nitrogen removal. As illustrated in Figure 2, the dissolved oxygen presented an inverse variation with temperature, so when water temperature was greater than 17°C the dissolved oxygen concentration decreased affecting the nitrification negatively, as reported in summer and fall. In contrary, the water temperatures recorded in winter and spring were between 12°C and 16.5°C with high concentration of dissolved oxygen affecting the nitrification positively. The average removal rates of $NH_4^+$ (according to HLRs) were 50%, 54%, 45% for HLR1, HLR2 and HLR3, respectively. According to

Figure 8: Ammonia removal during study period according to HLR and season (0.25 m/d = 250 Liters/m²/day, 0.35 m/d = 350 Liters/m²/day and 0.5 m/d = 500 Liters/m²/day)

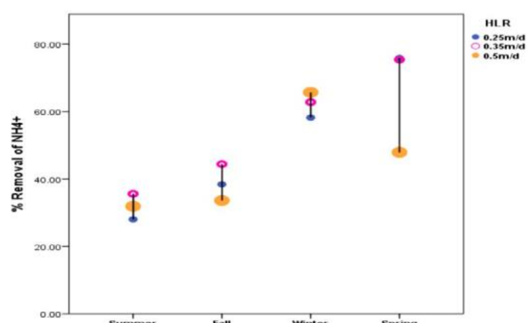


Figure 9: Performance of VFCW to remove Ammonia according to HLR and season (0.25 m/d = 250 Liters/m²/day, 0.35 m/d = 350 Liters/m²/day and 0.5 m/d = 500 Liters/m²/day),

the seasons, the average removal rates of $NH_4^+$ were 31.9±3.8%, 38.8±5.4%, 62.2±3.8% and 66.4±16% for summer, fall, winter and spring, respectively (Table 5 and Figures 8 & 9). As can be seen, these results did not follow the logical order which reported the decrease of the VFCW performance when the hydraulic loading rate increased due to do variation of water temperature and dissolved oxygen between the months of each season (Figure 2 and Table 5). Despite the difference shown between the averages of ammonium removal according to the three HLRs tested (Tables 4 & 5 and Figures 8 & 9), the ANOVA test did not show any difference between the concentrations of $NH_4^+$ and $NO_3^-$ at $p < 0.05$ (Table 7).

### *Elimination of Orthophosphate*

The average concentrations of $P0_4^{3-}$ in influent and effluent were 4.2±1.7 mg/L and 1.3±0.5 mg/L, respectively (Figure 10). The average removal rates of $P0_4^{3-}$ for the three HLRs (HLR1, HLR2 and HLR3) tested were 71.8 ± 8.3%, 64.6 ± 7.4%, 68.6 ± 8.6%, respectively (Table 5 and Figure 10). According to the seasons, the average removal rates of $P0_4^{3-}$ were 73.5±15.4%, 63 ± 7.9%, 67.7 ± 2.1% and 69.1 ± 7.5% for summer, fall, winter and spring, respectively (Table 5 and Figure 10).

Table 7: ANOVA test of nutrients

| Variable | (I) HLR | (J) HLR | Difference (I-J) | Signification (p) |
|---|---|---|---|---|
| $NH_4^+$ mg/L | 0.25m/d | 0.35m/d | -1.05750- | 0.948 |
| | | 0.5m/d | -6.31750- | 0.204 |
| | 0.35m/d | 0.5m/d | -5.26000- | 0.314 |
| $NO_3^-$ mg/L | 0.25m/d | 0.35m/d | -5.10000- | 0.289 |
| | | 0.5m/d | -8.47500- | 0.059 |
| | 0.35m/d | 0.5m/d | -3.37500- | 0.557 |
| $PO_4^{3-}$ mg/L | 0.25m/d | 0.35m/d | .16500 | 0.929 |
| | | 0.5m/d | .23750 | 0.859 |
| | 0.35m/d | 0.5m/d | .07250 | 0.986 |

* Significant difference at p <0.05

**I** and **J**: concentration of a specified variable at different HLRs (**I-J**): the difference between the concentrations of a specified variable under HLR (I) and HLR (J) (0.25 m/d = 250 Liters/m²/day, 0.35 m/d = 350 Liters/m²/day and 0.5 m/d = 500 Liters/m²/day)

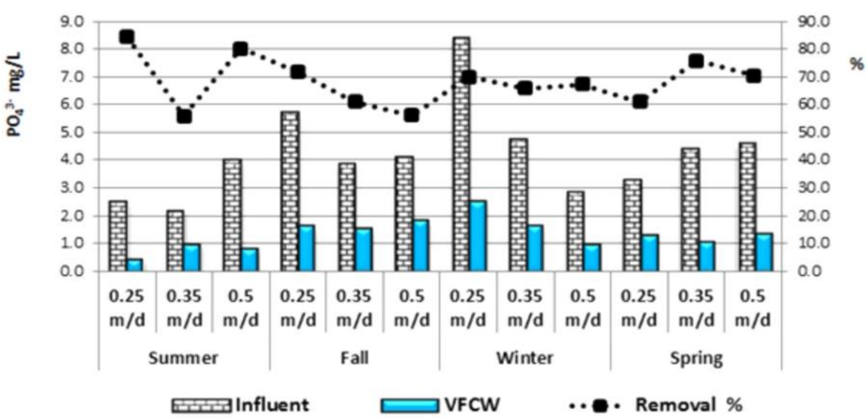


Figure 10: $P0_4^{3-}$ removal during the study period according to HLR and season (0.25 m/d = 250 Liters/m²/day, 0.35 m/d = 350 Liters/m²/day and 0.5 m/d = 500 Liters/m²/day).

