Wetlands for Wastewater Treatment

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ABSTRACT: An update on the current research and development of the treatment technologies, which utilize natural processes or passive components in wastewater treatment, is provided in this paper. The main focus is on wetland systems and their applications in wastewater treatment (as an advanced treatment unit or decentralized system), nutrient and pollutant removal (metals, industrial and emerging pollutants including pharmaceutical compounds). A summary of studies involving the effects of vegetation, wetland design and modeling, hybrid and innovative systems, storm water treatment and pathogen removal is also included.

KEYWORDS: wetlands, natural treatment, vegetation, hydrology, pollution, stormwater.

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doi: 10.2175/106143016X14696400494650

Wetlands for Wastewater Treatment

Constructed wetlands are known for their efficiency as a promising technology for domestic wastewater treatment. Several types of constructed wetlands, such as free water surface (FWS), vertical subsurface flow constructed wetlands (VSSF-CWs) and horizontal subsurface flow constructed wetlands (HSSF-CWs) have been introduced to remove various pollutants and contaminants from wastewater. The use of wetlands for wastewater treatment has been evaluated in laboratory, pilot, and full-scale studies. Martinez-Guerra et al. (2015) provided a review updating the research conducted in wetlands for the year 2014. Various applications of wetlands in wastewater treatment, wetland design and other factors affecting the performance were discussed. Schultze-Nobre et al. (2015) demonstrated a laboratory-scale fixed bed reactor planted with the halophyte *Juncus effuses* to remove dimethylphenols, while Ayaz et al. (2015) used an anaerobic pretreatment followed by horizontal and vertical sub-surface flow constructed wetlands in a pilot-scale study. On the other hand, Avila et al. (2015), studied a full-scale hybrid CW system based on three stages of different wetland configurations. All these studies demonstrated the feasibility of wetlands for wastewater treatment.

CWs are often used for metal removal from wastewater. In order to improve the removal efficiency, influential process parameters must be evaluated. Pedescoll et al. (2015) determined some of the most important factors affecting the removal efficiency and dynamics of metals and metalloids. Several metals including Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Sn, and Zn were analyzed. Interestingly, the presence of vegetation and flow type was found to be the most important design factors affecting metal removal from urban wastewater in horizontal CWs. FWS flow was observed to provide favorable conditions for the removal of As, Fe, and Mn; meanwhile, SSF (subsurface flow) favored the removal of Cu and Pb. CWs are also efficient in the removal of nutrients in water. For example, Park et al. (2015), evaluated the effectiveness of horizontal flow hybrid CWs utilizing a combined sulfur-based autotrophic and heterotrophic denitrification. The optimum ratio of sulfur: limestone: immobilized bead with *Thiobacillus denitrificans* was found to be 3:1:4; initial cell density of above 1×10^6 cells; the optimum temperature was between 25 and 35°C; and the optimum sulfur sources were thiosulfate and elemental sulfur to effectively treat hydroponic wastewater utilizing autotrophic denitrification with *T. denitrificans* in batch experiments. They concluded that a combined autotrophic and heterotrophic denitrification process in HF–VF CWs would be more suitable than the heterotrophic denitrification alone for treating nitrate in hydroponic wastewater since hydroponic wastewater contains little organic carbon. Different hydraulic loading rates (HLR) were evaluated on pollutant removal efficiency of subsurface horizontal-flow constructed wetlands. The removal rates varied with applied hydraulic loading levels; 64.9%, 62.5%, 86.3%, and 80.34% for BOD_5 (5-day Biochemical Oxygen Demand, COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), and oil and grease were removed, respectively (Cakir et al., 2015). This study was performed over three years which concluded the use of constructed and planted wetlands for wastewater treatment.

Constructed wetlands (CWs) can also be used as a tertiary wastewater treatment. For example, Chen, Wen et al. (2015) studied the microbial community evolution in constructed wetlands. They applied 454 high-throughput pyrosequencing to analyze the bacterial community in unplanted, planted, and litter loaded CWs; and observed that the effect of plant biomass in the bacterial communities at the phylum level was not pronounced. In addition, it was noticed that the presence of plants and litters significantly affected the bacterial composition via alteration of carbon content and pH values in the gravel mix. Ladislas et al. (2015) investigated the feasibility of using a floating treatment wetland for removal of dissolved metals from urban runoff under full-scale conditions. Analysis showed Ni concentrations were between 23 and 31 mg/g dry matter, in leaves and between 113 and 131 mg/g in roots. Accumulation of Zn was 45–80 mg/g in leaves and 168–210 mg/g in roots. The root/leaf ratios were between 2.6 and 5.7 for Ni and Zn respectively, which highlights the important function of roots in heavy metal accumulation.

No cadmium accumulation was detected in plants. All three metals were also present in the biofilm on roots.

Rural communities often lack appropriate infrastructure for wastewater treatment. CWs are potential alternatives capable of meeting these needs (Calherios et al., 2015). CWs add aesthetic value and facilitate energy recovery. For instance, CWs can be coupled with microbial fuel cells to treat wastewater and generate electricity. Fang et al. (2015) modified constructed wetlands with the energy capacity of microbial fuel cells (CW-MFCs). They noticed that hydraulic residence time (HRT) influenced the decolorization process in the anode layer. Power density, coulombic efficiency, open circuit voltage, decolorization rate, and COD removal rates increased initially, and then decreased with the elongation of the HRT. The highest power density was 0.0619W/m^3 while the highest decolorization rate was 92.83% when the HRT was 3 days. Moreover, they suggested further investigations to maximize CW-MFC performance. Similarly, Oon et al. (2015) combined an upflow constructed wetland with a microbial fuel cell (UFCW-MFC). In this case, biodegradation of organic matter, nitrification and denitrification were investigated and the removal efficiencies of COD, NO_3^-, NH_4^+ were 100%, 40%, and 91%, respectively. The maximum power density of 6.12 mW/m^2 and a coulombic efficiency of 8.6% were achieved at an electrode spacing of anode 1 (A1) and cathode (15 cm). Both of these studies aimed to reduce energy and waste disposal burden in rural or isolated communities.

