Constructed Wetlands for the Wastewater Treatment

Subjects: Water Resources
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Wastewater is one of the major sources of pollution in aquatic environments and its treatment is crucial to reduce risk and increase clean water availability. Constructed wetlands (CWs) are one of the most efficient, environmentally friendly, and less costly techniques for this purpose.

Keywords: constructed wetlands ; wastewater ; water pollution

1. Introduction

Environmental degradation can be caused by both anthropogenic and natural sources of pollution. Anthropogenic pollution associated with the industrial and agricultural sectors, for instance, is contributing immensely to environmental deterioration, especially in the aquatic ecosystem [1][2]. Domestic and municipal wastewater, sewage from wastewater treatment plants, urban runoff, livestock wastewater, stormwater, and landfill leachate are other major sources of pollution to the aquatic environments. If wastewater coming out from these sources is released into a natural water body without proper treatment, it results in an algae bloom [3][4] that affects aquatic biodiversity [5]. Moreover, it can contaminate soil and groundwater, endangering human health [6]. Consequently, the remediation of polluted water is vital to both reduce such risk and increase clean water availability. Indeed, as recently highlighted by [7], wastewater treatment could contribute to achieving 11 out of 17 sustainable development goals (SDGs) adopted by the United Nations, considerably reducing the global water crisis. Nowadays, the use of green technologies for such purposes is increasing due to (i) their ability to reduce pollution without compromising environmental sustainability and (ii) low implementation and maintenance costs [8]. Among these emerging green technologies, phytoremediation is being recognized as a promising, low-risk, and environmentally friendly in situ clean-up method, where plants are used to decontaminate the environment by eliminating, holding, or providing nontoxic contaminants in soil or water [9][10][11]. Phytoremediation was successfully used in constructed wetlands (CWs), an artificially built pollutant removal method that utilizes the combined contribution of substrates, macrophytes, and microbial community [9]. CWs are designed and built engineering systems that use the natural processes of emergent/floating/submerged wetland plants, saturated or unsaturated substrates/soils, and associated microbial communities built for water pollution control [12][13][14]. They are synthetic systems that have been designed to resemble the biological, chemical, and physical processes that take place in natural wetlands [15].

With the use of CWs, wastewater remediation can be conducted more affordably, sustainably, and easily, with a high rate of nutrient recovery, and minimal maintenance/operation costs [16][17][18][19] in an eco-friendly way [20][21]. CWs are capable of treating wastewater from different sources such as municipal, livestock, industrial, agricultural, domestic, acid-mine waste, storm run-off, and landfill leachate [22][23][24][25][26][27][28][29]. Numerous harmful chemicals, including antibiotics, heavy metals, landfill leachate, textile dyes, pesticides, hormones, petroleum, and explosives are removed or degraded by the phytoremediation technique [30]. With the help of CWs, a variety of pollutants can be eliminated from wastewater, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SSs), total Kjeldahl nitrogen (TKN), total phosphorus (TP), total coliforms (TCs), and metals by microbial degradation, plant absorption, substrate adsorption, and filtering by the packed media and biological predation [26][31].

2. Classification of CWs

2.1. Free Water Surface Flow (FWS) CWs

In this system, the wastewater flows through a shallow, planted basin or channel. It has exposed water surfaces and macrophytes that simulate natural wetlands [32], and as a result, high wildlife diversity is expected (insects, molluscs, birds, mammals, etc.) within the large land area required [33]. FWS CWs are reportedly employed less frequently due to the significant risk of human exposure to pathogens [34]. However, it can be utilized in rural areas where access to land is typically better than in urban areas. The wastewater being treated here must have effectively completed secondary or tertiary treatment elsewhere to avoid the system becoming clogged with solids. TSS, COD, BOD_5, and pathogens, such as bacteria and viruses, can all be removed with an effectiveness of greater than 70% [35].

