

Constructed and Floating Wetlands for Sustainable Water Reclamation

Muhammad Arslan ^{1,*} , Muhammad Afzal ^{2,*}  and Naser A. Anjum ^{3,*}

¹ Civil and Environmental Engineering Department, University of Alberta, Edmonton, AB T6G 2R3, Canada

² Soil & Environmental Biotechnology Division, National Institute for Biotechnology and Genetic Engineering (NIBGE), Faisalabad 38000, Pakistan

³ Department of Botany, Aligarh Muslim University, Aligarh 202001, India

* Correspondence: marslan@ualberta.ca (M.A.); afzal@nibge.org (M.A.); naanjum1@myamu.ac.in (N.A.A.)

1. Introduction

Modern urbanized societies are facing serious challenges in the maintenance of their water resources. Anthropogenic activities result in the production of large quantities of wastewater, carrying a wide array of organic and inorganic pollutants. Most of these pollutants could successfully be removed using conventional remediation technologies; nevertheless, passive and minimally invasive treatment schemes are preferred, as per the sustainable United Nations guidelines (UN SDG6). Being a part of the sewage treatment infrastructure, this would alleviate a substantial economic burden on low- and lower-middle-income countries. Phytoremediation—the use of plants for wastewater reclamation—is one such ecotechnology that offers engineered solutions such as constructed wetlands (CWs) and/or variants, i.e., floating treatment wetlands (FTWs). One successful example is the field-scale application of FTWs, which effectively attenuated a large fraction of diverse organic and inorganic contaminants, with as low as US\$0.0026/m³ of wastewater in Pakistan [1].

2. The Concept

CWs are modern variants of *Rieselfeld* (German: sewage trickle fields) systems, which were introduced by German social reformers in 1891. In *Rieselfeld*, effluent is trickled over gravel or water-permeable soil and degraded by microflora within the substrate [2]. Later, in the 1950s, Dr. Käthe Seidel (a German limnologist) developed a hybrid system for the faster treatment of municipal wastewater by introducing vegetation/plants in the filtering bed [3]. In these systems, multiple horizontal and single vertical seepage beds were used, along with gravel as a substrate, which were further vegetated with marsh plants (i.e., lakeshore bulrush, *Schoenoplectus lacustris*). These systems were recognized as *Pflanzenkläranlage* or “plant-based sewage treatment systems”; these inspired the terminology of the “constructed wetland”. As of today, several CW and FTW variants have been engineered to harness the synergistic interactions among plants, microbes and substrates for the treatment of various contaminants from the water bodies. At first, the application of CWs and variants (FTWs) was limited to municipal and/or domestic wastewater treatment. However, modern research has expanded the scope of this ecotechnology to treat wastewater of variety of origins, i.e., stormwater, industrial water, landfill leachates, mine wastewater, and polluted river water [1,4].

3. The Appraisal

This Special Issue ‘*Constructed and Floating Wetlands for Sustainable Water Reclamation*’ compiles six research and three review articles showcasing the use of CWs and variants, for the treatment of wastewater in diverse environmental settings such as that of swine, textile, hydrocarbons, pharmaceutical, and agricultural origins.



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Swine breeding farms are major contributors to the production of swine wastewater (SW) that contains large fractions of urine, feces, antibiotics, pathogens, and residues of undigested food. The chemical oxygen demand and nutrient contents are tremendously high in SW, along with a large proportion of pharmaceuticals [5,6]. Hence, the direct discharge of untreated SW could negatively impact the biotic components of the receiving ecosystem [6]. In conventional settings, pre-treatment of SW is carried out in anaerobic lagoons for the degradation of organic matter, whereas CWs are used for the removal of nutrients [7]. However, in the absence of pre-treatment schemes, the performance of CWs is not efficient for the complete depuration of livestock wastewater. Given this, Denisi et al. (<https://doi.org/10.3390/su132212390> (accessed on 20 December 2021)) showed that both aerated and non-aerated lagoons, when combined with CWs (plant: *Typha latifolia* L.), improve the depuration-efficiency of SW at the pilot-scale. This system attenuated ~99% of organic matter and total suspended solids, along with 80–95% removal of total nitrogen. The study could provide a starting point to establish similar treatment systems for the effective treatment of livestock wastewater at an impaired C/N ratio.

The agriculture sector heavily relies on agrochemicals such as pesticides, herbicides, fungicides, and hormones, to achieve higher yields and feed the burgeoning world population [8]. As a result, agricultural runoff carries a large proportion of nutrients, suspended solids, pesticides, veterinary medicines, pathogens, and potentially toxic metals. To this end, Tang et al. (<https://doi.org/10.3390/su132413578> (accessed on 20 December 2021)) highlighted CWs as a panacea for the effective treatment of various contaminants in agricultural runoff. This review article proposes CWs as an innovative solution to mitigate the emerging negative environmental impacts of agricultural intensification.