Wetlands for Nutrient Removal

Constructed wetlands (CWs) are sustainable and energy-efficient systems for reducing the nutrient load in wastewater. Studies have confirmed the nutrient removal capability of wetlands. For example, in a case study in Taiwan, CWs removed the total nitrogen (TN) by 25% and total phosphorus (TP) by 60% (Lin et al., 2015). In eastern China, a paddy eco-ditch and wetland system reduced 87.8% of TN and 70.4% of TP (Xiong et al., 2015). Furthermore, Hallin et al. (2015) identified denitrification as a major pathway for N-removal in sub-arctic wetlands with the evidence of denitrification genes. Li, He et al. (2015) revealed the dominant nitrogen removal pathway in the tidal flow constructed wetlands was simultaneous nitrification, anammox, and denitrification process, in which the anammox 16S rRNA was the key factor of the NH_4^+–N transformation rates, and (napA + narG) was the key factor regulating the NO_3^-–N transformation rate. Coban et al. (2015) studied the nitrogen-transforming bacteria and spatial distribution of the nitrification, anammox, and denitrification processes in horizontal subsurface-flow constructed wetland (HSSFCW) using molecular markers and isotope labeling techniques. The nitrate consumption under aerobic conditions suggested that the denitrification process could also be aerobic with comparable rates to that of anaerobic denitrification. Multistage constructed wetlands using saturated vertical flow (for denitrification), free-drain vertical (for nitrification), and horizontal flow (for denitrification) units in series could largely enhance the total nitrogen removal even in cold weather (Vymazal and Kröpfelová, 2015). Substrate adsorption was the major mechanism of phosphorus removal in vertical-flow constructed wetlands (VFCWs). One study showed the reduction of phosphorus in constructed wetland was mainly by granule interception and plant's uptake, 74.7% and 25.3%, respectively, in a subsurface flow wetland filled with calcium-rich ceramic granules (Jing et al., 2015). Another study found that 53.3% of TP was removed by adsorption, 13.5% by leaching, and only 0.49% by uptake in VFCW planted with *Cyperus alternifolius* (Ouyang et al., 2015).

Plant absorption is another important process for removing nutrients from wastewater with proper plant harvesting (Wang, Shi et al., 2015).Vertical subsurface flow constructed wetlands (VSSFCWs) with *C. alternifolius* or *C. dactylon* plant performed much better in nutrient removal than the unplanted wetlands (Mustapha et al., 2015). Result from duckweed-based CWs showed 22.4 g N/m^2•yr removal and 7.4 g P/m^2•yr removal by harvest (Adhikari et al., 2015). One study showed that increasing plant biomass will improve the redox conditions in the substrate layer and increase dissolved N and P removal by harvesting plant (Dzakpasu et al., 2015). Another study showed the proportional relationship between increased plant biomass and high P removal, and it suggested harvesting above-ground vegetation in June or September for maximum P removal in Floating treatment wetlands (Wang, Sample et al., 2015). Nitrogen standing stock in *Phragmites australis* growing in constructed wetlands was highest in the upper leaves (38%) and lowest in the stem bottom (3.7%) (Brezinová and Vymazal, 2015b). However, some researchers argued that plant uptake for nutrient removal was minor. Nutrient removal rate increased by 9% only for nitrogen and 17% for phosphorus in a HSSFCW planted with *Typha latifolia* compared to the control CW without plants (Costa et al., 2015). In addition, Zheng et al. (2015) found harvesting had minimal increase in nutrient reduction (only 5.4% increase in TN and 9% in TP removal) by comparing harvested and unharvested constructed wetlands.

Many factors affect the removal efficiency of nutrients. In one study, removal efficiency of ammonia was decreased by increasing ammonium loading in tidal-operated constructed wetlands (Wu, Dong et al., 2015). Another important factor affecting nutrient removal is temperature. For instance, the performance of ammonia treatment of wetland exhibits the highest removal rate in summer and lowest in winter (Postila, Ronkanen, and Klove, 2015). Mietto et al. (2015) found that a temperature of 14.8°C was a threshold for TN and NO_3^--N reduction efficiency in a hybrid wetland system. Phosphorus removal performance also varies with weather. A study showed the P removal rate was higher in the cold season from September to May than in warm periods from June to August in a CW receiving eutrophic lake water (Dunne et al., 2015). Water saturation levels in the VFCWs affected the nutrient retention because of the different redox conditions, for example, the fully unsaturated and partly saturated conditions provided high treatment efficiency in P retention (Kim et al., 2015), and the 25 cm saturation when operating filter showed higher removal rate for nitrogen than 15 cm saturation (Silveira et al., 2015). Different plant species affect the treatment performance of CWs. Therefore, different techniques to improve the nutrient removal rate have been explored. A CW system planted with *Celtis laevigata* removed more than 90% phosphorus from urban runoff (Mutiti et al., 2015). One study showed that floating wetlands planted with endophytic-inoculated *Brachiaria mutica* achieved 67.2% of nitrogen and 81% of phosphate removal (Ijaz et al., 2015). CW planted with a polyculture of five ornamental flowering species removed up to 92% of PO_4^{3-} and 84% of NH_4^+ (Calheiros et al., 2015). Another study also found higher N removal in wetland with diverse plant communities than monotypic stands (Weller et al., 2015). Two large-scale CWs in South Florida achieved 77% to 84% of TP reduction over long term operation (Pietro and Ivanoff, 2015). A two-stage VFCW with new media material like rice husks and steel slag removed TN and TP by 100% and 90%, respectively, due to the treatment of aerobic, anoxic and anaerobic conditions in sequences in different heights of the wetland (Zhang, Tan and Peng, 2015).

Wetlands for Pathogens and Viruses Removal

Waterborne pathogens along with viruses present in wastewater (greywater, stormwater, seepage water, and blackwater) are a threat to human and animal health, and are a major cause of water impairment. One of the main contaminants found in water is *Escherichia coli* (*E. coli*), a fecal (indicator) pollutant in aquatic environments. Other fecal-borne viruses that are also used as fecal indicators include human enteric viruses, such as human adenovirus and human polyomavirus (Kuroda et al., 2015). Among common pathogens are protistan pathogens such as *Giardia*, *Crystosporidium*, and *Taxoplasma* (Marangi et al., 2015). Although, highly efficient pathogen and virus removal systems have been developed, persistent intrusion of these contaminants is almost inevitable, especially in combined sewer flow. In fact, it is known that current wastewater treatment systems do not remove viral pathogens completely (Polo et al., 2015). A major concern in the analysis of viruses is that these analyses are known to have variable and relatively poor recovery efficiencies (Patterson et al., 2015). Therefore, quantitative method recovery data are needed to correct virus enumeration results, which led Patterson et al. (2015) to study the use of mengovirus process control data for quantifying recovery efficiency of human adenovirus and noroviruses (major cause of human gastroenteritis). They suggest that better estimates of virus concentration can be achieved if a sample-specific spiking control could be developed, to closely simulate the behavior of human viruses. On the other hand, Marangi et al. (2015) established a multiplex real-time PCR (qPCR), coupled with high resolution melting (HRM) analysis, for the specific detection and quantification of each *Giardia duodenalis*, *C. parvum*, and *T. gondii*. The assay was subsequently applied to samples of treated wastewater and mussels; and the results showed that of 119 water samples 28.6% were test-positive *for G. duodenalis*, *C. parvum* and/or both pathogens; of 113 mussel samples, 66.6% were test-positive for *G. duodenalis*, *C. parvum* and/or both pathogens, and 13.2% were test-positive for only *T. gondii*. According to the obtained results, this assay is a promising tool for the simultaneous detection and quantification of the aforementioned contaminants.

