Chapter

Constructed Wetlands Process for Treating Sewage to Improve the Quantitative and Qualitative Management of Groundwater Resources

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Abstract

Water scarcity limits access to safe water for drinking and communities face some form of water stress, which can be related to insufficient supplies or inadequate infrastructures. Climate change plays a crucial role in water stress worldwide, as rising temperatures lead to more unpredictable weather and extreme weather events. In face of this challenge, the need to seek an alternative to protect groundwater resources and to decrease the use of public water is imposed. Sewage management seems to be a significant treatment of removing contaminants and undesirable components from polluted waters and safely return it to environment for irrigation and other uses. For this consideration, many treatment technologies are discussed in the literature including biological, physical and chemical processes. Among biological processes principally used for the treatment of sewage figured constructed wetlands. Constructed wetland system is considered as an economic, efficient and environmentally friendly sewage treatment method, based on adsorption and retention of pollutants by substrates, sorption by plants, and decomposition by microorganisms. Therefore, the chapter of this book throws will light on the principal mechanisms responsible to organic matter, nitrogen and phosphorus removal in different types of constructed wetlands, and provides recommendations concerning the factors affecting pollutants removal performance of constructed wetlands from sewage.

Keywords: water scarcity, sewage characteristics, treatment, constructed wetlands process, pollutants removal, mechanism approach

1. Introduction

Many parts of the world suffer of water scarcity and insufficient water quality demanded by population and environment. Water stress effects can vary dramatically from one region to another; it can damage not only public health, economic development, and global commerce, but also can increase migrations and spark conflict.

According to Food and Agriculture Organization (FAO), in the case of demand side, around 70% of the world's freshwater is used for agriculture, 19% for industrial uses and 11% for domestic uses [1]. In the case of supply side, the water sources include groundwater and surface water such as rivers lakes and reservoirs. Indeed, many causes can trace to the water stress including the increase of human withdrawals from surface or groundwater and the increased need of agricultural irrigation. The population growth who lead to economic development, change of lifestyle and consumption patterns, and the increase of agriculture production impact dramatically the planet's reserves, also the climate disruption as rising temperatures, floods and drought who can decrease water supply. Another important approach of water scarcity is identified by discharge of polluted wastewater generated from industry, agriculture and household activities causing deterioration of freshwater quality and infiltration of contaminant compounds in the groundwater [2, 3]. Around 80% of wastewater in the world is evacuated, largely untreated, in the lakes, rivers, oceans and environment [4]. In face of this challenge, many countries seek an alternative to protect water resources and to improve international collaboration on water practices, as well as to implement innovative and sustainable technologies in order to ameliorate the water quality by suggesting significant processes to reduce hazardous organic pollutants from polluted wastewater. Several approaches have been investigated to eliminate the contaminants from domestic sewage using physical, chemical and biological processes. Physical processes include evaporation, distillation, combustion, centrifugation, filtration, pyrolysis and membrane separation [5–7]. While chemical processes include coagulation-flocculation, electrocoagulation, oxidation and advanced oxidation and ion exchange [8–10]. Infiltration-percolation, aerobic, anaerobic and constructed wetland are included in biological processes [11–13].

The limitations of physical and chemical processes like expensiveness, high power consumption and production of toxic products, as well as the risk of secondary pollution, can affect the performance of these techniques for the treatment of sewage [14, 15]. Thus, biological processes are widely considered among the efficient techniques and have become the center of interest of several researchers in the pollutants removal of sewage. Nowadays, constructed wetlands have been attracting increasing attention compared to other treatment techniques. Constructed wetlands are a cost-effective and sustainable approach to treat not only sewage but also agriculture and industrial wastewater as olive mill wastewater, tannery wastewater, winery wastewater and petrochemical industry wastewater [16–19]. Constructed wetlands system offers many benefits, such as less expensive to construct, low operational and maintenance expenses, tolerate fluctuation in water flow, eliminate odors associated with wastewater, allow a high process stability during wastewater treatment and facilitate wastewater reuse and recycling.

Constructed wetlands are a natural wastewater treatment system that use natural wetland vegetation (aquatic plants), substrate (sand, soil, gravel, zeolite, pozzolan) and microorganisms for the removal of conventional pollution parameters such as metals, organic matter and nutrients (nitrogen and phosphorus) from polluted water [17, 20–23]. Aquatic plants are considered as a central of sewage treatment and they play a major role in the adsorbion, precipitation and degradation of organic compounds, as well as concentration of heavy metal from contaminated water. While substrates are also beneficial to the efficiency of the constructed wetlands, they provide storage for many contaminants by the adsorption process and they report support to many microorganisms responsible to degradation of organic matter in the favorable conditions by biological process. On the other hand, different designs and structures of constructed wetlands are investigated in the literature. Overall, we can distinguish three types of constructed wetlands (i) surface flow constructed wetlands (SF CWs), (ii) horizontal subsurface flow constructed wetlands (HSF CWs) and (iii) vertical flow constructed wetlands (VF CWs). The selection of the effective constructed wetlands depends on several parameters such as load and type of pollutants, material of substrates, local available vegetation, climatic conditions, nature of polluted water, and hydraulic loading rate (HLR) and hydraulic retention time (HRT).