2.2. Sub-Surface Flow (SSF) CWs

It is a type of CWs, the porous substrate media allows the wastewater to flow either horizontally or vertically beneath the surface. According to [36], SSF CWs are efficient in carbon and nitrogen compound removal because of the aerobic nature of the media. SSF CWs usually classified into two, depending on the direction of the water flow: horizontal sub-surface flow (HSSF) and vertical sub-surface flow (VSSF) CWs [37].

2.2.1. Horizontal Sub-Surface Flow (HSSF) CWs

In HSSF CWs, the wastewater moves horizontally below the surface through the substrate media, plant roots, and rhizomes towards the system outlet [24]. According to [38], unlike the FWS CWs, HSSF CWs require a small land area but with high investment costs. HSSF CWs are poor in removing ammonia nitrogen (nitrification) but because of anoxic and anaerobic conditions, they can treat nitrate nitrogen (denitrification) very well [15]. TSS, BOD_5, and COD were reported to be effectively removed by HSSF CWs at rates of 83.9%, 79.2%, and 72.1%, respectively [25].

2.2.2. Vertical Sub-Surface Flow (VSSF) CWs

The wastewater in VSSF CWs moves vertically either as an up-flow or downflow [39] movement. In a downflow movement, wastewater is applied intermittently (with filling and draining) and it inundates the surface before entering the system through gravity [40][41]. As wastewater passes through the medium (substrate), air enters the pores and facilitates the nitrification process [42], hence improving pollutant removal efficiency. This process can be further improved by inserting aeration pipes in the system [35]. Clogging in this system may be caused by degraded macrophytes, pollutants, and particles in the system affecting the hydraulic conductivity that influences the treatment process [43]. VSSF CWs are well-aerated (aerobic condition); therefore, ammonia nitrogen is removed through the nitrification process but not nitrate nitrogen because of the absence of denitrification [15]. According to [25], TSS, BOD_5, and COD removal efficiencies for VSSF CWs were found to be 81.8%, 80.0%, and 78.7%, respectively.

2.3. Hybrid CWs

Hybrid system is a combination of various types of CWs. This system is capable of removing ammonia, nitrate, and total nitrogen from different types of wastewater by combining VSSF CWs with HSSF CWs [44]. The very high pollutant removal efficiency of hybrid CWs is due to the presence of aerobic, anaerobic, and anoxic phases [24][32][45]. Hybrid systems outperform single-stage systems in the removal of TSS (91.2%), BOD_5 (82.7%), NH_4-N (77.6%), TN (73.3%), and TP (69.9%), as well as other contaminants, when compared to other types of treatment wetlands [25].