Wastewater treated with wetlands may not be suitable for recycling in domestic use or irrigation purposes. Almuktar and Scholz (2015) compared the use of domestic wastewater treated by wetland (vertical flow) to tap water for the irrigation of Chilli fruits. They carried out this study for approximately one year (2013-2014). Results indicated no bacterial contamination in fruits harvested from plants irrigated by wetland outflow water; however, it was reported that fruits harvested from plants irrigated by wastewater treatment plant effluent showed high contamination by total coliforms, such as *Streptococcus spp*. and *Salmonella spp*.

E. coli along with other pathogens and viruses can also be removed by using the Aquifer Storage and Recovery (ASR) system, which has been historically used to store harvested urban stormwater in aquifers for subsequent reuse (Page et al., 2015). Stormwater was injected into a confined carbonate aquifer that initially contained brackish water. They noticed that at all sites, E. coli concentrations in recovered water was 2-3 $\log_{10}$ (90-99%) less than the injected water, which allowed them to conclude that ASR systems has the potential for integration with engineered treatments. Membrane bioreactors can be used to determine which virus removal mechanisms have the most impact by differences in the virus removal surface (Chaudhry et al., 2015). According to a recent study, the virus removal most affected by virus type was attachment to biomass with removals of 0.2 log for MS2, 1.2 log for phiX174, and 0.3 log for fr; long-term operation (years) may increase virus removal.

Wetlands for Emerging Pollutants Removal

Emerging contaminants including endocrine disrupting chemicals (EDCs) and pharmaceutical and personal care products (PPCPs) are harmful to human health and often difficult to remove by conventional treatment methods. Constructed wetlands provide an alternative method to reduce emerging contaminants efficiently.

Pesticides are one category of the EDCs that can be successfully removed by wetlands. A review by Vymazal, Březinová (2015) on 47 studies of pesticides removal revealed that free water surface CW was the most common type and the removal efficiency varied among pesticides species and systems. CWs with optimized water residence time by vegetation or installing weirs showed satisfactory removal of pesticides (Romain et al., 2015). Results from a study showed that SSFCW reduced the MCPA (4-Chloro-2-methyphenoxy acetic acid) by 97.87% (Elmaci, 2015). Processes responsible for pesticide mitigation are hydrolysis, photolysis, sedimentation, adsorption, microbial degradation, and plant uptake; however, it is difficult to determine the most influential ones, especially without knowing specific process conditions (Vymazal and Březinová, 2015).

Free water surface CWs are also widely used for effective removal of antibiotics and hormones such as estrogens, progesterone, and testosterone (Vymazal et al., 2015). Free water surface CWs removed veterinary antibiotics such as enrofloxacin by 98% and tetracycline by 94% (Fernandes et al., 2015), sulfonimides, chloramphenicol, fluoroquinolone, and dyes by 43% to

>87% (Hsieh et al., 2015). Vertical up-flow CW receiving livestock wastewater decreased the tetracyclines by 69.0%-99.9%, and tet genes by 33.9%-97.8% (Huang, Liu et al., 2015). Triclosan removal efficiency was over 90% in batch-loaded CWs with emergent, submerged, or floating plants (Zhao, Xie et al., 2015). Integrated (four surface and subsurface flow) constructed wetlands could remove the antibiotics such as leucomycin, ofloxacin, lincomycin, and sulfamethazine by 78-100%, and antibiotic resistance genes by more than 99% (Chen, Liu, Su et al., 2015). Estrogen removal rates were between 31.3% and 57.1% in free water surface CW (Hsieh et al., 2015). In another study, organic-based VFCW almost completely removed natural and synthetic hormones (Herrera-Melian et al., 2015).

Wetlands are also effective in heavy metal reduction. Rout and Munavalli (2015) reviewed heavy metal removal by multi species and multimedia CWs. Cd removal rate could reach 70% in VFCW with macrophytes (Arivoli et al., 2015), 82.4% by HSSFCW (Zhang, Gao et al., 2015), and 91.8% in VSSFCW planted with *Iris sibirica* (Gao et al., 2015). HSSFCW was able to reduce Mercury from municipal wastewater by 63.7% (Sima et al., 2015), and Pb by more than 78.6% with vegetation (Rai et al., 2015) or 95% with proper influent concentration (25 mg/L) (Han et al., 2015). Heavy metal removal rate by the plant uptake differs according to metal species in the order Cr, Ni > As, Cd, Pb consistent to relative concentration in the rhizosphere environmental of microcosms (Guittonny-Philippe et al., 2015).

CWs can remove PPCPs in large quantities, including pharmaceutical drugs, cosmetics, and fragrances. SSFCW removed 13 pharmaceutical compounds by more than 70% (Rühmland et al., 2015). Carbamazepine was effectively reduced in SSCW by plant activities of *C. indica* and *P. australis* (Macci et al., 2015). Inoculation of bacteria isolates *Diaphorobacter nitroreducens* and *Achromobacter mucicolens* to *Phragmites australis* can enhance the phytoremediation of carbamazepine (Sauvetre and Schroder, 2015). A hybrid system with three stages of different types of constructed wetlands (VSSFCW, HSSFCW, and FWSCW) showed above 80% of PPCPs and EDCs (Avila et al., 2015). Another hybrid constructed wetland system was able to remove more than 94% of PPCPs including sodium dodecyl sulphate, propylene glycol, and trimethyl amine (Ramprasad and Philip, 2015). Plants in the wetlands affected the removal rate of pharmaceuticals and EDCs, thus selection of appropriate plant species could improve the removal efficiency (Garcia-Rodrıguez et al., 2015).

Wetlands for Stormwater Treatment

Every year, 119,000 km^3 of precipitation are recorded worldwide. About 61% (72,000 km^3) evaporates, and 39% (47,000 km^3) continues to flow on the earth’s surface (Ladislas et al. 2015). Stormwater management and treatment is a constant concern du to the risk of flooding during heavy rains, especially in urban areas. Conventionally, stormwater management has consisted of collecting the stormwater in a piping system and transporting to a stream of a river, or to a combined sewer system flowing to wastewater treatment plant (Ladislas et al., 2015). Often, the transported or collected rainfall, is polluted and requires treatment to protect the aquatic life where the rainfall flows to. Therefore, stormwater must be often treated prior to disposal into a water body.

