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Constructed Wetland as a Low-Energy Technique for Wastewater Treatment – Seasonal Impact, Performance and Phytomanagement

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ABSTRACT

This work aims to study the seasonal impact on pollutant removal efficiency of constructed wetland (CW) units which treat domestic wastewater in the region of Rabat, Morocco. In this context, four vertical flow-constructed wetlands (VFCWs) were investigated for one year. Each CW unit has a surface area of 1m² and a depth of 60 cm. The difference between the units is the vegetation. The experiments are conducted on a laboratory scale and outdoors, to investigate also the direct effect of the climate. The purpose is to investigate the CWs performances with two different plant species (*Phragmites Australis* and *Arundo Donax*) and plant arrangements (mono-culture and poly-cultures). Since the region of Rabat has a semi-arid climate, plants behave during seasonal changes was explored. The elimination of organic matters showed a seasonal variation in the CW systems, with higher rates during the hot season and lower rates during the cold ones. Planted systems outperformed the unplanted system and the polyculture system was the most effective, reaching removal rates of 99.47%, 99.58%, and 85.64%, for, COD, BOD_5, and TSS in the summer season where the temperature reaches its maximum promoting plant growth as well as microbial activity. Anyhow, results showed that the VFCWs used in this study are a successful technology for the region that is cost-effective and requires low energy.

Keywords: environment, wastewater treatment, constructed wetlands, bioremediation, sustainability, energy saving.

INTRODUCTION

In Morocco, sanitation and wastewater treatment are the main environmental issues, especially in decentralized, rural and remote areas [14], where conventional wastewater treatment is not achievable [3]. However, untreated wastewater discharges impact negatively the environment through the eutrophication or the transmission of pathogenic germs, leading to direct health effects [28]. Since water resources are increasingly scare due to the climate change situation and to over-exploitation of groundwater resources especially in agriculture [30] and also due to population growth and over-consumption [7, 48], wastewater collection, treatment and reuse become necessary. In addition, nowadays, wastewater is not considered a source of pollution, but a renewable and non-conventional resource [7]. Since it contains the nutrient, treated wastewater can be used for irrigation. Nevertheless, because of the high operating cost and maintenance, intensive wastewater treatment processes are not possible all the time nor adapted for every zone such as remote areas [28]. For this reason, the search for a suitable method is essential. CWs present a viable alternative to traditional wastewater treatment plants, especially in the context of rural and semi-arid regions of Morocco. One of the primary advantages of CW systems is their low energy consumption [27], leveraging natural biological processes for wastewater treatment, which is particularly beneficial in areas with limited access to reliable energy sources. Additionally, CWs are often more cost-effective [12] to construct and maintain due to the utilization of locally available materials and the reduced need for complex mechanical systems. This economic efficiency is crucial for small communities with constrained financial resources. Furthermore, CW systems provide significant environmental benefits by enhancing local biodiversity and contributing to ecosystem services, such as habitat creation and nutrient recycling. This technology can be easily used for treating different types of wastewater [23, 44] including domestic [17, 39] and municipal sewage [3], olive mill [5] and tannery wastewater [6], agricultural [29] and industrial effluent [44], mine drainage sludge [26] and landfill leachate [34]. This engineered system was initially discovered by Dr Käthe Seidel in Germany in the early 1950s, to treat wastewater, and since 1960, it has been spreading all over the world [42]. CWs are composed of plants, soils and microbial assembly, to facilitate the treatment of wastewater, using biological (biomass attached to small media), chemical (adsorption, complexing, etc) and physical (filtering) processes, which are all similar to natural processes occurring in natural wetlands [14, 18]. Thereby, they are very effective in reducing wastewater pollution, especially, the organic compounds, suspended solids, nutrients, heavy metals and pathogens. However, CWs are not without limitations. They require substantial land area [11], which may be challenging in densely populated or land-scarce regions. Moreover, the start-up period for CW systems is typically longer compared to conventional WWTPs, as the biological processes must be established before achieving optimal performance [10]. CWs are classified depending on the type of macrophyte used (emergent, submerged, free-floating) and depending on the wastewater flow regime (free water-surface flow (FWSF) and subsurface flow (SSF)) [43]. The SSF CW can be also divided into two types, depending on flow path direction (horizontal and vertical). Indeed, horizontal and vertical flow systems can be combined to obtain a hybrid system that gives better results in terms of pollution removal [23, 37]. In vertical flow, the wastewater percolates vertically through the flat bed which is composed generally of sand and gravel and planted with vegetation and therefore the water produced is collected by a drainage system at the output of the CW unit. A slope of 1% to 2% is highly recommended to facilitate drainage to the system outlet [7]. However, the vertical percolation of water allows air to refill the bed and then provides a high oxygen transfer into it, which leads to nitrification and the elimination of organic matter [42]. For this reason, the interest in this type of system progressively increased over time and got more studied [37]. Nevertheless, the suitable conditions for denitrification are not afforded in this system category and consequently, gaseous nitrogen forms that escape to the atmosphere are not formed, and thus ammonia-N is generally only transformed to nitrate-N [42, 43]. To improve the nitrification processes and also organic matter elimination, aeration pipes are implanted in the system [7]. Concerning phosphorus (P) removal, it is generally limited and can be the most difficult contaminant to eliminate using those systems [31]. P removal is due to plant uptake [14] and is also related to the substrate type and its hydrological and physicochemical properties since Phosphorus is principally sorbed by the media or precipitated in it [41]. However, several factors can affect CWs performances such as the substrate type, vegetation type, configuration systems (vertical or horizontal feeding), hydraulic loading rate, but also temperature. Since higher temperatures promote plant growth and microbial activity, CWs treatment performance, particularly for the removal of organic materials, nutrients, and microbial contamination is affected and varied depending on temperature variation and thus seasons [15]. Indeed, several studies concluded that during the hot season, CW systems produced the best results for removing the organic load, nutritional load, and parasite load. As it is the case of the study done by [24], explaining that the exponential development phase of reeds occurs during this time. That shows that there is a strong relation between plants and seasonal variations leading to contaminant removal fluctuation. It is also the case for the study of [48] where authors concluded that CWs are anticipated to work better in warm areas since the higher temperatures and year-round direct sunlight would improve plant productivity and speed up the degradation of microbial contaminants. Certainly, because plant development, physiology, and debris formation fluctuate periodically, it is judicious to predict that their effects on treatment processes will also vary seasonally and interact with the temperature effects [40]. The purpose of this study was to investigate the impact of season, climate, and wastewater quality on the effectiveness of four VFCWs in removing contaminants from domestic wastewater in the region of Rabat. The four CW systems had the same experimental setup.

