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Significance of Constructed Wetlands for enhancing reuse of treated effluent

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ABSTRACT

Natural treatment systems are quite effective in the treatment of biodegradable organic pollutants. Constructed wetlands (CWs) are a class of natural treatment systems which have a potential in contributing towards sustainability since they return nutrients to the environment and do not consume energy as well. They can also be incorporated in peri-urban and rural landscapes quite easily. The important criteria for categorizing constructed wetlands include hydrology (open water surface and subsurface flow), flow path (vertical and horizontal) and type of macrophytic growth of plants. One practical example is a constructed wetland installed in the Katchpua slum in Agra city where the treated effluent was used for the irrigation of grass fields. The removal of conventional pollutants has already been widely studied. However, the removal of emerging pollutants is also important for reuse of treated effluent from urban sewage streams. The emerging pollutants include pharmaceuticals, pesticides and other micropollutants. This review paper describes the application of constructed wetlands which were involved in the effective removal of both conventional and emerging pollutants along with some suitable modifications required to improve its effectiveness..

1 Introduction

In today's context, the number of challenges associated with the disposal of treated sewage and effluents has increased multi-fold. Nearly all communities are thriving to have potable as well as processed waters. It is therefore suggested that the newer solutions should be such that the small and peri-urban communities should be able to operate their wastewater treatment systems.

A class of sewage treatment technologies that mimics natural processes such as interaction of soil micro-organisms with pollutants as well as the interaction of plants and other life in natural settings with pollutants in wastewaters are called as natural treatment systems (NTSs). The engineered NTSs render quite effective environmental services in two ways: (a) by treating biodegradable carbonaceous pollutants and (b) by separating particulates load [1]. These treatment systems typically include constructed wetlands (CWs), waste stabilization ponds (WSPs), hyacinth and duckweed ponds, sewage fed aquaculture ponds, oxidation ponds, algal-bacterial ponds, lemna ponds and polishing ponds. These systems have attracted the attention of environmental engineers by the virtue of treating sewages and wastewaters at phenomenally low operation and maintainance costs as well as rendering a high degree of treatment. In India, the climatic conditions and land availability also play an important role in selection of NTSs as an appropriate technological solution for cost effective wastewater management.

The phyto-remediation based sewage treatment facilities were popular for the decentralized treatment among the rural and peri-urban communities in the population range 2000– 40000. These systems were also found to be efficient in the removal of faecal coliforms as well.

Constructed wetlands (CWs) are among the attractive options for reuse of treated wastewater due to lower cost as well as lower operation and maintainance requirements. They can be effective for removing both conventional and emerging pollutants from wastewater. The removal of conventional pollutants can be investigated primarily from BOD_5 and COD removals whereas the removal of emerging pollutants can also be investigated primarily from the removal of pharmaceutically active compounds (PhACs), antibiotic resistance bacteria (ARBs) and antibiotic resistance genes (ARGs). An urban community in Jaipur is well known for using constructed wetland as a tertiary treatment option of the secondary treated sewage (capacity ~ 8 MLD) generated by a wider population (~ 125000) [1]. It also acted as a promising tertiary treatment for removal of PhACs and ARGs in lab scale [2] and field scale [3]. This review paper describes the application of constructed wetlands involved in the removal of both conventional and emerging pollutants with three field scale case studies. It provides an insight about the factors affecting the sustainability of constructed wetlands as well. It also provides a future outlook to improve the effectiveness of constructed wetlands for wastewater treatment.

2 Constructed Wetlands and Categorization

2.1 Definition

Constructed wetlands (CWs) are engineered wetlands which are designed and constructed to mimic natural wetland systems for wastewater treatment. These systems are mainly composed of soils, substrates, vegetation, microbes and water. These systems utilize complex processes involving physical, chemical and biological mechanisms to remove various contaminants or to improve water quality [4].

2.2 Categorization

Constructed wetlands (CWs) may be categorized according to various design criteria. The three important design criteria include hydrology, flow path and type of macrophytic growth [4]. According to hydrology, they are classified into free water surface (FWS) and subsurface flow (SSF) CWs. Based on the flow direction, SSF CWs can be classified into vertical flow (VF) and horizontal flow (HF) CWs. The categories of CWs also depends on type of macrophytic growth (submerged or emergent or free floating plants).