Constructed and natural wetlands have been often used as "filters" in stormwater treatment. Several characteristics must be accounted for when using wetlands for rainfall treatment (Wang, Tian et al., 2015); including soil type, hydrologic characteristics of the wetland, and the volume of nutrients and/or pollutants to be treated. Bhomia et al. (2015) demonstrated a new technique to determine rate of soil accretion in selected subtropical treatment wetlands. They utilized a "changing points" technique (CPT) that corresponded to specific events in the life span of a wetland. The CP was observed as an abrupt transition in the physico-chemical properties of soil as a manifestation of prevailing historical conditions. Annual soil and phosphorus accretion rates determined using CPT in studied wetlands ranged from 1.0 ± 0.3 to 1.7 ± 0.8 cm/yr and 1.3 ± 0.6 to3.3 ± 2 g/m^2 •yr, respectively. They concluded that commonly analyzed stratigraphic characteristics of wetland soils can be utilized to determine sediment and nutrient accretion rates in FWS treatment wetlands. Furthermore, the use of constructed wetlands to reduce runoff from impervious area (contributors of contaminant loads) can provide important habitat for urban wildlife (Mackintosh et al., 2015). Urban ecosystem is now being threatened, and its restoration involves slowing down urban runoff to restore its local hydrology with green infrastructure (Yang et al., 2015). Therefore, the addition of different types of plants play an important role in the construction of these infrastructures to up-take pollutants such as heavy metals and metalloids. Metals, such as zinc (Zn), which is a common metal found in high concentrations in urban runoff can be reduced by using CWs planted with native species, such as *Phalaris arundinacea* (Aucour et al., 2015).

Extensive studies have been done on nutrient removal using CWs (Chen, Ivanhoff, and Pietro, 2015; Lynch et al., 2015; Dunne et al., 2015; Jones et al., 2015). Chen, Ivanoff, and Pietro (2015) examined annual removal of phosphorus (P) from 1995-2011 in the six Everglades stormwater treatment areas (STAs) located in Florida, US. The STAs received approximately 13.6 billion m^3 of stormwater inflow containing an annual total P (TP) concentration (flow-weighted mean) of 143±62 µg P/L, and the effluent discharge with an annual TP concentration of 41±31 µg P/L. Long-term monitoring studies of the STAs provided insight on treatment performance in CWs and input for adaptive management strategies. Similarly, Mitsch et al. (2015) studied the Florida Everglades wetlands. They focused on the removal of nutrients (mainly phosphorus) from agricultural runoff into the Everglades. The high amount of P in the Everglades causes highly oligotrophic sawgrass or *Cladium jamaicense* in the area to become eutrophic. Thus, a three-year (March 2010 to March 2013) experiment was conducted with eighteen flow-through mesocosms (6 m x 1 m x 1 m with 40-cm water depth) assigned with six different plant communities and three replicates of each treatment. The average TP decreased by 51% from 2010 to 2011; however, it took a minimum of 2 years to become sinks of P. Furthermore, Dunne et al. (2015) used CWs in a large-scale to mitigate P impact in contaminated watersheds. The purpose of that study was to determine long-term P removal with CWs to treat lake water. The marsh flow-way treated substantial amounts of lake water (30 m/yr, which is about 30% of the lake's volume on an annual basis). Associated with this, P was removed at an average rate of 0.85 g/m^2•yr (2.6 metric tons/yr). The marsh flow-way removed mostly particulate P, while it released dissolved P fractions. Additionally, it was reported that P removal performance increased during cool periods.

A relatively new stormwater treatment practice is touse floating treatment wetlands (FTWs) that consist of emergent wetland plants planted on floating mats constructed of buoyant material. Lynch et al. (2015) utilized batch-fed mesocosms with a seven-day retention time, to investigate the total nitrogen (TN) and TP remediation capability of two commercially available FTW technologies (Beemats LLC, New Smyrna Beach, FL, USA) and BioHaven1 floating islands (Floating Island International, Inc. Shepard, MT, USA) planted with *Juncus effusus* (soft rush) using runoff from a combined irrigation holding and stormwater retention pond. . The results were favorable for both treatments; however, further investigation on FTWs was suggested to optimize the nutrient removal percentage. According to Rooney et al. (2015), policy development encourages developers to build stormwater wetlands instead of stormwater ponds because agriculturally impacted wetlands provide biophysical values equivalent to those of natural wetlands. In Tennessee, USA, integrated CWs were implemented to reduce nutrient and sediment transport from a confined animal dairy operation (Ludwig and Wright, 2015). The implementation of these integrated CWs greatly improved the removal rate of suspended solids and nitrogen, and event based phosphorus. According to the obtained results, a total of 2200 kg of suspended solids and 0.22 kg of nitrogen were retained in just one integrated CW.

Vegetation in Wetlands

Vegetation is important in pollutant removal in wetland systems. CWs achieved higher treatment efficiency in COD, nutrients, and *E.coli* with vegetation plants compared to unplanted ones (Toscano et al., 2015). This might be partially due to the effect of plant biomass on bacterial community structure in CWs, which was positively related to pollutant treatment performance (Chen, Wen et al., 2015). Plant diversity (number of plant species and species compositions) could enhance plant biomass (Wang, Chen et al., 2015) and nitrogen removal (Ge et al., 2015). Seasonal growth pattern of plants also affects plant biomass and the treatment efficiency; and harvesting the plants in inflow and outflow zones at different periods of growing season was recommended to increase N and P removal by 42% (Brezinová and Vymazal, 2015c).

Different plant species might have different wastewater treatment performances in wetland systems. In the aspect of nutrient treatment, one study found *Trianthema portulacastrum* planted CW had 10-20% higher removal than that with *Brachiaria reptans* (Sehar et al., 2015). Another study comparing the performance of C. *aquatilis*, *C. rostrata*, *E. angustifolium*, *E. fluviatile*, and *D.*

fluitans indicated higher denitrification rates by *D. fluitans* (Hallin et al., 2015). *Phragmites australis* was more competitive than *Typha orientalis* in regeneration and nutrient removal in wetlands (Dzakpasu et al., 2015). The native *Phragmites australis* subsp. *Americanus* showed higher P removal compared to European *Phragmites australis* (Rodríguez and Brisson, 2015). *Pickerelweed* had four times more P removal (164.4 mg P/m^2, whole plant) than the soft stem bullrush did (35.1 mg P/m^2) in floating treatment wetlands (Wang, Sample et al., 2015). *Canna indica* and *Phragmites australis* have shown similar efficiencies in TKN and phosphate removal (Bhardwaj et al., 2015). *Pennisetum sinese Roxb* and *Pennisetum purpureum Schum* had same effect on nutrient and clogging reduction (Xu et al., 2015). *Ranunculus muricatus* and *Typha latifolia* both performed well in COD, BOD, and nutrient removal in a constructed wetland (Aziz et al., 2015). For industrial wastewater remediation, *Iris sibirica* was effective in Cd removal (Gao et al., 2015). *Borassus aethiopum*, *Parawaldeckia karaka* (Terfie and Asfaw, 2015) and *Leersia hexandra* Swartz (Liu, Zhang et al., 2015) showed enhanced Cr reduction by plant uptake and influencing other removal processes. *Colocasia esculenta* had higher uptake of Cd and Zn than *Typha angustifolia* (Chayapan et al., 2015). *Typha angustifolia* and *E. arundinaceus* exhibited comparatively higher bioconcentration factors than *Phragmites australis* for Cd and Ni removal (Arivoli et al., 2015). Since the heavy metal accumulation in plant biomass had seasonal pattern, their removal rate could be increased by setting optimum harvesting time for plants such as *Phalaris arundinacea* (Brezinová and Vymazal, 2015a). *Canna indica* and *Phragmites australis* were more effective in both heavy metal and organic compound removal than *Zantedeschia aethiopica*, *Carex hirta*, *Miscanthus sinensis* in SSVFCW (Macci et al., 2015). *Juncus effuses* in wetland was able to remove more than 90% of dimethylphenols (Schultze-Nobre et al., 2015), and *Scirpus grossus* was promising for degradation of total petroleum hydrocarbon (Al-Baldawi et al., 2015). Another study showed hydrophytes' removal efficiency of polycyclic aromatic hydrocarbons in VFW followed the following order from highest to lowest: *H. verticillata* (34.4%), *A. donax* (33.2%), *P. australis* (28.7%), *I. aquatica* (28.5%), *Z. aquatic* (27.6%), *C. palustris* (27.2%), *A. calamus* (26.8%), and *Hardy canna* (17.9%).