In this chapter, the treatment of sewage using constructed wetlands as approach to improve the quantitative and qualitative management of groundwater resources will be discussed. For this purpose, selection of favorable constructed wetlands design, optimization of operation parameters and factors affecting remediation processes such as substrates, aquatic plants type and availability of microorganisms can improve the performance of sewage treatment. Finally, the recommendations and future possibilities in this field will also be discussed.

2. Characteristics and composition of sewage

Sewage is classified mainly into two categories, namely, domestic and industrial wastewater. Domestic wastewater is derived from human activities in households such as bath, laundry, dishwashing, garbage disposal and human waste, mainly feces and urine [24]. The variation in the characteristics of domestic wastewater depends on several factors such as the water use, quality and type of water supply, nature and condition of sewerage system and population habits. Compared to industrial wastewater, domestic wastewater usually contains low content of pollutants but even small amounts of contaminants can be responsible of environment pollution. Industrial wastewater is generated from various industrial processes, namely, the water released from battery, chemical and pharmaceutical manufacturing, agricultural and mine activities, paper and fiber plants, refining and petrochemical operations and other industrial activities [25]. The volume, flow and load of wastewater is closely linked to the type of industries and industrial establishment.

Generally, the characteristics and composition of sewage depend on the nature of wastewater discharged and its source. Sewage contains a high content of organic compounds, which may be in dissolved, suspension and colloidal state. These compounds may be toxic, resist to biological degradation, can damage sewers and other structures, and affect the condition operation of the wastewater treatment plant. Sewage also may contains some heavy metals provided through industrial discharges. These compounds limit the treatment by biological process and their disposal in stream and land affect the human and aquatic life. On the other hand, various types of microorganisms may be identified in sewage. Some of these are pathogens and are harmful to the human and animal life.

Many heavy metals are identified in sewage, such as Lead (Pb), Zinc (Zn), Mercury (Hg), Nickel (Ni), Cadmium (Cd), Copper (Cu), Chromium (Cr) and Arsenic (As) released by paint and dye manufacturing, textile, pharmaceutical, paper and fine chemical industries. These metals are non-biodegradable and can be carcinogenic, their easily adsorption to suspended particles in water threat dramatically ecosystems and their infiltration in the groundwater can present a risk for living organisms. Solids contained in sewage may be classified into dissolved solids, suspended solids and colloidal solids. Suspended solids and dissolved colored material and reduce water clarity by creating an opaque, hazy or muddy appearance. Their remove can be

Industrial wastewaters	pH	BOD_5 (mg/L)	COD (mg/L)	NH^{4+}-N, (mg/L)	NO_3^--N, mg/L	PO_4^{3-} (mg/L)	Phosphorus (mg/L)	TSS (mg/L)	Chlorides (mg/L)	Total phenols (mg/L)	Cr-Ca-K (mg/L)	References
Domestic	7.6	78.4	ND	27.4	0.4	3.1	ND	75.1	ND	ND	ND	[29]
Pulp and paper	7.41	1928	4103	47.52	ND	ND	105	612	ND	ND	ND	[30]
Textile	9	1010	3200	ND	ND	ND	ND	2185	213	ND	ND	[31]
Olive oil mill	5.06	ND	7022	1960	0.64	0.40	4200	2070	1420	1345	ND-0.06-2.11	[32]
Coke plant	8.28	80.60	692.11	454.95	49.30	ND	ND	1122.65	ND	92.82	ND	[33]
Distillery	7.5–8	8000	45,000	ND	ND	ND	ND	40.700	7997	7202	ND	[34]
Winery	7.15	2950	4283	170.6	ND	7.0	ND	580	ND	ND	ND	[35]
Brewery	2–12	1000–37,500	1900–50,000	19–22	ND	ND	5–100	560–3000	ND	ND	ND	[36]
Tannery	7.6	ND	17.618	ND	ND	ND	ND	20.498	ND	ND	44-372-50	[37]
Slaughterhouse	7.28	10,172	16,910	1520	ND	ND	25.5	7267	ND	ND	ND	[38]
Meat processing	7.1	1966.7	2250	50.37	80.8	ND	9.6	1120.7	ND	ND	ND	[39]
Cigarette industry	6.9–7.4	516–540	1120–1245	ND	ND	ND	ND	998–112	460	ND	ND	[40]
Fish market	7.1	ND	1079	66.7	ND	ND	56.0	ND	ND	ND	ND	[41]