The ANOVA test showed that there is a significant difference between the $P0_4^{3-}$ means of the VFCW and the influent at $p < 0.05$ (Table 3), but it did not show any difference of the removal performance of $PO_4^{3-}$ between these three hydraulic load rates (Table 7). According to Schonerklee *et al*., (1997), there is a correlation of phosphorus removal rate and HLR, they reported that higher performances were obtained by lower HLRs, however, the average removal rates of their filters were lower around 29% (3-65%). Similar performances were also reported by Cooper *et al*. (1997) and Cooper (1999) for a full-scale system, where the first two stages were VFCWs (19.4% and 7.7% in the first and second stages, respectively). Furthermore, values of 20-30% for P removal are reported for VFCW beds alone in Danish and Greek systems for single households (Brix & Arias, 2005; Gikas & Tsihrintzis, 2012). Generally, the efficiency of VFCWs in phosphorus retention is limited compared to the other pollutants (Brix & Arias, 2005; Prochaska & Zouboulis, 2006; Stefanakis & Tsihrintzis, 2012). Lantzke *et al*., 1999 reported that in VFCWs subjected to the filling and emptying regime, phosphorus removal increases with increasing retention time, due to increased contact time. This indicates that retention time is a crucial parameter for effective phosphorus removal (Drizo *et al*., 2006). On the other hand, phosphorus uptake by plants takes place at a slower rate compared to adsorption to the substrate (Lantzke *et al*., 1999), mainly through their root system (Vymazal *et al*., 1998). According to Reddy *et al*., (1999), Plant uptake proceeds faster and is more intense during the growing period, especially in the first months after the winter period when the new shoots are regenerated (Figure 10).

Taking into account that phosphorus adsorption to the substrate is regarded as the main removal mechanism, the research around filter media today is targeting mainly at the investigation of various filter materials with special properties for the enhancement of phosphorus adsorption (Brix & Arias, 2005; Gikas & Tsihrintzis, 2012; Stefanakis & Tsihrintzis, 2012). According to several studies, the presence of iron (Fe) and calcium in the filter medium increased the adsorption and precipitation reactions of phosphorus (Vymazal, 2007; Guan *et al*., 2015). The adsorption process of $P0_4^{3-}$ on iron layer into the filter is shown in Figure 11. This is why, after a thorough bibliographic research, our choice is made on the use of iron (Fe) and crushed concrete materials since they composed mainly of Fe and Calcium ions that could enhance phosphorus removal and were economic and ecologic materials (Table 1 and Figure 1). Thus, the high removal of phosphorus in our VFCW system is very likely related to its precipitation on the ferrous layer (thickness=1cm) and crushed concrete (thickness=15cm) added into this filter.

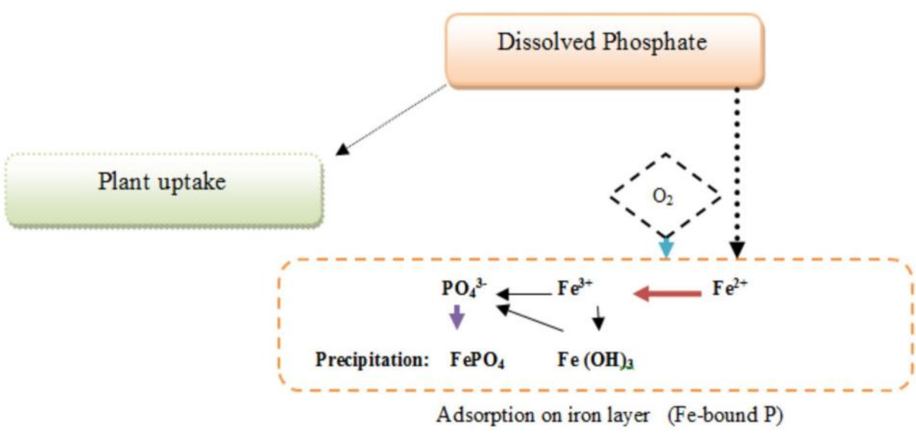


Figure 11: Phosphorus removal processes in VFCW (adapted from Vymazal, 2007)

## Conclusion

Domestic wastewater treatment by the VFCW system under three hydraulic loading rates (250 L/m$^2$/day, 350 L/m$^2$/day and 500 L/m$^2$/day) tested in this work showed a high performance (between 74 - 92 %) to remove organic matter ($BOD_5$, COD and TSS) and good performance (68±9%) for $PO_4^{3-}$. However, the VFCW performance is still moderate (47±23%) to remove $NH_4^+$. In addition, this study showed that the performance of this filter is affected by the HLR used and season. On the other hand, the high removal of phosphorus in our VFCW system is very likely related to its precipitation on the ferrous and crushed concrete layer added into this filter. As a low-cost wastewater treatment technology with fewer constraints of operation and maintenance, the VFCW system could be considered an effective solution to be adopted for decentralized domestic wastewater treatment in Moroccan rural areas.

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