Beside plants effect on the pollutant treatment in wetland, vegetation has impact on other aspects. The microbial community was different among different plants such as *Phragmites australis*, *Typha orientalis* and *Arundo donax* (Zhang, Wang et al., 2015). Different plant species also affect the water balance especially evapotranspiration in constructed wetland systems. Tuttolomondo et al. (2015) found that *Arundo donax L.* (giant reed) have higher cumulative evapotranspiration than *Cyperus alternifolius L.* (umbrella sedge). Plant biomass (especially *Rumex japonicas*) largely influenced both methanogens and methanotrophs, thus increased the CH_4 emission of constructed wetlands (Niu et al., 2015). A study found the free water surface CWs receiving eutrophic inflows could produce large amount of zooplankton especially cladocerans and ostracods thus could be used to enhance planktonic biodiversity (Calero et al., 2015).

Wetlands for Pollutant Removal

The concern of potential carcinogenity and mutegenicity of organic pollutant degradation in wastewater is increasing. Therefore, the use of conventional treatment methods such as oxidation, photo-degradation process, CWs, and ozonation has been investigated for the removal of these organic pollutants in wastewater and surface water (Araghi and Entezari, 2015). Biotechnologies are also being investigated to remove specific organic pollutants from water including agricultural chemicals and polycyclic aromatic hydrocarbons (PAHs). For example, low-cost biosorbents obtained from lignocelluloses and chitin/chitosan for specific organic pollutants (SOPs) for absorption have demonstrated their capability of removing SOPs such as phenols, PAHs, organic pesticides, and organic herbicides from water (Tran et al., 2015). However, further investigation on these biosorbents is required to improve their absorption capacity. Atta et al. (2015), on the other hand, opted for investigating dispersed organophilic clay minerals to increase the adsorption of water pollutants (organic and inorganic) into the clay galleries. They reported the use of sodium montmorillonite (Na-MMT) using crosslinking technique to produce reactive amphiphile dispersed Na-MMT sheets having the affinity to reduce the surface tension of water to enhance clay adsorption of pollutants on their surfaces. The use of Na-MMT nanogel results showed that methylene blue (MB), cobalt (Co) and nickel (Ni) cations can be removed from water within 60 minutes, which makes Na-MMT a potential technique to increase removal of pollutants in water.

TiO_2 coatings can also be used to remove emerging pollutants from water. The TiO_2 coated with titania is prepared on the outer wall of the inner tube of a glass tubular reactor by dip-coating method (Espino-Estevez et al., 2015). The effect of deposited mass and photoactivity was studied in the coating prepared after milling TiO_2 for 5 min. Photodegradation of phenol increased linearly with the number of coatings up to 60 dip-withdrawal cycles and the mass of deposited TiO_2 was equal to 0.32 mg/cm^2. The highest mineralization of phenol was reached with 80 dip-withdrawal cycles and 0.73 mg/cm^2 of TiO_2 mass. It was suggested to further investigate larger surface area such as ceramic foams to increase the photodegradation rate of pollutants. Similarly, Vaiano et al. (2015) investigated the possibility of increasing the photoactivity of semiconductors, such as TiO_2 and ZnO to minimize the volume of slurry-photoreactors to be used in wastewater treatment. This photocatalyst formulation increases the photoreaction rate and results in lower residence times in photocatalytic water purification. Continuing, Araghi and Entezari (2015) used amino-functionalized silica magnetite nanoparticles for the simultaneous removal of pollutants from aqueous solution. The A-S-MNPs were prepared through coating of sono-synthesized magnetite nanoparticles (MNPs) in a basic medium by SiO_2 and then modified with 3-aminopropyltriethoxysilane (APTES). The absorption behavior of this novel magnetic sorbent for the simultaneous removal of two organic pollutants containing a sulfonate group followed Langmuir isotherm with q with q_{max} of 83.33 and 62.5 mg/g for RB5 and SDBS at pH 2 and 298°K, respectively. Meanwhile, Chen, Ma et al. (2015) used advanced functional composite of ZnO nanoparticles embedded in N-doped nanoporous carbon, which was synthesized by a simple one-step carbonization of zeolitic imidazolate framework-8 under a water stream atmosphere. Some of the advantages include significant increases in the porosity of composites and the crystallinity of metal oxides.

Water hyacinth has the ability to absorb pollutants from aquatic environments. Upon the removal of pollutants from wastewater, water hyacinth can be used for recovering some of the toxic and non-degradable materials such as heavy metals (Rezania et al., 2015). One of the drawbacks of water hyacinth is that it can cause economic, environmental disaster and is difficult to control. However, they concluded that the use of phytotechnology utilizing water hyacinth has a positive effect on the environment by up-taking CO_2 from the atmosphere and by gathering supplements for the plant.

Metoprolol (MPTL) used for cardiovascular diseases treatment is a common pharmaceutical pollutant found in wastewater and surface water. Olvera-Vargas et al. (2015) implemented a hybrid process coupling electron-Fenton (EF) process and aerobic biological treatment (Bio-EF process) for efficient and cost-effective mineralization of beta-blocker metoprolol aqueous solution, and demonstrated complete mineralization (global mineralization rate of 90%) of MPTL solutions under optimal experimental conditions. Superparamagnetic iron-oxide nanoparticles (SPION) and their nanocomposite with β-cyclodextrin (SPION/β-CD) have been used to remove oil, dyes, and micropollutants, such as Bisphenol A (BPA), in water (Kumar et al., 2015). The treatment performances were evaluated in terms of BPA degradation, and this technique was able to remove 94.22% of dye in 2 hours sunlight driven by a photocatalysis process. Additionally, an oil retention capacity of 7.2 g/g of nanocomposite was observed.

Hu et al. (2015) used spent granular activated carbons (sGACs) from drinking water treatments via pulverizing as low-cost adsorbents for micro-pollutant adsorption from a secondary treated wastewater effluent. Two NOM-saturated GACs were studied in terms of their physicochemical properties and their reuse potential for atrazine adsorption, and it was observed that there is a possibility of reusing surface water preloaded GAC for micro-pollutant removal in the treated wastewater.