Table 1.
Examples of concentrations of major pollutants in various industrial wastewater reported in the literature.

assured by sedimentation if their size comparatively large or by filtration process. Generally, solids are an important factor for sewage treatment processes. Sewage also contains high load of organic pollutants, namely, phenolic compounds, dioxins and dibenzofurans, polycyclic aromatic hydrocarbons, and organochlorine pesticides [26]. Organic pollutants are highly resistant to environmental degradation via physical, chemical and biological processes. They have long half-lives in soil, water, and air and their toxicity can pose a threat to human health and environment. High content of nitrogen and phosphorus are also one of the major contaminants present in sewage. The principal nitrogen elements in sewage are proteins, amines, amino acids, and urea. Indeed, the ammonia nitrogen in sewage results from the bio-degradation of organic matter present in the water. In domestic wastewater, human urine contains approximately more than 95% of total nitrogen, 90% of total phosphorus and 50% of the total COD [27]. Phosphorus is contributing to sewage from laundry detergent, human waste and other household cleaning products with 0.30, 0.60 and 0.10 kg of phosphorus per capita/year, respectively [28]. It considered as an essential element for the biological method. With an adequate concentration, phosphorus can support aerobic biological wastewater treatment. **Table 1** summarizes the concentration of major pollutants resulting from different industrial sector.

3. Constructed wetlands as sewage management pattern

3.1 Free water surface constructed wetlands

Free water surface constructed wetlands (FWS CWs) are defined as wetland systems comprise shallow basins or channels, with a sealed bottom to prevent waste-water to infiltrate in the groundwater. FWS CWs are characterized by the presence of dense aquatic plants covering more than 50% of surface, emerged in 20–40 cm of water into 20–30 cm of rooting soil [42]. In FWS CWs, water flows through over vegetated soil surface from an inlet to an outlet point (**Figure 1**). This operation allows the physical, chemical and biological processes to take place in order to remove and degrade the various contaminants. However, in some cases, standing water may increase the possibility of mosquito breeding, or water may completely lost by evapo-transpiration especially in the hot region, which affect the treatment process.

Based on the literature, FWS CWs are efficient in removal of organic pollutants through bio-degradation and settling of colloidal particles. Suspended solids removal is assured by sedimentation, filtration and aggregation mechanisms in function of particles size and structure [43]. The smaller and lighter particles may settle out through the dense wetland plants, while largest and heaviest particles may settle out in

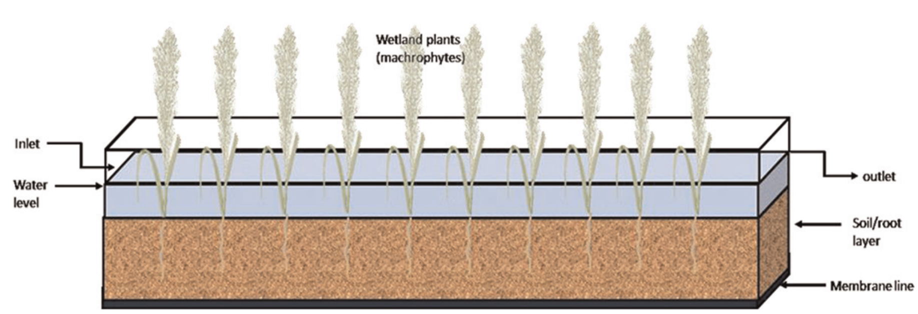

Figure 1.
Free water surface constructed wetlands (FWS CWs).

the inlet open water zone. Indeed, the wetland plant tissue play a major role in suspended solids removal by reducing wind speed which supports sedimentation of suspended solids and prevents re-suspension [44]. On the other hand, many studies indicated that the high suspended solid concentrations can cause clogging of the soil and effects negatively the treatment process. To avoid the excess accumulation of solids, FWS CWs facilities should be coupled with a pretreatment stage, namely septic tank, lagoons, settling basins or compost filter [45].