In recent years, self-buoyant hydroponic root mats have received tremendous attention to reclaim wastewater in open systems, i.e., lagoon, pond, lake [9]. The enrichment of specialized microorganisms along with appropriate choice of macrophytes could greatly enhance the remediation potential of FTWs. To this end, Nawaz et al. (<https://doi.org/10.3390/su12093731> (accessed on 20 December 2021)) reported that the bioaugmentation of plant-growth-promoting and pollutant-degrading bacteria efficiently removed a variety of pollutants from textile wastewater. Further, the high persistence of inoculated bacteria in the water, root interior, and shoots interior of the wetland plant was positively correlated with the performance of FTWs. The proliferation of rhizospheric and endophytic bacteria efficiently reduced the total dissolved solids, total suspended solids, chemical oxygen demand, biochemical oxygen demand, electric conductivity, color, and toxic metals from the dye-polluted wastewater. Additionally, the plant's growth was improved, and toxicity was alleviated from the textile effluent, which ultimately promoted the plants' ability to tolerate pollutant-induced toxicity. Accordingly, Fahid et al. (<https://doi.org/10.3390/su12062353> (accessed on 20 December 2021)) reported that the synergism of plant- and hydrocarbon-degrading bacteria could improve the remediation of diesel oil from the contaminated water in FTWs.

Sodium dodecyl sulfate (SDS) is a commonly found anionic surfactant in detergents and is extensively applied in various sectors [10]. The direct discharge of these wastewaters without pre-treatment may have harmful effects on biotic elements, particularly the aquatic life [11]. The adoption of conventional and unsustainable methods (i.e., coagulation, filtration with coagulation, adsorption, ion exchange, ozonation, reverse osmosis) may achieve sufficient removal of pollutants; nevertheless, these methods are also known to produce secondary pollution by generating toxic sludge [12,13]. Here, Yasin et al. (<https://doi.org/10.3390/su13052883> (accessed on 20 December 2021)) inoculated a consortium of rhizospheric and endophytic bacteria in FTWs comprising two wetland plants. The system achieved a significant removal of sodium dodecyl sulfate (97.5%) concentration in the contaminated water. The authors argued that plant-bacteria synergism provided a congenial environment for the survival and proliferation of inoculated bacteria within the plant tissues for necessary catabolic functioning.

Significantly higher concentrations of acetaminophen (N-acetyl-p-aminophenol, ACE) were reported in the influents and effluents of sewage treatment plants [14]. This has raised serious concerns for natural aquatic ecosystems [15]. One example is the disturbance of mangroves ecosystems, which are known to sink pollutants in tropical and subtropical regions [16]. The sediments in mangroves can accumulate high concentrations of nonylphenol, polycyclic aromatic hydrocarbons, sulfonamides, which could be degraded with the microbial action [17,18]. The application of ACE-degrading bacteria and white-rot fungus appeared to be a promising approach for ACE removal from the aquatic environment [19,20]. Yang et al. (<https://doi.org/10.3390/su12135410> (accessed on 20 December 2021)) achieved the successful removal of ACE in mangrove sediments by adding microcapsules, ACE-degrading bacteria, and electron acceptors (Na_2SO_4 , NaNO_3 , and NaHCO_3). To this end, the best ACE-degradation was reported with the addition of NaNO_3 . It was further reported that the addition of an electron acceptor could enrich sixteen microbial genera, which are primarily involved in the anaerobic transformation of ACE.

4. Conclusions and the Way Forward

A thorough understanding of different wetland variants and their working principles is crucial in the customized treatment of wastewater of multiple origins. The major outcomes of the discussion in the research and reviews of this Special Issue may provoke future studies on the subject and help governmental bodies and/or industries to cost-effectively treat wastewater and meet discharge standards. Furthermore, by employing these ecotechnologies, the accumulation of toxic chemicals in the food chain can be reduced, and the local population can be protected against the potentially toxic effects of organic and inorganic pollutants. This approach can also be applied to promote the sustainable production of bioenergy crops, in conjunction with the remediation of municipal effluents. The plant biomass may also be used as wood fuel, especially in the villages and towns, which could greatly reduce the cutting of trees for fuel in underprivileged societies. Last but not least, public, farmers, industrialists, traders, exporters, and commercial entrepreneurs could directly benefit from the useful aspects of CWs and FTWs that are highlighted in this Special Issue.

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