Wetlands Design and Operations

The overall performance of CWs depends on design, maintenance parameters and operation strategies (Vergeles et al., 2015). Wu, Zhang et al. (2015) did a comprehensive review on the design and operation of CWs for treating wastewater. They summarized that the main design parameters and operational conditions of CWs were plant species, substrate types, water depth, hydraulic loading rate (HLR), hydraulic retention time (HRT), and feeding mode. With proper design considerations for the technological process, pollution load, wetland bed structure, bed filter, plants selection, and hydraulic condition of SSFCW; the flow pattern, treatment efficiency, and clogging and cost issues can be optimized (Li, Wang et al., 2015). Vegetation was a key design factor affecting pollutant removal such as metals (Pedescoll et al., 2015). The roots of plants such as reeds had high capacity of accumulating and removing lead in HSSFCW (Ghannad et al., 2015). Plant vegetation also significantly affected COD removal (Sultana et al., 2015).

HLR and HRT are two key design parameters. The loading of influent is an important design parameter. The acceptable loading differed between wetlands with different conditions (Campbell and Safferman, 2015). When planning for wetland construction to treat wastewater, attention should be paid to ensuring sufficient residence time (Postila et al., 2015). One study found 0.050 m^3/day•m^2 HLR and 5.6 days of HRT achieved the highest removal rates for BOD, COD, TSS, and oil and grease in HSSFCW (Cakir et al., 2015). Sultana et al. (2015) found lower HRT (especially HRT smaller than 1 day) adversely affected removal efficiency in CWs. Enhancing water circulation and shortening hydraulic retention time will effectively diminish the effect of nutrient salts and organic pollutants (Li, Huang et al., 2015). Larger HRT in HSSFCW can also increase lead removal rate (Ghannad et al., 2015).

Substrate selection is another consideration in wetland performance. Song et al. (2015) compared three filter media packing strategies for VFCWs and found increasing-sized packing was optimal for nitrogen removal and slowing down clogging compared to the decreasing-sized packing and uniform-sized packing. Using media with high P binding capacity can improve P removal (Arias et al., 2015). Results from a study comparing the impact of zeolite and calcium silicate hydrate substrates indicated that calcium silicate hydrate had high removal rates for PO_4^{3-}-P, while zeolites showed higher NH_4^+-N removal (Li, Dong et al., 2015). Substrate type (sand, zeolite, and gravel) also influenced microbial community diversity and structure in a VFCW (Guan et al., 2015).

Many studies showed the positive effects of aeration in pollutant removal in wetlands. In a study, a CW with aeration, sucrose and oyster shell addition reduced the NH_4^+-N to non-detectable levels (Beebe et al., 2015). Labella et al. (2015) found that continuous aeration increased COD and ammonium nitrogen removal by over 50%. Another study confirmed the positive effect of aeration in increasing COD and polyphenols removal (Svensson et al., 2015). Aeration position can also largely affect pollutant removal such as organics (better with middle aeration) and nitrogen (better with surface aeration) (Wang, Tian et al., 2015).

The configuration of the wetland also matters. Zhao, Zhao et al. (2015) designed a “fan-shaped” CW to maximize the functions of wastewater treatment, recreation and attractive amenity. Johannesson et al. (2015) found the P retention was in a positive relationship with wetland length/width ratio, while it was not sensitive to the hydraulic load and phosphorus load. Pang et al. (2015) surveyed 169 full-scale French VFCW systems, and found that the removal efficiency was affected by wetland ages rather than by hydraulic or organic loads. Wu, Fan, Zhang, Ngo, Guo, Liang, Liu (2015) reviewed strategies and techniques to enhance CW performance for wastewater treatment. Hybrid CWs system showed promising result for pollutant removal and power production with microbial fuel (Corbella, Guivernau et al., 2015).

Wetland Modeling

Constructed wetland models are useful in describing the phenomena in CWs, comparing the behavior of similar systems, and predicting the performance of a system. Meyer, Chazarenc et al. (2015) did a comparative review on modeling CWs, and classified the models into three categories: biokinetic models, process dedicated models, and design support models. Biokinetic models include mechanistic models such as HYDRUS Wetland Module and BIO_PORE for simulating biological transformation, degradation processes, and microbial dynamics. The HYDRUS/CW2D model could successfully predict the COD, BOD_5, TN, TIN (Total Inorganic Nitrogen), and TP in HFCW in scenarios where the electron acceptors were not depleted (Pálfy et al., 2015). BIO_PORE was used to assess the effect of two parameters controlling realistic bacteria growth rates and dynamics on the effluent COD and ammonia nitrogen concentration (Samso et al., 2015). Endogenous and exogenous sunlight-mediated inactivation rates in an open-water CW was modeled to improve design and optimize the treatment system for virus activation (Silverman et al., 2015; Nguyen et al., 2015).

Process-dedicated models are used to gain understanding of a particular phenomenon such as simple kinetics related to degradation of compounds (Meyer, Chazarenc et al., 2015). First-order, second-order, and Stover-Kincannon models were used to determine nutrient removal efficiency and kinetic coefficients in SSCW (Farzadkia et al., 2015). The first-order removal rate constant of nitrogen was determined based on classic k-C* model (Zhang, Li et al., 2015). Nitrogen dynamics model could simulate nitrogen concentrations in different forms considering processes including ammonification, ammonia volatilization, nitrification, denitrification, plant uptake, plant decaying, and uptake of inorganic nitrogen by algae and bacteria (Kumar et al., 2015). A dynamic model was used to study the phosphorus dynamics in a wetland system considering processes like mineralization, uptake, grazing, predation, settling, resuspension, and sorption (Mandal et al., 2015). Ouyang et al. (2015) developed a model called STELLA (structural thinking, experiential learning laboratory with animation) to estimate P removal in a VFCW. First-order rate constants were also found by modeling BOD, *E. coli*, and TN in arctic tundra wetlands (Hayward and Jamieson, 2015). The LOEM-CW model developed and improved from the LOEM (Lake Okeechobee Environment Model) is a powerful tool in simulating hydrodynamics and transport processes in the wetland environment receiving stormwater runoff (Jin and Ji, 2015). A finite volume technique was applied for hydrodynamic modelling on hydraulic efficiency of free water surface CWs (Zounemat-Kermani et al, 2015). A spatio-dynamic model was developed to explain the spatial distribution of plant communities in response to hydrological pressures from the catchment (Martínez-López et al., 2015).