Nitrogen is generally removed from wastewater through nitrification/denitrification mechanisms. Before nitrification step, organic-nitrogen is converted to ammonia by hydrolysis process, ammonia is oxidized to nitrate by nitrifying bacteria under aerobic conditions. Nitrate is reduced to free nitrogen or nitrous oxide under anaerobic conditions by denitrification process. Many parameters may influence nitrification-denitrification processes such as carbon source, temperature, pH, dissolved oxygen availability and nitrite accumulation. In CWs, nitrogen is effectively removed primarily by nitrification/denitrification, and ammonia volatilization under higher pH values due to algal grow. However, the presence of the ammonia in the atmosphere can pollute aquatic and terrestrial environments [46]. Indeed, in FWS CWs, the growth of algae is very limited, due to the presence of emergent wetland plants, which cover completely the surface water and as consequence limit algal photosynthesis by preventing light to penetrate into the water column. Denitrification can be increased by availability of carbon provided from decaying plant biomass. The supply of dissolved oxygen in FWS CWs is assured by the air-water interface and the plant roots, which release oxygen into the environment media, creating the favorable conditions for nitrification process. While in the soil layer below the water, the dissolved oxygen is practically non-existent. A viable solution to this behavior is to report an extended aeration to achieve nitrification process and provide biological treatment for the removal of bio-degradation pollutants. Air may be supplied by diffusion or mechanical in required conditions to maintain the aerobic biological process.

FWS CWs are efficient in removal of organic pollutants trough aerobic and anaerobic processes. The aerobic process is carried out under redox conditions in the water columns, while anaerobic process is realized by fermentation or biomethanation in the litter layer near the bed bottom. The decomposition performance of organic pollutants is assessed by the balance between organic load and available oxygen. Other pathways for organic matter removal are identified, namely, photochemical reactions, uptake by plants and metabolization [47, 48]. Removal of phosphorus in CWs is assured by adsorption, complexation-precipitation and plant uptake if the biomass is harvested, otherwise, the phosphorus releases in the system and its concentration increase in wastewater. The complexation-precipitation mechanism is highly dependent on the origin and chemical composition of the substrate used. Soil rich in reactive minerals such as Fe, Al or calcareous materials that favorite Ca phosphate precipitation are very significant in phosphorus removal. In FWS CWs the elimination of phosphorus is relatively with a slow rate, due to little contact between water column and the soil containing mineral elements for precipitation.

Based on the literature studies, CWs have been generally designed to treat municipal and domestic wastewater. Recently, CWs are strongly applied to other type of wastewater as industrial wastewater. Among effluents treated by FWS CW are petrochemical wastewater, pulp mill wastewater, tannery wastewater, aquaculture wastewater, distillery wastewater, brewery wastewater, meat processing wastewater, abattoir wastewater, seafood wastewater and olive mill wastewater. Goulet and

Sérodes [49] reported that the treatment of abattoir wastewater using FWS CWs planted with *Typha sp*. and consisted of storage tank (750 m^3) and two cells a total surface area of 1420 m^2 allowed removal efficiencies amounted to 95%, 85%, 66%, 54% and 74% for TSS, BOD_5, TKN, NH_4^+-N and TP respectively. Two FWS CWs occupied an area of 45.5 m^2 for each, planted with *Phragmites australis* and filled with gravel were used to treat diluted olive mill wastewater. The results showed that the bed without recirculation allowed a reduction of 80%, 83%, 80%, 78% and 74% for TSS, COD, total phosphorus, NH_4^+-N and phenols respectively. While the reduction using bed with recirculation acceded 90%, 98%, 85%, 55% and 87% respectively [50]. In another study, the treatment of petrochemical wastewater by 15.5 m^2 FWS CW planted with *P. australis*, *Typha angustifolia* and *Typha latifolia*, and HLR ranged between 1.3 and 1.6 cm d^{-1} was investigated. The average annual removal of COD, BOD_5, TN and total phosphorus from pretreated wastewater reached 54%, 59%, 22% and 43%, respectively [51]. Allen et al. [52] presented the results from a full-scale FWS CW (8.19 ha) designed to treat increasing amounts of pre-treated domestic wastewater. The system received an annual average loading rate of 947 kg/year BOD_5, 19,644 kg/year TN, 31039 kg/year NH_4-N, 18140 kg/year TKN and 807 kg/year total phosphorus and removal rate of 8%, 72%, 73%, 78% and −246% respectively. The study of Bydalek et al. [53] aimed to assess microplastics fate in FWS CW following an oxidation process. The FWS CW has an operational surface of approximately 8000 m^2 and planted with *Schoenoplectus lacustris* and *Typha angustifolia*. The results showed that over 95% of microplastics were retained within the first 20% of the FWS CW and allowed an aerial removal rate exceed 4000 microplastic m^{-2} d^{-1}.