MATERIALS AND METHODS

Study site

The climate of Morocco has seen a lot of variation caused by climate change. In Rabat, the summers are warm, arid, and mostly clear and the winters are cool and partly cloudy with rare precipitation. During the year, the temperature generally varies from 8 °C to 27 °C and is rarely below 5 °C or above 31 °C [49].

Constructed wetland system description

The study area is located at the domestic wastewater pre-treatment plant of the city of Rabat-Temara in Morocco, which is set up and managed by Redal, the concessionary company for the delegated management of electricity, drinking water and sanitation services. The climate in the region of Rabat is warm and temperate. Four CW units are placed in the open air in a green space inside of Redal site. The surface area of each unit is 1 m^2 with a depth of 60 cm and a 1% slope along the unit. The design of those four vertical flow units was based on Directive DWA A262 (Version 2017), published by the German Association for Water Management, Wastewater and Waste. They were all filled with four layers of materials which are coarse gravel, fine gravel and sand. The first layer is filled with 20 cm of coarse gravel (with a diameter between 16 and 25 mm) and placed at the distribution tap to facilitate the passage of the effluent, followed by a 20 cm layer of fine gravel (with a diameter between 2 and 8 mm), the third layer of 30 cm which is the filter layer is filled with sand and the last layer is filled by 20 cm of coarse gravel (with a diameter between 16 and 25 mm) placed at the top to avoid odours and wastewater evapotranspiration. An opaque material for the units was chosen to prevent light entrance that can cause algae development in the substrate. A settling tank of 2 m^3 with a retention time of 24 hours, was used before the unit feeding to improve inlet wastewater quality by the removal of suspended particles and hence to prevent units clogging. Each unit was homogeneously supplied in parallel with 25 litres of wastewater by an electric pump every four hours. The treated wastewater is reused for green space irrigation.

Vegetations

The experimental system consists of four beds. The first bed was planted by *Phragmites Australis*, the second bed by *Arundo Donax*, the third bed by a mixture of *Phragmites Australis* and *Arundo Donax* and the fourth and last bed was unplanted, for control, to investigate and confirm the efficiency and the role of the vegetation. Young plants of *Arundo Donax* and *Phragmites Australis* were planted in the middle of the summer of 2021. The vegetation was planted in each of the three units at a density of five rhizomes per unit. Harvesting was done at the end of autumn 2021 and at the beginning of summer 2022. At each time of harvesting, all vegetation was collected and weighed on site.

As shown in Figure 1, tank 1 is systematically filled every 24h with domestic wastewater coming from the outlet of the pre-treatment plant of the region Rabat-Temara. While, tank 2, is the

Figure 1. Overview of constructed wetland unit systems

settling tank, filled automatically with decanted wastewater and feeds the 4 CW units every 4 hours by 25 litres per unit which gives a total of 150 litres per day per unit.

Sampling

The sampling was conducted at 10 AM once a week, in the initial monitoring period then twice a month. After the biocenosis has developed and the system reaches a relatively stable condition, shown mainly by reproducible analysis results, samples were taken monthly. The collected wastewater samples were transported in plastic bottles in an icebox at a temperature of 4 °C and transferred directly to the university laboratory to be analyzed. The samples were collected and analyzed for a whole year from September 2021 to September 2022.

