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REVIEW ARTICLE

CONSTRUCTED WETLANDS IN WASTEWATER TREATMENT

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ABSTRACT

Constructed wetlands are proven to be cost-effective, reliable, and alternative technology in treating wastewater because the implementation of conventional wastewater treatment methods in developing countries has higher operation and maintenance costs. It also reduces the disposal of waste into natural wetlands and helps in maintaining biodiversity. Constructed wetlands are called man-made wetlands and can be used for treating municipal wastewater, agricultural runoff, and mine drainage. Through this technique, biological oxygen demand and total suspended solids are effectively reduced. Land availability is one main limiting factor in the development of constructed wetlands, especially in regions where land resources are scarce or there is high population density. Design, operation, technical guidance, and maintenance are the factors to be considered in improving the sustainability of constructed wetlands. Further, new studies are required to gain long-term operational data, which in turn is helpful in the successful application of constructed wetlands for treating wastewaters.

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INTRODUCTION

A wetland is defined as land that transitions between terrestrial and aquatic ecosystems and has a water table at or near the surface or is covered by shallow water. Wetlands are important as they play a major role in treating wastewater. The plants in wetlands absorb nutrients and toxic substances, which results in the purification of water (Gopal, 1999). Further, natural wetlands improve the water quality of effluents received from conventional municipal wastewater treatment plants (Dordio *et al*., 2008). The usage of natural wetlands for wastewater treatment needs to be promoted as they have conservational value when compared to other systems (Verhoeven and Meuleman, 1999). Traditional centralized sewage treatment systems are more successful at controlling water pollution in developing countries (Li *et al*., 2014). The widespread application of conventional wastewater treatment technologies in rural areas is more expensive (Chen *et al*., 2014b). Hence, there is a need for a feasible technology for treating wastewater, especially in developing countries.

Constructed Wetlands: Constructed wetlands, or artificial wetlands, are regions created artificially for the purpose of waste water treatment, mimicking natural wetlands. The design consists of a shallow basin filled with different types of filter material called substrate, which includes sand, gravel, and planted vegetation to tolerate the saturated conditions arising due to the disposal of waste water. These constructed wetlands employ complex processes involving physical, chemical, and biological mechanisms that aid in the removal of contaminants in wastewater and the improvement of water quality (Vymazal, 2011). The performance of the wetlands for water purification depends on the loading rate (wastewater per area per time) and its specific hydrological and ecological characteristics. Even though it is not their primary purpose, constructed wetlands provide habitat for native and migratory wild life

(Verhoeven and Meuleman, 1999). In the last few decades, CWs have been put in place to treat various kinds of wastewater, such as domestic sewage, agricultural wastewater, industrial effluent, mine drainage, landfill leachate, storm water, polluted river water, and urban runoff.

Components of Constructed Wetlands: There are five components to a constructed wetland. 1) Basin; 2) Substrate; 3) Vegetation (primarily macrophytes); 4) Inlet; and 5) Outlet. Fig. 1 depicts the components of constructed wetlands (Kumar and Dutta, 2019).

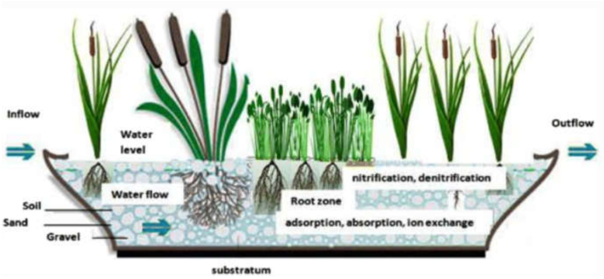

Fig. 1. Components of constructed wetlands

Primary Treatment: Untreated wastewater is loaded with suspended particulates that are heavier than water. Hence, primary treatment is necessary to reduce the suspended solids and organic load. In primary treatment, particulate matter is allowed to settle down, and the surface water moves on to the next component. Septic tanks and anaerobic baffle reactors are commonly used methods to carry out the primary treatment (UN -Habitat, 2008).

Septic tank: Septic tanks are most commonly used in small-scale constructed wetlands for primary treatment**.** For efficient removal of solids, two-compartment septic tanks are used instead of single-compartment tanks. A tank with a minimum capacity of 3700 litres provided with the inlet and outlet piping can serve as a septic tank. For effective operation of constructed wetlands, the desludging of septic tanks should be done periodically. This avoids the generation of poor effluents with high suspended solids content, which may cause clogging of constructed wetlands. Desludging of septic tanks can be done when the sludge and scum accumulation exceeds 30 percent of the tank's volume.

Anaerobic baffle reactor (IMPROVED SEPTIC TANK): An anaerobic baffle reactor is an improved septic tank design that enhances the removal efficiencies of solids and organic pollutants. The basic principle of such systems is to increase contact between the entering wastewater and the active biomass in the accumulated sludge. It is achieved by inserting baffles into the tank, which forces the wastewater to flow under and over the baffles. Wastewater flowing from bottom to top passes through the settled sludge and enables contact between the wastewater and biomass, thus improving the removal of organic load.

Inlet and outlet: Inlet and outlet structures are essential to distribute the flow path of effluent through the wetland, and also control the water depth. Multiple inlet and outlet can be planned to prevent dead zones. The inlet structure collects the wastewater from the septic tank, called the primary treatment system, and transports it to the constructed wetlands. The inlet structure must be designed in such a way that it helps to minimize the clogging of media and maximize even distribution. It facilitates the movement of greywater through the filter media, which allows the settlement of solids. Wastewater also comes in contact with bacterial populations present on the media surface, roots, and stems of macrophyte vegetation. It then reaches the outlet with better quality, and this can be reused. The outlet structure is designed to maximize even flow, to vary the operating water level and drain the bed. (Elzein *et al*., 2016).