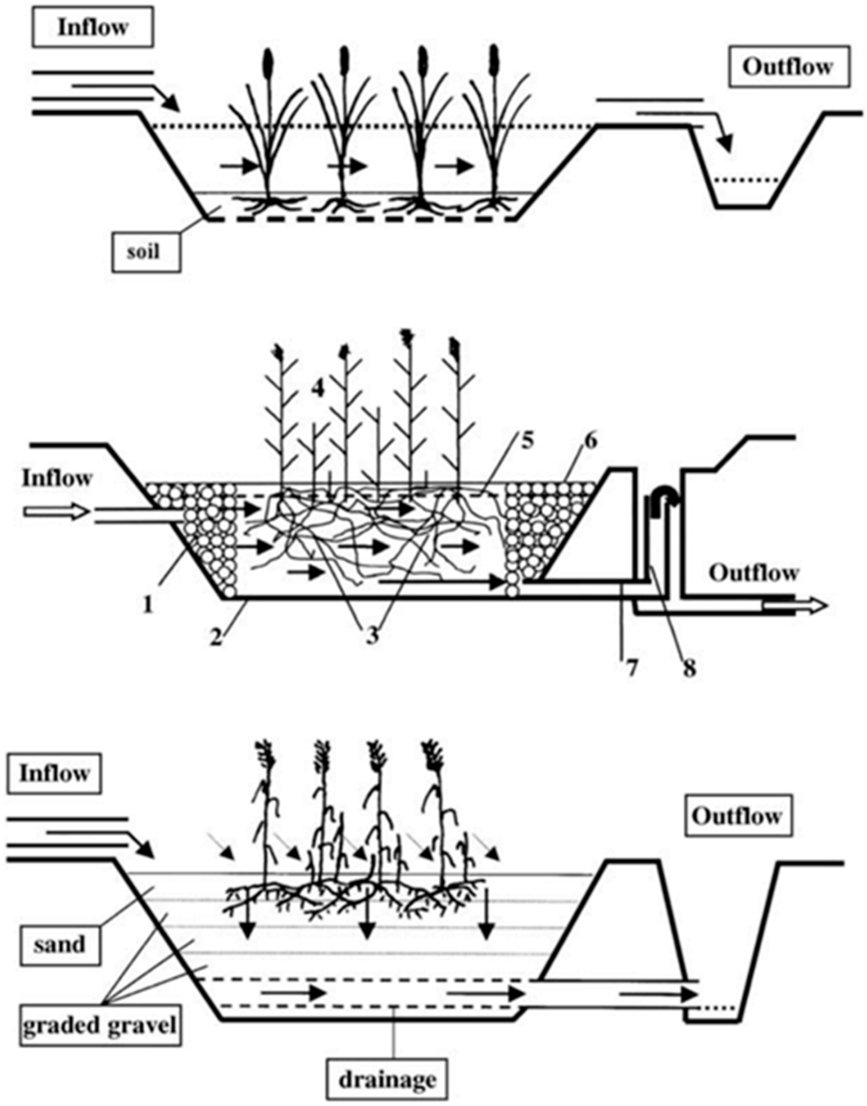

Figure 1. Top to bottom, CW with free water surface (FWS), CW with horizontal sub-surface flow (HSSF, HF), 1 inflow distribution zone filled with large stones; 2 impermeable layer; 3 filtration material; 4 vegetation; 5 water level in the bed; 6 outflow collection zone; 7 drainage pipe; 8 outflow structure with water level adjustment, CW with vertical sub-surface flow (VSSF, VF) (Vymazal, 2007) [39].

2.4. Macrophytes

Wetland plants are classified as emergent plants, floating leaf macrophytes, submerged plants, and freely floating macrophytes [46]. Macrophytes are components of the CW treatment systems that play major roles in the breakdown and removal of nutrients and other contaminants. Aquatic macrophytes are widely employed in wastewater treatment because they grow more quickly, produce more biomass, and have a higher capacity to absorb and store pollutants [47][48]. Through photosynthesis, macrophytes in CWs can also act as a reliable source of energy (carbon from root exudates) for microorganisms [17], and in the rhizosphere, macrophytes offer surfaces and oxygen for the growth of microorganisms [49]. *Phragmites australis*, *Typha latifolia*, *Lemina minor*, *Arundo donax*, *Cyperus alternifolius*, *Canna indica*, and *Cyperus papyrus* are some of the aquatic plants used in wastewater treatment.

2.5. Substrate

The substrate in CWs is usually constituted of soil, sand, gravel, or organic matter such as compost [50]. It is a crucial component of CWs performing several functions, including the following: physical support for wetland plants [51]; controls hydraulic conductivity and plant growth [52]; removal of pollutants by ion exchange, adsorption, precipitation, and complexation [49][53][54]; electron donor function for metabolism and denitrification; and carrier function for microorganisms. For such reasons, CWs substrate has a big impact on the implementation costs, as well as the effectiveness and sustainability of the treatment [51]. Specifically, the substrate in CWs strongly affects the performance of microorganisms by providing aerobic and anaerobic zones that promote denitrification, nitrification, adsorption, ion exchange, and precipitation processes with organic carbon as an accessible energy source [13][55][56].

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