Wastewater quality monitoring

To monitor wastewater quality before and after treatment, numerous physicochemical parameters were done: pH, electrical conductivity, Total Dissolved Solids (TDS), total suspended solids (TSS), turbidity, dissolved oxygen, five-day Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), nitrate, nitrite, orthophosphates and heavy metals. The pH meter used is a Thermo Scientific Orion 2-star pH meter. Temperature, electrical conductivity, TDS and salinity were measured with a WTW Inolab multi-parameter conduct meter. AQUALYTIC® sensor system BD 600 was used to determine BOD_5. It allows precise measurements of BOD based on the manomeric principle. COD which reflects a large part of the organic matter in the water and indicates water quality, was measured using COD test kits where 2 ml of wastewater sample is added and then put in a reactor at 148 °C for 2 hours. Once it cools down, the absorbance value is read by AL200-photometer and thus giving us the COD values of the sample in mg of O_2 per litre. The Ammonium, nitrate, nitrite and orthophosphates were measured using HACH test kits LCK 304, LCK 339, LCK 341and LCK 348 respectively.

RESULTS AND DISCUSSION

The effectiveness of the VFCW systems utilized in this study in removing organic pollutants and the impact of seasonal variation on the performances of the CWs were examined. The experiment ran for one year.

Domestic wastewater quality

Wastewater received at the pre-treatment plant comes from networks which drain domestic wastewater from the region of Rabat - Temara. Wastewater characteristics in the outlet of the pre-treatment plant results are shown in Table 1 below. This pretreated domestic wastewater is

Table 1. Minimum, maximal and average values of the physico-chemical characteristics of the influent over the entire study period from August 2021 to September 2022

Parameters	Unit	Minimum	Maximum	Average	Moroccan Discharge limits [25]	Limits for irrigation [32]
pH		6.12	7.26	6.6	-	6.5 – 8.4
Temperature	°C	13.2	26.6	20.75	-	35
EC	µS/cm	1079	2680	1754	-	12000
TSS	mg/L	198	645	349	150	-
COD	mg O_2/L	360	960	650	250	-
BOD_5	mg O_2/L	159	557	368	120	-
Turbidity	NTU	54	366	170	-	-
Salinity	mg/L	0.4	1.2	0.8	-	7680
TDS	mg/L	1264	2000	1825	-	-
TP	mg/L	0.29	2.8	1.85	-	-
NH_4-N	mg/L	14	78	43.75	-	-
N-NO_3^-	mg/L	0	0	0	-	-
N-NO_2^-	mg/L	0	0	0	-	-

used in our study to investigate CWs efficiency in depollution.

Domestic wastewater from Rabat city that has been investigated has a brown color. According to the Physico-chemical analysis results shown in Table 1, this wastewater has a high level of organic matter that exceeds Moroccan discharge regulations (average BOD_5 = 368 mg/LO_2 and COD = 650 mg/L O_2). Those high concentrations are principally due to the presence of oil, grease, human and animal waste, as well as surfactants themselves that contributed to the high quantities seen in domestic wastewater samples. This does in fact support the need for treatment of the wastewater before disposal. However, the organic pollution ratio COD/BOD_5 is equal to 1.76, which is less than 2, indicating that the organic load of this wastewater is easily biodegradable. The wastewater can hardly be biodegradable when the COD/BOD_5 ratio is between 3 and 7 [9]. 1754 µS/cm is the average electrical conductivity, which complies with regulatory standards. Salinity concentrations varied between 0.4 and 1.2 with an average value of 0.8 mg/L. TSS also varied considerably with an average value of 349 mg/L and it is related to the variation of organic loads, and the average value of turbidity is 170 NTU. Ammonia (NH_4-N) in the influent ranged between 14 and 78 mg/l with an average value of 43.75 mg/l, while nitrates (NO_3-N) and nitrites (NO_2-N) are not present. Total phosphorus (TP) in the wastewater is fluctuating between 0.29 and 2.8 mg/l with an average value of 1.85 mg/l. The average temperature of the influent was 20.75 °C. The temperature reached its highest level (26.6 °C) in August, while its lowest level was recorded in January (13.2 °C). As it is shown in table 1. The pH value is close to neutral during the whole study period and ranges between 6.12 recorded in September and 7.26 in August. The findings showed that the season had a significant impact on the concentrations of all parameters in the influent.

Settling tank effluent quality

The wastewater settles for 24 hours in a 2 m^3 settling tank before feeding the 4 parallel VFCW units, in order to improve wastewater quality by the elimination of suspended particles and therefore to prevent unit clogging. The average characteristics of the settling tank effluent are shown in Table 2.