3.2 Horizontal sub-surface flow constructed wetlands

Horizontal sub-surface flow constructed wetland (HSF CW) systems are filled with gravel or soil and usually planted with common reeds [54]. The depth of the substrate varies between 30 and 80 cm and it is most often selected based on many parameters such as low patterns, effluent charge and aquatic plant types as a nutrient source required for removal process [55]. Generally, the media mostly used include gravel, sand, soil and compost. In HSF CWs, the wastewater is fed in at the inlet and flows horizontally along bed media below substrate surface through its pores and plant roots. The treated wastewater is collected in outlet zone from the opposite side of the system before leaving level control arrangement at the outlet, thus keeping a large contact between water and substrate (**Figure 2**). Consequently, the availability

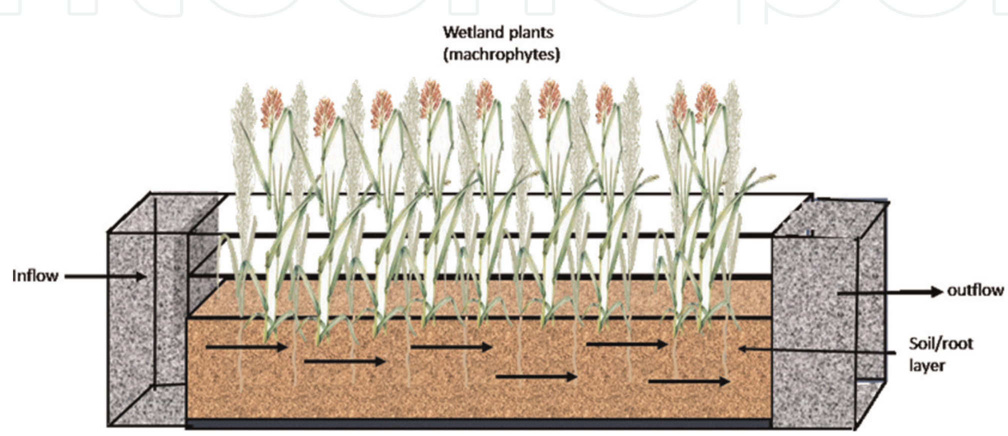

Figure 2.
Horizontal sub-surface flow constructed wetlands (HSF CW).

of oxygen in the substrate for organic matter oxidation is limited despite the creation of some aerobic zones by plants by transportation of oxygen from the atmosphere to the roots through the plant stems. HSF CWs included many processes and mechanisms for removal of contaminant elements and compounds from sewage such as sedimentation, filtration, and aerobic and anaerobic microbial processes for organic matter remove, nitrification/denitrification for nitrogen elements remove, and sorption and precipitation for phosphorus remove.

Organic compounds in HSF CWs are very effectively degraded by aerobic and anaerobic microbial processes as well as by filtration and sedimentation. The aerobic process is carried out in plant roots and surface waters where oxygen can be supplied from atmosphere, while anaerobic process is occurred in the soils with microorganisms adapted to each condition. The aerobic microorganisms consume oxygen to degrade organic contaminants to produce biomass for microorganism. The methane is produced through the degradation of organic matter by anaerobic bacteria. The presence of plant roots favors the development of biofilm, which increase the organic matter decomposition. The amount decomposed of organics is related dramatically to the availability of dissolved oxygen in HSF CWs. On the other hand, plant biomass are capable to storage organic carbon thus making constructed wetlands as an alternative approach to remove organic matter. Suspended solids are removed in HSF CWs by gravity sedimentation, flocculation/settling of colloidal particulates and adsorption. Gravity sedimentation occurred when particle sediment independently without contact with other particles. While, flocculation/settling involves the interacting of particles in order to form large flocculants result from charge imbalances on the surface of particles. The settling rapidly take place when a new particle as larger flocs are formed. Filtration and adsorption onto gravel and plant media play an important part in suspended solids removal. The surface of gravel, stem, and root plants are coated by biomass film, which can absorb colloidal and soluble matter. The solids adsorbed may be metabolized, and then converted to biomass or gases.