SubWet 2.0 was effective in modeling TP and BOD_5 treatment in VSSFCW (Huang, Gao et al., 2015). TP removal in HSSFCW can be potentially predicted by artificial neural network including radial basis function (RBF) and multilayer perceptron (MLP) with input parameters such as influent TP concentration, water temperature, flow rate, and porosity (Li, Zhang et al., 2015). A robust computational fluid dynamics (CFD) model integrated fluid transport, solute transport, biokinetics, and biofilm formation which had the ability to predict bio-clogging in SSVFCW (Rajabzadeh et al., 2015). RSF_Sim can predict the effluent COD and NH_4-N fairly well (Meyer and Dittmer, 2015). One study found that the variation in chloride concentrations was best simulated by a model containing the number of wells and the surficial geology (glacial till and outwash) surrounding a wetland (Burg and Tangen, 2015). Two methods of artificial neural networks including feed forward back propagation (FFBP) and radial basis function (RBF) were successfully used to predict the water quality index for 11 water quality variables in a free water CW (Mohammadpour et al., 2015).

In addition, CW network optimization can be achieved by using a GIS-based compound topographic index to find potential wetlands sites at watershed-scales, a GIS-based export to estimate the nutrient load from nonpoint source, and fuzzy-stochastic two-stage programming to map the optimal spatially distributed network (Dai et al., 2015). Wetland ecosystem change was predicted with multiple logistic regression models so accurate projection of locations of wetlands that need to be restored or regenerated could be found (Sanchez-Gonzalez et al., 2015). The Sea Level Affecting Marshes Model (SLAMM) could simulate wetland change more accurately compared to two traditional neutral models (Wu, Yeager et al., 2015).

Other Areas of Consideration

Low temperature raised unique challenges for using CWs in cold climates (Chouinard et al., 2015). There is evidence that treatment performance (such as COD, SS, and TKN) was improved by warmer temperature (Molle et al., 2015; Yu, Hawley-Howard et al., 2015). A study by Mietto et al. (2015) showed TN and NO_3-N reduction rates in hybrid CW systems were higher in temperature above 14.2°C than in colder weather. Cold temperature affected the long-term nitrate concentration: with a temperature rise from 4 to 12°C, the denitrification process increased while the anammox process decreased (Paing et al., 2015). Another study showed anammox process was seriously inhibited with mean temperature lower than 15°C (Wang and Li, 2015). Season variations (higher in summer, lower in winter) were also found for the plant bioconcentration factor, translocation factor, and heavy metal removal including Cr, As, Ni, Mn, Co, and Zn (Rai et al., 2015). To overcome the adverse effect of cold climates, Zhang, Mu et al. (2015) proposed a natural heating technology using the pure pig manure as compost material.

Microbial community is essential for wetland performance. The bacteria profile (number of viable and dead bacteria) in the VSSF soil depended on the depth (upper layer had more viable bacteria) and the material grain size (Foladori et al., 2015). The distribution of anammox bacteria varied under heterogeneous environmental conditions in free water surface CWs with the highest activity and copy number at submerged and vegetated sites immediately adjacent to the inflow source (Waki et al., 2015). Variation in the metabolic function of microbial communities was influenced by system design and sample locations instead of plants or depth of media in SSFCW (Button et al., 2015).

Gas emission and seepage are two important concerns for wetland applications. Carbon and nitrogen gaseous emissions from CWs provide fingerprints for microbial wastewater treatment process in CWs, and the amount of gas emission will differ with the existence of plants and different hydraulic loading rates (Bateganya et al., 2015). A study found that livestock enteric fermentation was the main source for CH_4, while livestock manure management and crop residue burning were the major source of N_2O, NH_3, and NO_2^- from wetlands (Gurjar et al., 2015). Methane emission rate was increased significantly under lower redox conditions and higher organic loading rates (Corbella and Puigagut, 2015). Another study also showed similar methane production in a HSSF-CW planted with *Phragmites australis* (1455 ± 482 mg $CH_4/m^2 \bullet d$) and *Schoenoplectus californicus* (1305 ± 27 mg $CH_4/m^2 \bullet d$) (Lopez et al., 2015). In addition, another study revealed that the nirS gene of the Anammox-specific gene could be related to both denitrification and ANAMMOX processes producing N_2 in wetland soils (Ligi et al., 2015). Seepage of nitrate from wetlands does not necessarily pose risk to groundwater contamination since the soil has higher nitrate removal via denitrification (Brauer et al., 2015). There is concern about microbial contamination when recycling and reusing the treated domestic wastewater. However, a study showed that it was safe to grow crops with CW treated flow (Almuktar and Scholz, 2015).

Besides the benefit of CW in wastewater treatment, CWs could sustain wildlife habitats and biodiversity at local and global scales, as well as its potential usage in recreational and educational opportunities (Semeraro et al., 2015). On the cost aspect, it was shown that the cost effectiveness of the SFCW was higher in the drainage catchments with higher nutrient loads (Gachango et al., 2015). Natural wetlands degradation has been a serious global issue (Chen and Liu, 2015). Water scarcity, changing biodiversity and human intervention are the most common threats to wetlands (Chatterjee et al., 2015). Fuzzy Analytic Network Process (FANP) was able to assess the relative importance of different factors responsible for preservation and restoration of ecological balance of natural wetlands.

Innovative & Hybrid Wetlands

Innovative design and operation of CWs have significantly increased CW system’s performance. Techniques for enhancing performance in CWs includes use of towery hybrid CW system, artificial aeration CW, baffled CW, microbial fuel cell CW, electrolysis-integrated CW, and biological reactor-combined CW (Wu, Zhang, et al., 2015). A study showed that using an electric fan blower for the hybrid VF-HF CWs enhanced the sewage treatment efficiency for BOD, TN and TP (Lee et al., 2015). Baffled HSSF-CW achieved 100% azo dye Acid Orange 7 removal against 73% for conventional CW at HRT of 5 days due to the benefit of multiple aerobic, anoxic, and anaerobic conditions sequentially (Tee et al., 2015).

Hybrid CW systems made up of a series of VFCWs and HFCWs provide efficient removal of organic matter, nutrients (Vymazal and Kröpfelová, 2015; Zhang, Tan and Peng, 2015), and emerging contaminants (Avila et al., 2015; Herrera-Melian et al., 2015). 12 hybrid SSCWs (VF-VF-HF CWs) in Japan showed 90% removal of COD, BOD, and SS in cold climates through six years of operation (Harada et al., 2015). One study showed that a HSSF-VSSF CWs system achieved over 95% of organic matter removal and over 90% of nitrogen removal, where HSSF-CW mainly reduced organic matter and supported denitrification while VSSF-CW provided nutrient removal (Ayaz et al., 2015). HF-HF CWs utilizing a combined sulfur-based autotrophic and heterotrophic denitrification improved the nitrate removal compared to the conventional CWs with only heterotrophic denitrification process (Park et al., 2015). Substrate material palm kernel shell in two-stage VFCWs was more effective than sand in nitrate removal (Jong and Tang, 2015). Zurita et al. (2015) compared three two-stage hybrid CWs and concluded the HF-VF system was more effective in total coliforms removal than VF-HF and HF-stabilization pond systems. Zapater-Pereyra et al. (2015) evaluated three different configurations of hybrid CWs with VFCW on top of a horizontal flow filter. Results suggested that "fill and drain" configuration performed better than "stagnant batch" and "free drain" configurations for COD, TSS and total phosphorus treatment.