The following formula was used to determine treatment efficiency as the percentage of removal (RR) for each parameter:

$$RR = \left(1 - \frac{Ce}{Ci}\right) \times 100 \quad (1)$$

where: C_i and C_e are the concentrations of influent and effluent respectively (g/L).

COD, BOD_5 and TSS average concentrations in the outlet of the settling tank are 357.5, 202.4 and 190.31 mg/l respectively. Equivalent to a reduction of 45.59, 45 and 46%. Almost the same results were noted in the study of [33] in Tunisia. However, removal rates can achieve more than 65% for BOD_5 and more than 70% for TSS as it is mentioned in [16]. Indeed, sedimentation and microbial degradation are the key processes for COD, BOD_5, and TSS elimination in a settling

Table 2. Average characteristic of the settling tank effluent (Tank 2)

Parameters	Unit	Average influent	Average settling tank effluent	Removal rate (%)
pH		6.6	6.63	-
Temperature	°C	20.75	20.2	-
EC	µS/cm	1754	1667	-
TSS	mg/l	349	190.31	45.59
COD	mg O_2/l	650	357.5	45
BOD5	mg O_2/l	368	202.4	46
Turbidity	NTU	170	102	40
Salinity	mg/l	0.8	0.77	-
TDS	mg/l	1825	1815	-
TP	mg/l	1.85	1.43	-
NH_4-N	mg/l	43.75	28.5	-
NO_3-N	mg/l	0	0	-
NO_2^--N	mg/l	0	0	-

tank. This removal efficiency depends on the influent quality as well as on the pattern of sewage arrival. Nevertheless, even though the settling performs well, the wastewaters at the outlet, which will feed the four CW units still contains high concentrations of COD, BOD_5, and TSS as well as a very high concentration of NH_4-N (28.5 mg/L). Nitrites (NO_2-N) and nitrates (NO_3-N) remain not present and this is due to the dominant anaerobic conditions in the settling tank. The average TP concentrations did not change significantly, but some concentrations increased after the settling of the influent and this can be explained by the conversion of long-chained polyphosphates to short-chained phosphates throughout the sedimentation stage [33]. Wastewater turbidity was reduced by 40% and the pH values remain almost the same. Salinity and electrical conductivity and TDS slightly decreased.

Constructed wetlands performances

CWs are typically viewed as an efficient technique for reducing wastewater contaminants because of their affordable construction and operation costs. Table 3 compares the four VFCW unit efficiencies in the reduction of each of COD, BOD_5, TSS, as well as NH_4-N, NO_2-N, NO_3-N and PT, due to the complete system, including settling.Table 3 displays effluents concentrations of, COD, BOD_5, TSS and, other pollutants, indicating the CWs systems removal efficiencies. Indeed, all four studied VFCW systems have shown good depollution capacity. Even though the units received high charge influent, the reductions were notable.

The comparison study between unplanted and planted CW units shows that all pollutants removal efficiencies were high in the planted ones, especially the polyculture unit (U3) which achieved the highest average removal rates of 95.15%, 96.29% and 84.35% for COD, BOD_5, and TSS respectively. Followed by the unit planted by *Arundo Donax*, reaching an average removal of 93.9%, 93.49% and 81.81% for, COD, BOD_5 and TSS respectively. Then the unit planted by *Phragmites Australis* reached an average elimination of 90.73%, 90.42%, and 80.99% for COD, BOD_5, and TSS respectively. The unplanted soil filter achieves the lowest average removal rates of 88.73%, 86.21% and 75.63% for COD, BOD_5, and TSS respectively. That confirms that vegetation impacts and contributes to pollutants degradation and then improve the treatment performances. Actually, the presence of plants enhances system oxygenation and their roots are the right place for bacteria development. This statement was also noted in the studies of [1,2] that confirmed that the presence of species such as *Typha latifolia*, *Juncus Subulatus*, or *Arundo donax* on the CWs provides enough porosity due to the quicker development of roots and rhizomes that allows water percolation and clogging symptoms were not seen in them throughout the experiment in contrast to unplanted soil, which was clogged in winter. Clogging was also noticed in our experiment

Table 3. VFCW units' efficiencies in the reduction of organic matters as well as nutrients, due to the complete system, including settling