As viewed in the literature for nitrogen removal, regardless of removal pathways including plant uptake, ammonification, plant root and substrate adsorption, volatilization in forms of ammonia, fixation by converting nitrogen gas to organic nitrogen, and transformation into nitrogen gas, the nitrification-denitrification is usually considered as the principal mechanism to reduce nitrogen amount in constructed wetlands. Nitrification is carried out by converting ammonia and ammonium to nitrite and then nitrite to nitrate. Many parameters influence nitrification process such as temperature, pH, alkalinity, dissolved oxygen concentration, retention time, and organic load. According to Vymazal et al. [55], the optimum temperature for nitrification is generally considered from 30°C to 40 °C, pH values range from 6.6 to 8.8, and dissolved oxygen and alkalinity amounts reach 4.3 mg of oxygen and 8.8 mg/mg of ammonia oxidized respectively. Denitrification process is the process in which microorganisms reduce nitrate to nitrite and nitrite to nitrogen gas. The nitrogen gas produced is in the form of nitric oxide (NO), nitrous oxide (N_2O) or nitrogen gas (N_2). Environmental conditions that affect the efficiency of denitrification include nitrate concentration, anoxic conditions, presence of organic matter as well as pH, temperature, alkalinity and the effects of trace metals. Denitrification rate decreases as dissolved oxygen increases and can occur between 5 and 30°C, and under optimum pH values between 7.0 and 8.5. In HSF CWs the denitrification process is favorable due to availability of carbon source contained in raw sewage. However, the nitrification process is limited by the absence of oxygen in these systems. The alimentation process of HSF CWs maintain filtration bed submerged continually by water, consequently the presence of oxygen is limited and, therefore, the removal of nitrogen is less effective. The major phosphorus removal mechanisms in wastewater wetlands are physical/chemical (adsorption, absorption, precipitation) and biological processes. The main mean for phosphorus removal in constructed wetland is plant absorption. The absorption is carried out through leaves and root plants, and is increased at the beginning of the plants growing season. Many aquatic plants were showed their efficiency in the storage of phosphorus such as *Iris pseudacorus*, *Panicum virgatum*, *Canna sp*., *Oenanthe javanica*, *Myriophyllum aquaticum*, etc. [56, 57]. However, the die of plant parts and the beginning of their decay generates the release of plant matter above ground in the water and the secretion of decaying roots into the soil and, therefore, the contamination of groundwater. Adsorption and precipitation is another process to removal phosphorus amounts. Different cations present in the substrate such as Fe^{3+}, Ca^{2+}, Al^{3+} can be combined with orthophosphate and forme insoluble phosphates. In addition, phosphates charged negatively can react by anions-cations exchange with substrate elements. Various substrates such as steel slag and oyster shell approved their efficiency to removal phosphorus from sewage [58]. Although the removal of phosphorus can takes place by microorganisms absorption due to their availability and quick multiplication, microorganisms are unable to storage a large contents of phosphorus.

Several studies applied HSF Cws as a promote technology to treat industrial wastewater. Chapple et al. [59] study focused on the reduction of dissolved hydrocarbons (Diesel Range Organics-DRO- C_{10}-C_{40}) from oil refinery using four pilot wetlands. Two filled with soil and others filled with gravel (300 m^2 each), and planted with *P. australis*. The results showed that with the mean inflow DRO concentration of 410 mg/L, all beds presented an efficiency removal, which exceed 99%. Choudhary et al. [60] studied 5.25 m^2 HSF CW filled with gravel and planted with *Canna indica* to treat chlorinated resin and fatty acids (RFAs) from a paper mill wastewater. The system achieved 92% removal of 9,10,12,13-tetrachlorostearic acid and 96% removal of 9,10-dichlorostearic acid. The authors concluded that at hydraulic retention time of 5.9 days, the most probable mechanism for this removal is microbial decomposition in the plant roots as well as adsorbtion/absorption. To treat a primary treated sewage, Shukla et al. [61] study three HF CWs (35 m^2 each) filled sequentially and supplied with gravel media. CW_1 (unplanted), CW_2 (planted with *Typha latifolia*) and CW_3 (planted with *Typha latifolia* and *Commelina benghalensis*). The CWs were aerated and operated in continuous mode at an average hydraulic loading rate of 250 L/h with different hydraulic retention time (HRT) 12, 24, 36 and 48 h. The authors reported that among the constructed wetlands used, CW_3 was the best performer reducing 79, 77, 79, 79 and 78% of BOD, COD, N-NO_3, N-NH_4 and phosphate respectively in 48 HRT.

3.3 Vertical sub-surface flow constructed wetlands

Vertical sub-surface flow constructed wetlands (VSF CWs) are a flat bed filled by graded gravel topped with sand layers and planted with macrophytes usually is common reeds. Wastewater is poured onto the bed surface from above. The water is draining vertically down by gravity through the porous media to the bottom of the bed where is collected by a drainage pipe (**Figure 3**). With this mode of operation, the bed inside is aerated by pushing out the trapped air, thus increasing aeration. On the other hand, the aeration may be enhanced by insertion of aeration pipes, and employing a wet-dry cycle of operation. This way of feeding plays an important part