A combination of various wetland systems, known as hybrid CWs was also introduced for the treatment of wastewater. This design generally consisted of two stages of several parallel CWs in series, such as VF–HF CWs, HF–VF CWs, HF-FWS CWs and FWS-HF CWs. The multi-stage CWs that were comprised of more than three stages CWs were also used. In recent years, to intensify removal processes of CWs, enhanced CWs such as artificial aerated CWs, baffled flow CWs, hybrid towery CWs, step feeding CWs and circular flow corridor CWs have been proposed to enhance the performance of systems for wastewater treatment [5].

3 Case Studies

3.1 Constructed wetland in Agra, India

In the city of Agra, the construction of a wetland facility was done in a Katchpua slum as a part of Crosscutting Agra Program (CAP) for low income communities [1]. The capital cost was 1.1 million INR whereas annual operation and maintainance costs were 70000 INR. The aim of the program was to improve the sanitation conditions in urban slums. This facility treats approximately 0.05 MLD of sewage by diverting a part of the flow generated by the five clusters of slums conveyed through an open gutter passing through the community. The system comprises a good primary treatment comprised of the screen chamber and primary settling chamber. It is followed by secondary treatment comprising of nine chambered baffled anaerobic reactors packed with gravel. The hrdraulic retention time of this treatment facility has been maintained at nearly 2.5 d (or 60 h).

Subsequently, the anaerobically treated secondary effluent is subjected to constructed wetland bed for tertiary treatment. The bed is filled with three different types of packing material (media) having the bottom most layer of river pebbles and red stone overlain with a layer of white river pebbles. It is planted with *Canna indica* vegetation. The local community of Katchpua uses the treated effluent for irrigation of grass fields which act as fodder for animals. The performance of the system was found to be satisfactory in terms of pollutant removal and with respect to the regulatory parameters. The treatment system is being properly operated and maintained by local people appointed for operation and maintainance. The seasonal performance with respect to the mass removal rate in the parameters of constructed wetland has been summarized in Table 1. The comparative mass removal rates of BOD_5, COD and TKN were found to be higher in the summer season as compared to winter and rainy seasons.

Table 1

Mass removal rate (kg/day) in parameters of constructed wetland in Katchpua slum, Agra [1]

Parameter	Winter season	Summer season	Rainy season
BOD (mg/L)	10.5	12.75	7.5
COD (mg/L)	15	21	13.75
TP (mg/L)	0.085	0.12	0.18
TKN (mg/L)	0.4	0.53	0.45
TSS (mg/L)	9.5	9.75	6

3.2 Constructed wetland in Kaihui of Hunan province in South China

The performance of integrated constructed wetland (ICW) to treat rural wastewater fraom a small village in Kaihui of Hunan province in South China was evaluated [3]. The plant species used was *Myriophyllum verticillatum L*. The removal rates of the various parameters (BOD_5, NH_3-N, TN and TP) in the ICW system ranged between 81 – 100% whereas COD removal was found to be only 65%. The removal of various antibiotics (Ofloxacin, Lincomycin, Leucomycin, Sulfamethazine, Trimethoprim and Sulfamonomethoxine) was in the range of 78 – 100% in the ICW system. However, the removal of the other antibiotics (Sulfadiazine, Sulfacetamide and Salinomycin) was found to be in the range of 10 – 25% only. The removal of various ARGs (intI1, intI2, sul1, sul2, sul3, tetM, tetO, tetX, tetB/P, erm B, erm C) was in the range of 83 – 100%. However, the removal of ARG ermC was found to be only 43%.

The pollution loading of antibiotics in the influent to the ICW was 3479 μg/day whereas the pollution loading to the receiving environment (a small river) was 199 μg/day. The individual mass loadings of the various antibiotics in the influent and effluent are shown in Table 2. Lincomycin (87 μg/day) was the main antibiotic detected in the effluent to the receiving environment. It was suggested that integrated constructed wetland could be applied as an important treatment technology for the removal of antibiotics and ARGs.