Parameter	Unplanted (U1)				Polyculture (U2)				Arundo Donax (U3)				Phragmites Australis (U4)			
	Min	Max	Average	RR	Min	Max	Average	RR	Min	Max	Average	RR	Min	Max	Average	RR
pH	6.5	7.7	6.85	-	6.39	8.04	6.8	-	6.48	8.01	6.72	-		8.06	6.17	
EC µS/cm	904	2210	1713	-	959	2290	1807	-	973	2490	1817	-	1012	2710	1834	
TSS mg/L	50	155	82.18	75.63	15	110	52.5	84.35	40	120	59.38	81.81	45	120	62.19	80.99
COD mgO_2/L	0	143	70.47	88.73	0	68	32	95.15	0	85	37.82	93.9	0	123	56.59	90.73
BOD_5 mgO_2/L	0	90	43.06	86.21	0	38	13.5	96.29	0	43	20.56	93.49	0	61	30.06	90.42
Turbidity NTU	1.07	37.5	19.79	-	0.32	13.53	13.19	-	0.32	16.13	17.7	-	0.44	30.7	19.14	
Salinity mg/L	0.4	1.1	0.78	-	0.4	1.2	0.84	-	0.4	1.3	0.86	-	0.4	1.1	0.85	
TDS mg/L	1178	2000	1821	-	1233	2000	1861	-	1239	2000	1870	-	1272	2000	1868	
TP mg/L	0.05	3.2	1.57	15.13	0.11	2.2	1.19	35.6	0.12	2.1	1.21	34.5	0.24	2.2	1.24	32.5
NH_4-N mg/L	1.1	9	3.9	-	0.3	2	1.06	-	0.5	3	2.4	-	0.12	3	2.3	
NO_3-N mg/L	5.5	27	20.58	-	2.7	26.2	24.86	-	9.8	29.9	27.18	-	4.2	29.6	27.48	
NO_2-N mg/L	2.7	9.7	7	-	0.9	3.25	2.35	-	0.7	4.6	2.35	-	0.13	5.86	2.46	

for the unplanted filter in the winter period. The purpose of plant roots is to maintain uniform permeability and to develop a rhizosphere that is favourable to the development of aerobic bacteria. It was asserted that plant root secretions affected both the number of rhizosphere microorganisms and the variety of microbial communities [47]. However, the good removal rates obtained in the unplanted unit proved that substrate plays a role in the removal efficiency as well. In general, microorganisms degrade organic matter in the top soil layers, where oxygenated conditions are typically dominant. It can be concluded that the removal of organic materials is almost completely a result of physical processes (sedimentation, filtration), in addition to biological processes connected to the microbial community or with higher plants [1].

It is also observed that TP concentrations decreased in all four CWs, and better results were noticed for the polyculture unit that reached an average effluent concentration of 1.19 mg/l representing a removal rate of 35.6% followed by 34.5%, and 32.5% for U3 and U4 respectively. Unplanted units (U1) get the lowest removal rate of 15.13%. That should be explained by the aerobic condition created by the oxygen released into the substrate through the root system, which is responsible for a secondary absorption of phosphorus onto the soil in addition to the direct uptake of nutrients and that was also concluded in the studies of [1, 2]. An excellent removal rate of TP = 97.53% was achieved in the study of [4] where a combination of a sand filter and VFCW was investigated to treat olive mill wastewater. Nevertheless, low TP removal rates in our study may be explained by the short contact time of wastewater and substrate since no retention time is applied. That was also concluded by [21, 35] confirming that low phosphorus removal is because of the insufficient interaction between wastewater and substrate. TP removal fluctuations in the units can be related to plant growth and microbial activity and also depend on seasons [15]. TP removal rates in the unplanted unit are the lowest and this is surely due to the clogging of the unit that lowers oxygenation content in the system.

Also, the comparison between the average concentration of NH_4-N before and after CW treatment shows a significant difference. The average NH_4-N concentrations in the outlet of the CWs are respectively 3.9 mg/L, 1.06 mg/L, 2.4 mg/L and 2.03 mg/L for the units U1, U2, U3 and U4. The abatement achieved are then 90.75%, 97.90%, 96.26% and 94.19% respectively for U1, U2, U3 and U4. However, this vertical feeding configuration became widely employed and achieves a high rate of oxygen transfer [22, 45], compared to a horizontal flow system where the presence of oxygen is limited which led to nitrification inability [36]. Indeed, in VFCW, when wastewater fed penetrates the substratum by gravity, the air comes into the pores which increase aeration and thus biological treatment [13,36]. Certainly, oxygen transfer and distribution in wetlands have been shown to have a substantial impact on CW performances. Organic matter and ammonium elimination are directly impacted by the oxygen supply in the CW system [22]. Also, the feeding of units intermittently every four hours promotes good oxygen conditions which good nitrification requires. It is seen that the system removes ammonia-N very well and good nitrification conditions are affordable but has limited denitrification. In consequence, the presence of nitrate-nitrite ions in the treated wastewater is due to the elimination of ammonia (i.e. the oxidation of ammonia to nitrate). Nitrogen removal in the studied CW systems is higher compared to other VFCW systems in other countries like it is the case of Tunisia [33] where VFCW were used but only a reduction of 38% of NH_4-N was observed. Generally, the nitrogen removal mechanism in VFCWs can be ammonification, nitrification, vegetation uptake and substrate adsorption [19].