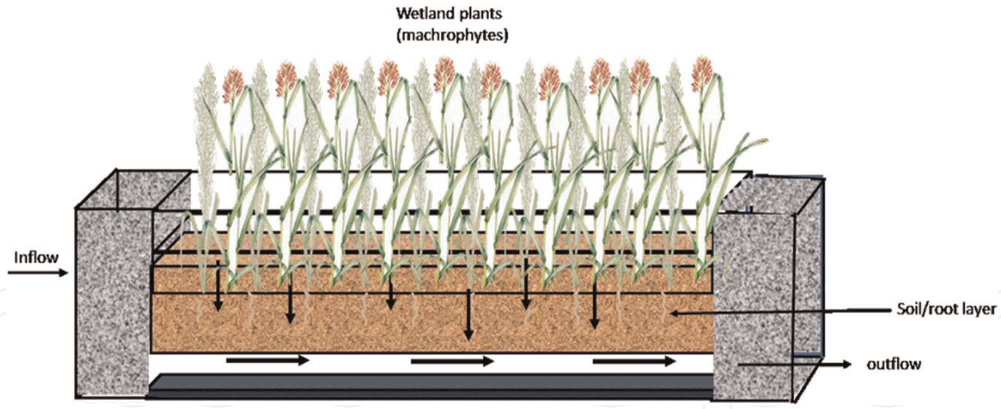

Figure 3.
Vertical sub-surface flow constructed wetlands (VSF CW).

in the provide of aerobic conditions, since increase of oxygen transfer within the filter enhance the oxidation of ammonia nitrogen by nitrification and decomposition of organic contaminants. The crucial difference between HSF CWs and VSF CWs is not only the direction of the flow path, but also the availability of the oxygen in the bed.

In VSF CWs, the mechanisms removal of pollutants follow the same approach applied in HSF CWs. The main chemical-physical and biological processes mentioned are filtration, sedimentation, sorption, chemical oxidation, evaporation as well as aerobic/anaerobic degradation, plants adsorption, phytodegradation and phytoevaporation. In addition, due to better aeration of the bed, VSF CWS are very effective in the removal of organic contaminants (COD, BOD_5) and ammonia nitrogen. Concerning phosphorus, the removal rate remains limited. For this purpose, different filter materials were investigated in order to improve the efficiency of phosphorus removal such as fragmented Moleanos limestone, bauxite, and zeolite, a mixture of river sand and dolomite and wollastonite [62, 63].

VSF CWS are applied for treatment of sewage from different sources, namely, olive mill wastewater [17, 64], laundry wastewater [65], aquaculture wastewater [66], textile wastewater [67] and olive pomace leachate [68].

Achak et al. [17] showed the potential application of experimental system composed of sand filter and VSF CW to achieve nutrient and COD removal from olive mill wastewater. VSF CW consists of a tank (1 m^3) filled with gravel and soil, and planted with a mixture of aquatic plants (*Phragmites australis*, *Typha latifolia* and *Arundo donax*). The presence of aquatic plants was more efficient in removing of nutrients and organic load. The average elimination of experimental system in terms of flow was 62.48% for NTK, 90.43% for NH_4^+, 77.25% for NO_3^-, 98.51% for PO_4^{3-}, 97.53% for PT and 99.05% for COD. The same wastewater was treated by Herouvim et al. [64] using three identical series with four pilot scale VSF CWs filled with various porous media such as gravel, sand and cobble, with several sizes. Two series of pilot scale units were planted with common red and the third is as control unit (unplanted). The authors concluded that COD, phenol and TKN removal seems to be significantly higher in the planted series, while orthophosphate removal shows no significant differences among the three series. The purpose of the study reported by Sotiropoulou et al. [65] aims to indicate the significant improvement in the overall quality of laundry wastewater due to the use of the VSF CW. The VSF unit had a length of 64 cm and a diameter of 20 cm, filled with sand/gravel of different gradations, and planted with *Zantedeschia aethiopica*. Results showed an important decrease of microfibers concentration, COD and turbidity of 98, 93 and 94% respectively from laundry wastewater when a hydraulic load retention of 63.7 mm/d was applied. The treatment of aquaculture wastewater by a system composed of an intermittent sand and VF CWs with a total surface area of 9.5 m^2 was studied by Behrends et al. [66]. At 5.5 days of hydraulic retention time, the inflow concentrations of BOD_5, COD, TN, ammonium and TP of 771 mg/L, 3609 mg/L, 67.4 mg/L, 0.22 mg/L and 40.5 mg/L respectively were amounted to rate removal of 99.5% for BOD_5, 99.1% for COD, 95.5% for TN, 85.9% for ammonia and 84.4% for TP. Davies et al. [67] used VF CWs to remove an azo dye acid orange (AO7) from textile wastewater. VF CWs planted with *Phragmites australis* received an organic loading rates varied between 21 and 105 g COD/m^2 d and reduced to 11–67 g COD/m^2 d. The rates removal of COD, total oxygen carbon and AO7 amounted to 64%, 71% and 74%, respectively. The authors concluded that *Phragmites australis* not simply had a principal role in AO7 removal but also can degrade aromatic amines released during AO7 degradation. The combination of electrochemical oxidation for 360 min at 20 A and VSF CWs planted with *Phragmites australis* at retention time of 3 days and hydraulic organic loading between 5 and 15 g COD/m d was studied by Grafias et al. [68] for treating olive pomace leachate fed intermittently at organic loadings between 5 and 15 g COD/m d and a residence time of 3 d. The treatment by VF CWs followed by electrochemical oxidation enhance rates removal from 86 to 95% for COD and from 77 to 94% for color. However, the reverse approach yielded only 81% COD and 58% color removals.