Table 2

Mass fluxes of antibiotics in wastewaters of integrated constructed wetland [3]

Antibiotic	Influent mass flux (µg/day)	Effluent mass flux (µg/day)
Ofloxacin	1255	n.d.
Lincomycin	395	22
Erythromycin	289	87
Leucomycin	784	40
Sulfamethazine	352	18
Sulfamonomethoxine	330	n.d.

n.d.= not detected.

3.3 Constructed wetland in Land van Cuijk (L), Hapert (H), and Kaatsheuvel (K) in the Netherlands

The performance of constructed wetlands acting as tertiary treatment to attenuate PhACs and ARGs for wastewater treatment plants (WWTPs) in Land van Cuijk (L), Hapert (H), and Kaatsheuvel (K) in the Netherlands was evaluated [6]. The constructed wetlands in Land van Cujik (CW-L) and Hapert (CW-H) were free water surface CWs whereas the constructed wetland in Kaatsheuvel (CW-K) was vertical subsurface flow CWs. The plant species used was *Phragmites australis*.

14 pharmaceutically active compounds (PhACs) (i.e. Ketoprofen, Diclofenac, Ibuprofen, Naproxen, Erythromycin, Lincomycin, Sulfamethoxazole, Propranolol, Metoprolol, Clofibric acid, Carbamazepine, Caffeine and Bisphenol A) and 3 ARGs (i.e. *sul1*, *sul2* and *ermB*) were detected in the wastewater samples. Among the detected PhACs, erythromycin, sulfamethoxazole, propranolol and metoprolol were highly removed (i.e. >75% removal) whereas diclofenac, naproxen and lincomycin were moderately removed (i.e. 30 – 60% removal). The median removal of PhACs in CW-K was 50% approximately whereas the median removal of PhACs was negligible in CW-L and CW-H. The removal of the absolute concentrations of all the ARGs was in the range of 14 – 95% for CW-L whereas it was in the range of 57 – 100% for CW-K. In addition, 70% removal of *ermB* was observed for CW-H.

4 Sustainability of Constructed Wetlands

For ensuring sustainability of constructed wetlands, a proper attention must be paid to both plants and substrates selection. The wetland macrophytes and substrates are critical for sustainable pollutant removal from wastewaters in constructed wetlands [5]. Some important considerations for selecting macrophytes include large biomass production, rich supply of oxygen and carbon compounds, high uptake of pollutants (both conventional and emerging pollutants) and tolerance of high pollutant loadings. An additional modification can be the use of non-conventional wetland media (industrial byproducts and agricultural wastes) which have high sorption capacity and may prove to be beneficial to the removal processes. The optimal treatment performance of the constructed wetlands largely depends upon the environmental, hydraulic and operating conditions. Some important parameters include water depth, loading rate and hydraulic retention time. An understanding of the key pathway and mechanism involved in higher pollutant removal in constructed wetlands may be equally essential. Some novel performance enhancement strategies include artificial aeration, step feeding, external carbon addition, microbial augmentation and combination of various substrates. Some management strategies include appropriate plant harvest strategies as well as well as recycling and reclamation of plant resources in constructed wetlands. These strategies may prove to be beneficial in sustainable water quality improvement.

5 Conclusions and Future Outlook

The balance of basic eco-characteristics, low operational costs, easy maintainance along with treatment capacity remain an important consideration for application of constructed wetlands. Wetland vegetation is an indispensable component of constructed wetlands since the plants play a significant role in treatment processes as well as ancillary functions such as biodiversity and food chain support. On one hand, the intensification of constructed wetlands improves the treatment capacity and results in lower footprint of the systems. On the other hand, the intensification strategies such as forced pressurized aeration may make the role of plants less or non existent.

The microbial communities in constructed wetlands may be important for the degradation of emerging pollutants. However, the role of various microbial communities may be weakened or lost under the intensified treatment. There is a possibility that the high microbial diversity may also be undermined in intensified constructed wetlands. Some intensifications may be suitable for constructed wetlands but operation and maintainance issues as well as the natural character must be the priority. A general principle may be applied to the constructed wetlands: "Try not to over-engineer the system, design it with nature and not against it".

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