Concerning the EC, the effluent in the outlet of the unplanted system (U1) has an average CE of 1713 µS/cm and has reduced a little compared to the average value obtained at the influent (1754 µS/cm). This is can be explained by some ions adsorption on the granular substrate. However, despite ion adsorption and nutrients plant's uptakes, EC in planted CW units showed a little increase reaching 1807 µS/cm, 1817 µS/cm and 1834 µS/cm for U2, U3, and U4 respectively. The same results were noted in the study of [20] where EC increased and reached 68%. That was also observed in the study of [14], in August at summer time, and explained that the increase of evapotranspiration had a part in helping the effluent to concentrate in addition to root plant assimilation [1].

In addition, the pH of the treated wastewater at the outlet of units increased slightly in U1, U2 and U3 with average values of 6.85, 6.8 and 6.72 respectively. Biological oxidation could be responsible for this increase as well as alkalinization due to the presence of carbonate ions in wastewater [20]. Concerning U4, a little decrease in pH (pH = 6.17) is observed. Also, turbidity in the effluents decreased notably achieving an average value of 13.19 NTU for the polyculture unit followed by units U3 (17.7 NTU), U4 (19.14 NTU) and the unplanted unit which has the highest average turbidity (19.79 NT).

Nevertheless, all the concentrations in the effluents of the four CWs were under discharge limit values (Moroccan Law) which are 250 mg/L, 120 mg/L and 150 mg/L for COD, BOD_5 and TSS respectively, except one exceptional value of TSS = 155 mg/L recorded at the outlet of the unplanted unit in winter (December 2021).

Seasonal impact on CW performances

It is observed in Figures. 2, 3 and 4 that, the effectiveness of removing organic matters changed with the season and seasonal variation does impact treatment performances. In the summer periods of 2021 and 2022, the average maximum temperature achieved in Rabat was 22.5 °C with some extreme temperatures recorded in September 2021 (43.6 °C) and in July 2022 (36.1 °C) leading to an average maximum temperature of 27 °C. The average removal rates of COD, BOD_5 and TSS in the four units were the highest reaching respectively for U1 (95.48%, 94%, 77,65%), U2 (99.47%, 99.58%, 85.64%), U3 (96.74%, 97.23%, 84.54%) and U4 (93.88%, 92.7%, 83.25%). The fall cycle of the study, was particularly warm, reaching an average temperature of 23 °C. 27.5 °C was the average maximum temperature achieved in the region in this period of the year with an extreme temperature of 29 °C recorded in October 2022. The average removal rates of COD, BOD_5 and TSS in the four units decreased in comparison with those recorded in summer and achieved removal rates