4. Conclusion and recommendations

Constructed wetland is a natural wastewater system that have been proven sustainable, eco-friendly and low-cost technology compared with many other wastewater treatment technologies. Constructed wetlands consist on aquatic plants, soils, bed media, water, and microorganisms and encompass many processes for eliminating various wastewater pollutants such as biological process (microbial oxidation), physical process (sedimentation, precipitation, adsorption, filtration, and absorption) as well as chemical process (ion exchange and chelation). Many different designs and structures of constructed wetlands are experimented to remove the maximum contaminants from different wastewater sources including FWS CWs, HSF CWs and VSF CWs. Each system as it has many advantages it also has disadvantages. FWS CWs are characterized by low operating costs, can be built with locally available materials, do not use chemical elements for treatment process and provide a high reduction of BOD and suspended solids. However, FWS CWs require expertise for system construction and a large land area for setup; also, they are not tolerant to cold climates. Although HSF CWs necessity low operation and maintenance cost, and allow a high reduction of BOD and suspended solids, but require large land area, allow a low remove of nitrogen and phosphorus (absence of oxygen), and can present a clogging risk. Contrary to FWS CWs and HSF CWs, VSF CWs are a high oxygen transfer capacity, require less land area, report a good nitrification (presence of oxygen) and present less clogging. Nevertheless, VSF CWs require frequent maintenance and pre-treatment of wastewater to prevent clogging.

The increase of water treatment efficiency is mainly based on the optimization of all operation parameters factors affecting processes application such as vegetation, wastewater sources, substrate media, feeding mode, and hydraulic loading rate (HLR) and hydraulic retention time (HRT).

- Vegetation is one of the important parameters in CW systems and could influence the depollution performance of wetlands. The performance of plant species principally depends on plant root characteristics. Since the roots are spread broadly and uniformly in the constructed wetlands filter bed, the decontamination is performed. On the other hand, the selection of vegetation with high biomass productivity while the transpiration needs is low (Higher Water Use Efficiency index), is a key factor in selection of constructed wetland species.

- Wastewater can be provided of many industries. Its concentration of organic matter, suspended solid, nitrogen, phosphorus and other contaminants is very high. The selection of constructed wetlands type to use for depollution of sewage is based on the BOD/COD ratio. If the ration is greater than 0.5, the sewage is biologically biodegradable such as wastewaters from dairies, breweries, food industry, abattoirs or starch and yeast production. While, BOD/COD ratio is lower than 0.5, the low level of biodegradability is reported such as pulp and paper wastewater an olive mill wastewater. In order to keep the efficient constructed wetlands operation, its use proceeded by preliminary treatment is recommended to remove various contaminants and reduce the potential risk of system clogging.

- Substrate media is one the main factors makes the use of constructed wetlands benefit since media can attribute to the decontamination of wastewater. Sand, soil and gravel are the current conventional materials of porous media. To enhance the removal efficiency of different types of constructed wetlands, alternative materials are used including (i) natural substrates which are directly used without any pretreatment such as zeolite, maifanite, pozzolane and limestone; (ii) agricultural by-products and industrial wastes are residue materials produced in the processes of many industries and agricultural operation such as quartz sand, fly ash, steel slag, oyster shell, sawdust, banana peel and coconut endocarp; (iii) synthetic substrates are the materials synthesized in the laboratory which their physical-chemical properties are modified including bio-ceramic, activated carbon and biochar.

- Feeding mode of wastewater is one of the main parameters, which influence constructed wetlands treatment processes. There are three modes, including continuous, batch and intermittent. The effect of each mode is dramatically related to transfer and diffusion of oxygen in constructed wetlands. The removal efficiency of pollutants in batch mode is better than in continuous mode, since the hydraulic retention time in batch mode is higher. While intermittent mode can provide a high removal of nitrogen and organic matter.

- HLR and HRT are the dominant factors which significantly affect the treatment processes in constructed wetlands and control flow rate in the system. Long HRT in constructed wetlands allows enough contact time between microorganisms and pollutants for organic matter degradation and nitrogen removal. While, larger HLR does not allow a sufficient contact time and leads to faster transfer of wastewater trough media that affect the removal efficiency of pollutants.

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