Doherty, Zhao, Zhao, Hu et al. (2015) conducted a state-of-the-art review on recently emerged CW-microbial fuel cells (CW-MFC) technology. In a recent study by Wu, Yang et al (2015), the CW-MFC achieved 91.2% of COD removal and 95-99% of nutrient removal along with satisfactory electricity generation. Doherty et al. (2015b) cross-compared the effects of electrode spacing and flow pattern on the treatment efficiency and power production of the CW-MFC systems. They suggested placing the cathode at the air-water interface and burying the anode at a depth of 0.4 m (Doherty et al., 2015a), and use simultaneous upflow (to anode)-downflow (to cathode) regime in order to boost power production density by 70% and ammonium and phosphorus removal to 75% and 85%, respectively. However, this operation strategy would decrease the COD removal efficiency to 64% compared to the 80% by the continuous upflow regime; while Corbella and Puigagut's (2015) study on the operation, design, and microbial aspects of CW-MFC revealed that the power production pattern was correlated well with water level fluctuations within the wetlands. Srivastava et al. (2015) found that closed circuit operations of CW-MFCs performed 12-20% better than the open circuit operation and 27-49% better than conventional CW as well as maximum power production (power density of 320.8 mW/m^3 and current density of 422.2 mA/m^3) using a granular graphite anode and a Pt coated cloth cathode. Fang et al. (2015) studied the effect of HRT, reactive brilliant proportion and COD concentration on the electricity production of CW-MFC system. Results showed that power density decreased with increasing reactive brilliant proportion and was highest at an HRT of 3 days and a COD concentration of 300 mg/L. The power production was also found to be associated with the complex structure of bacterial and plant communities (Lu et al., 2015). Wetser et al. (2015) achieved 10 times more electricity generation from *Spartina anglica* salt marsh than *Phragmites australis* peat soil based CW-MFC. It is a promising technique; however, there are still challenges of increasing the electrical output and overcoming the limited nitrification and denitrification in the CW-MFC system (Doherty, Zhao, Zhao, Hu et al., 2015).

Liu, Zhao et al. (2015) reviewed incorporation of constructed wetlands with other treatment processes such as MBR (membrane bioreactor) process, anaerobic processes, electrolysis, and biofilm reactor. One study showed that SSFCW followed by anaerobic stabilization ponds system had significant removal of BOD, COD, and TSS; and it was more efficient in TSS and nutrient removal than classic systems (Gholizadeh et al., 2015). An oxidation pond-CW integrated system showed effective reduction of COD, BOD and bacteria from Pig-slaughterhouse wastewater (Pitaktunsakul et al., 2015). A CW with an attached microbial growth Bio-hedge system enhanced the stability and performance in organic matter and nutrients removal with 33-67% lower HRT compared to conventional CW (Valipour et al., 2015). A double-layer biofilter-combined CW improved the removal efficiency of COD, TN, and especially TP, of which 74.7% was removed by interception of carbon-rich ceramic and 25.3% by plant uptake (Jing et al., 2015). The aerated gravel-packed contact bed with a CW system showed high pollutant removal efficiency due to the enhanced organic and nutrient removal in the contact bed (Lin et al., 2015).

Onsite Treatment

Wastewater discharged in rural areas has been a challenge because of inadequate infrastructure. Decentralized wastewater treatment systems are the most affordable and appropriate systems for rural and disadvantaged areas (Ghorpade and Sonawane, 2015). A CW is an attractive treatment method at small/single household levels and in community levels due to its effectiveness in pollutant removal with simple operation (Arunbabu et al., 2015). In addition, the CW assisted reuse system for a rural community improved the stability and resilience of water supply compared to the reuse system alone (Li, Chen, Su et al., 2015).

A HSSFCW is the most widely used system for onsite treatment. Studies showed promising results to scale-up a laboratory scale HSSFCW with *Axonopus compressus* to treat greywater with an average 95% COD, 98% of NO_3^--N, 67% PO_4^{3-}-P, and 95% anionic surfactants removal (Arunbabu et al., 2015). In another case study, HSSFCW was applied to treat greywater in a Moroccan primary school, and an acceptable level for BOD, COD, TN, and TP concentration was achieved (Laaffat et al., 2015). Treated wastewater outflow from HSSFCW following septic tanks could be sufficient for garden irrigation (Saad et al., 2015). Tan et al. (2015) reviewed the septage treatment using VFCW, and concluded that the substrates and operation factors such as solids loading rate were major factors governing treatment efficiency. Wu, Fan, Zhang, Ngo, Guo, Hu et al. (2015) revealed that intermittent aeration was an appropriate operation strategy for enhancing organic pollutants and nitrogen removal in VFCW. Another study (Yu, Bill et al., 2015) showed a semi-batch VFCW could reduce the pollutants (BOD, TSS, and turbidity) level to below regulatory limits, thus the semi-batch VFCW design was feasible for onsite residential greywater treatment.

Osmanaj et al. (2015) discussed the potential of CWs for wastewater treatment in rural areas in Kosovo with combination of 1st stage VFCW and 2nd stage HFCW. A CW designed and built for a small single household reduced TSS by 61%, 26-51% E. Coli by 51% and total coliforms by 63% in kitchen greywater (Wurochekke et al., 2015). A CW with bio-preparation BIOSAN KZ 2000 provided high removal of organic compounds, ammonia nitrogen and phosphates for household sewage (Puchlik et al., 2015). Murphy et al. (2015) applied the aerated HSSFCW to treat wastewater from de-icing operations at an airport in the UK. The aerated hybrid system was capable of removing 3500 kg/day of BOD_5 at a flow rate of 40 L/s. A case study showed that integrated SSFCW planted with *Phragmites australis* worked well in degrading high concentration of pollutants including BOD_5, TSS, NH_4^+-N, and TP in wastewater on a university campus (Sudarsan et al., 2015).

Zhang, Jinadasa et al. (2015) compared different CW systems for wastewater treatment in developing countries with tropical and subtropical regions. It was concluded that the hybrid CW was more efficient in COD, TSS and nitrogen removal followed by VSSFCW, while HSSF had better performance in TP removal. Obarska-Pempkowiak et al. (2015) conducted a study to compare the performance of nine CWs with three configurations for single-family wastewater. Single VSSFCW with a larger unit surface area was better in BOD, TN and TP removal. Cui et al. (2015) compared the nutrient removal efficiency for septic tank effluent of three baffled CWs with the traditional HSSCW and suggested that the baffled hybrid CW is a better design with a maximum of 46% TN and 96% TP removal at an optimal HRT of 2 days.

Acknowledgement

Authors acknowledge the support of Department of Civil and Environmental Engineering and the Bagley College of Engineering at Mississippi State University.

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