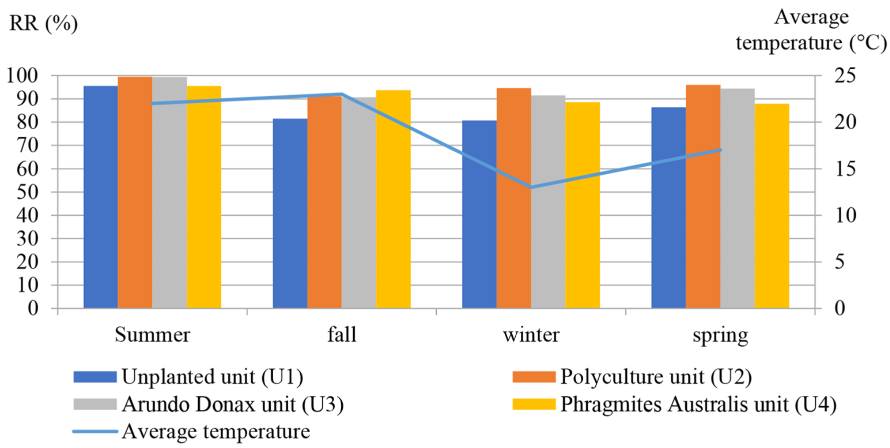

Figure 2. Seasonal variation of COD removal rates in each of the four CW units

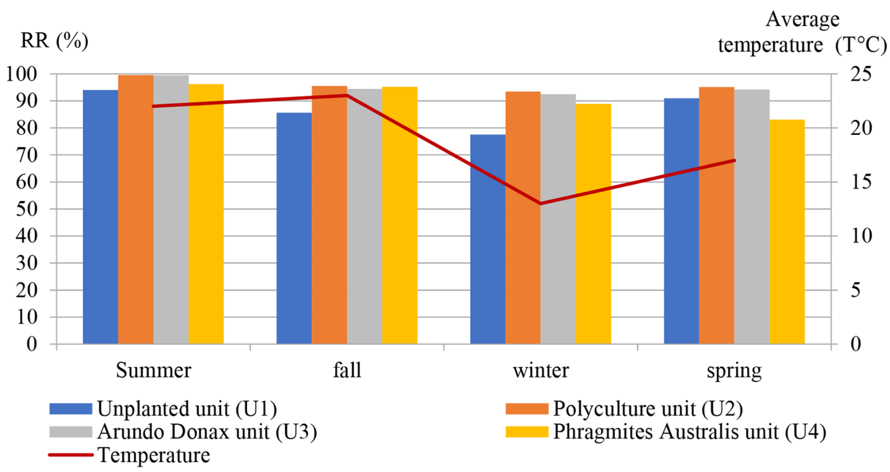

Figure 3. Seasonal variation of BOD_5 removal rates in each of the four CW units

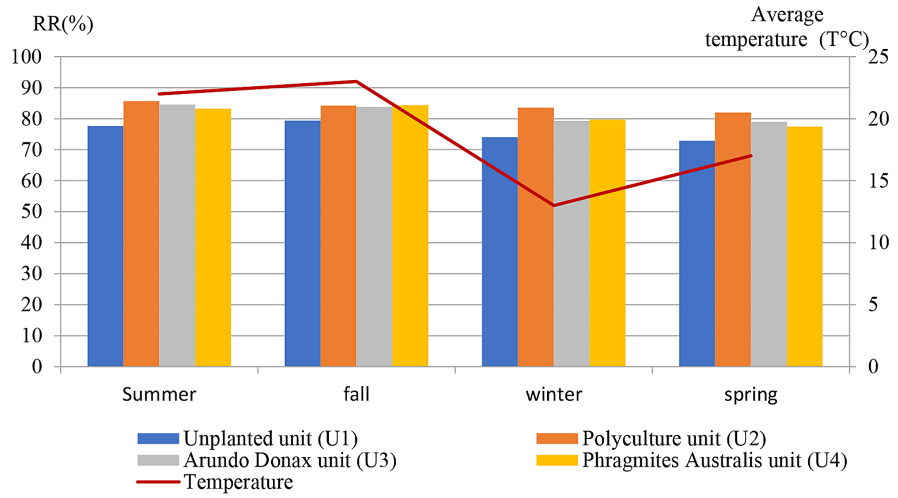

Figure 4. Seasonal variation of TSS removal rates in each of the four CW units

respectively for U1 (74.53%, 85.64%, 79.34%), for U2 (91.12%, 95.52%, 84.19%), for U3 (90.64 %, 86.45%, 86.81%) and for U4 (93.65%, 96.21%, 84.39%). In the winter season, the average temperature was the lowest reaching 13 °C. The maximum average temperature in this period was 25.7 °C and an extreme temperature was recorded in December 2021 (27.6 °C). The average removal rates of COD, BOD_5 and TSS in the four units were respectively for U1 (80.63%, 77.59%, 74%), for U2 (94.54%, 96.43%, 84.54%), for U3 (91.45%, 92.41%, 79.28%) and for U4 (88.51%, 88.92%, 79.74%). On spring days, the weather became warmer and the average temperature increased to 17 °C. An exceptional value of the temperature of 36.3 °C was recorded in May 2022. However, the average removal rates of COD, BOD_5 and TSS have reached respectively for U1 (86.42%, 90.95%, 72.88%) for U2 (95.01%, 95.13%, 81.96%), for U3 (95.32%, 95.22%, 78.95%) and U4 (87.85%, 83.04%, 77.46%).

Indeed, CWs are anticipated to work better in warm areas since the higher temperatures and year-round direct sunlight would improve plant productivity and speed up the degradation of microbial contaminants [48]. That was also observed in our study. In comparison with warm periods where the temperature reaches its maximum, cold ones had lower abatement for BOD_5, COD, and TSS. Lower water consumption during cold weather could be the cause of this [14]. Indeed, seasonal variation has an impact on treatment performances, for the removal of organic matters, since low temperatures directly impact microbial activity, while higher removal rates were always observed in warm and hot seasons because higher temperatures promote plant growth as well as microbial activity. Actually, in the summer cycle, the temperature is ideal for plant biological activity; there is a rise in photosynthetic activity, biomass development, and symbiosis-plant organic load during this time. However, the fall season recorded good organic matter removal rates, especially in planted units. This can be explained by the fact that, due to climate change and global warming, this season was particularly warm and reached an extreme temperature of 29 °C in October 2021. Nevertheless, since the sunshine duration was shorter in this season, that contributed to the reduction of performances compared to the summer cycle. In the winter time, especially on windy days, some removal rates recorded in planted units (U2, U3 and U4), were higher than those recorded in fall, even if the temperature in this season is lower. This is explained by the fact that in this season, the presence of wind provokes the movement of the long plant stems which leads to high oxygenation of the water and then organic matter degradation. This was also stated and concluded in the study of [17]. However, the unplanted unit was completely clogged during this period of the year, due to the non-presence of plants which preserved adequate porosity and allowed water percolation to permit wastewater treatment and which led to a decrease in the unit performance. The clogging process was also noticed in the study [2], in the winter period, where wastewater treatment was studied using VFCW with Arundo Donax as vegetation. The unplanted filter is unable to absorb the amount of water required by the experiment under the identical experimental conditions as the planted one. In springtime, system performances increased due to warmer temperatures and sunshine duration was longer in this season.

Plant growth

The planting of the basins with young local plants was done in the middle of the summer in August 2021. The plants have been watered with clear water for two weeks before being fed with domestic wastewater. However, plant growth was not rapid when vegetation was irrigated by fresh water during the initial period and this is explained by the lack of nutrients in freshwater that plants need for their rapid evolution. Nevertheless, their evolution and growth accelerated notably as soon as they were irrigated by wastewater. Besides, they tolerate wastewater that we used, and even with high pollutants concentrations, the leaves remained green and developed continuously during the entire monitoring period. This was also communicated in the research of [38], reporting that, the composition of the wastewater type that will be treated affects plant density and height in the system. After 3 months, the maximum biomass production was reached and at the end of their cycle of growth, *Arundo Donax*'s height was 250 cm and *Phragmites Australis* height was 170 cm. The biomass collected after the first three months of growth (from September 2021 to December 2021) was 5 kg, 7 kg and 6.5 kg for unit U4, unit U3 and unit U2 respectively. However, in summer 2022, the biomass collected after two months of growth (from the beginning of July 2022 to the beginning of September 2022), was almost two times greater and reached 10.5 kg, 15 kg and 15 kg for Unit U4, unit U3 and unit U2 respectively. In addition, beginning with 6 young *Phragmites Australis* plants in U4, and 6 young plants of *Arundo Donax* in the U3, after 10 months, more than 50 plant stems were observed in U4. Arundo Donax is taller but has developed less number of stems. At the beginning of spring, season harvesting became more frequent (every two months approximately). Indeed, frequent harvesting allowed a greater development of biomass with greater growth of new stems from the clump. Also, harvesting permits the elimination of old saturated plants by nutrient absorption and also plant regeneration and then allowing good long-lasting absorption efficiency.

Phyto management of wetlands waste perspectives

Phytoremediation is an effective technique for wastewater treatment. It generates interesting biomass quantity from an energetic point of view. Consequently, the plant waste generated after wastewater treatment via wetlands can be transformed from an environmental problem to an energy source by exploiting this biomass for energy production.

Several studies have been conducted on the recovery biomass from contaminated soils, to test their energy potential as well as the analysis of their life cycle and their effects on CO_2 reduction. Once harvested, plants from wetlands constitute a source of energy in traditional sectors. A study, carried out in the Campine region in Belgium, focused on three plant species: willow, corn and rapeseed. For each culture, the fresh and dry biomass was measured. The results obtained show a variable biomass production from one species to another. Thus, in the case of willows, it is 6 tons per hectare and per year, 5.2 for a crop of rapeseed and 20 for maize. Consequently, in the maize case, the annual crop of one hectare would produce a net energy of 148.289 megajoules (MJ), 63.230 MJ for willow and 35.640 Mj for rapeseed. These results were obtained taking into account the energy expenditure for cultivation, the treatment of plants and the waste produced. Beyond the energy gain, the CO_2 reductions during cultivation were also calculated. Thus, the cultivation of one hectare of corn would make it possible to avoid the emission of 14.214 kg of CO_2 per year, that of willow between 4.460 and 25.055 kg depending on the sector chosen, while the cultivation of rapeseed would avoid the emission of more than 2 tons of CO_2. Thus the sectors of the culture of plant species present a potential for phytoextraction [46].

Other researchers have carried out pilot tests for studies of the energy recovery of these biomasses, either on its facilities (biomass boiler, methanation pilot) or on the facilities of industrial partners (pyrogasification). Based on these results we can make recommendations, which make it possible to guide the selection of species studied in this work (*Phragmites Australis* and *Arundo*

Donax) with a view to their energy recovery or to contribute to adapting the regulations to prevent the transfer of pollutants to the environment [8].

CONCLUSIONS

Phragmites Australis and *Arundo Donax* are two types of plants with excellent wastewater resistance. The findings of this study demonstrate that CWs should be taken into consideration as an alternative to traditional wastewater treatment technologies. The system functioned admirably during the year of monitoring. It was concluded that plants contribute to waste removal and this was confirmed by comparative experiments of planted and unplanted CWs, therefore, higher removal efficiencies are attained for the planted filter. Also, better results were recorded for CWs planted with different types of vegetation in the same system. The VFCWs configuration seemed to be very efficient in the removal of organic waste and TSS from domestic wastewater as well as nitrogen and total phosphorus. The polyculture system achieved removal rates of 95.5 %, 96.29%, 84.35%, 97.90% and 35.6% for COD, BOD_5, TSS, NH_4-N and PT respectively. Rural areas should support these basic wastewater treatment facilities since they require little maintenance and use little energy. From an energy aspect, planted CWs produce an interesting amount of biomass. As a result, by using this biomass for energy generation, the plant waste produced after wastewater treatment by CWs can be changed from an environmental issue to a source of energy.

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