Impermeable liner: Liners are used to line the wetland bed to prevent the percolation of wastewater into the ground water. Materials made of polyvinylchloride (PVC), high-density polyethylene (HDPE), or polypropylene (PPE) can be used as liners. These liners are impermeable, resistant to sunlight, or covered to protect them from UV degradation (Farooqi *et al*., 2008).

Substrate: The substrate physically supports biotic and abiotic components in the constructed wetland. It should be selected based on hydraulic permeability and the capacity to absorb pollutants (Sundaravadivel and Vigneswaran, 2001). The most commonly used substrate in constructed wetlands is coarse and fine gravel. In constructed wetlands, hydraulic conductivity should be maintained to stabilize the hydraulic retention time. Poor hydraulic conductivity and substrates with low adsorption capacity decrease not only the effectiveness of the system but also the long-term removal performance of CWs (Wang *et al*., 2010). Gravel, sand, clay, calcite, marble, vermiculite, slag, fly ash, bentonite, dolomite, limestone, shells, zeolite, wollastonite, activated carbon, and light weight aggregates are the most commonly used substrates. For the removal of nitrogen and organic compounds, alum sludge, peat, compost, and rice husk are desirable (Saeed and Sun, 2012). Wetland systems with fine and soil-based substrates have low hydraulic conductivity, whereas those with coarse sand- and gravel-based medium have higher conductivity. Sand, gravel, and rock are poor substrates for long-term phosphorus storage. Artificial and industrial products with high hydraulic conductivity are suitable alternative substrates for CWs. The selected industrial products include flyash, alum sludge, and oil palm shell, whereas synthetic product substrates include slag, activated carbon, lightweight aggregates, and compost (Wu *et al*., 2015).

Wetland vegetation

Criteria in selection of vegetation

The criteria for selecting wetland vegetation include

- Tolerance to waterlogged anoxic and hyper eutrophic conditions
- High absorption capacity
- Native species
- Growth of a massive fibrous root system. This will provide good oxygen carrying capacity and a maximum surface area for the microbial population.

Macrophytes frequently used in CW wetlands are emergent (*Phragmites* spp, *Typha* spp, *Scirpus* spp, *Iris* spp, *Juncus* spp. and *Eleocharis* spp), Submerged plants (*Hydrilla verticillata*, *Ceratophyllum demersum*, *Vallisneria natans*, *Myriophyllum verticillatum* and *Potamogeton crispus)*, Floating leaved (*Nymphaea tetragona, Nymphoides peltata, Trapa bispinosa and Marsilea quadrifolia*) and Free-floating plants (*Eichhornia* *crassipes, Salvinia natans, Hydrocharis dubia* and *Lemna minor)* (Rozema *et al*., 2016, Rahman *et al*., 2020).

CWs with floating and emergent macrophytes: The most commonly used floating macrophyte is *Eichhornia crassipes*. According to Patil *et al*., (2016), water hyacinth survives in high concentrations of nutrients and contributes to the significant reduction in metals and nutrients. Furthermore, it reduces pollutant load and improves water quality, with the final treated water suitable for agriculture, washing, gardening, planting, and any other domestic use.

Phragmites spp and *Typha* spp. are commonly used emergent plants in horizontal flow constructed wetlands for treating domestic and municipal wastewater (Vymazal, 2011). These emergent macrophytes reduce wind speed, support sedimentation and prevent resuspension, and provide the substrate for periphyton and bacteria that take up the nutrients (Vymazal, 2013).

Major role of macrophytes in Constructed Wetlands: The role of macrophytes in constructed wetlands is illustrated in a table (Brix, 1997)

Parts of wetland plant	Main role
Aerial plant tissues	• Light attenuation causes reduction in phytoplankton growth. • It provides insulation during winter. • Reduces wind velocity, allowing suspended solids to settle • Gives an aesthetic appearance. • Stores nutrients.
Plant tissues in water	• Filter out large debris. • Reduces current velocity, improving the rate of sedimentation and reducing the risk of resuspension of settled solids. • Increased surface area for microbial growth. • Increased aerobic degradation due to photosynthetic oxygen. • Nutrient uptake.
Roots and rhizomes	• There is a less soil erosion due to stabilization of sediments. • Increase in organic degradation and nitrification • Nutrient uptake and release of antibiotics

Classification of Constructed Wetlands: According to Nikolic *et al*., (2009), constructed wetlands can be classified into surface flow and sub-surface flow, as detailed below in fig 2.

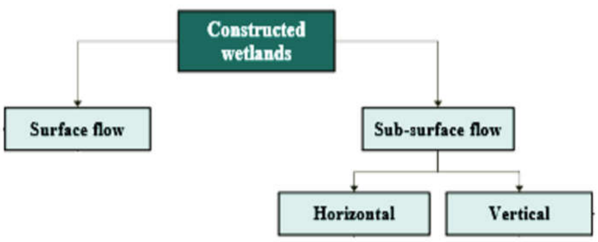

Fig 2. Classification of constructed wetlands

Surface flow: These wetlands are provided with shallow basin and barrier to avoid seepage to groundwater. This system has a suitable inlet and outlet structures for uniform distribution of wastewater and also supports the emergent vegetation include cattail, bulrush and reeds. In surface flow wetlands, waste water enters the basin and flows above the surface of the substrate. This system requires a larger land area when compared to other systems (Wetland, 2000).

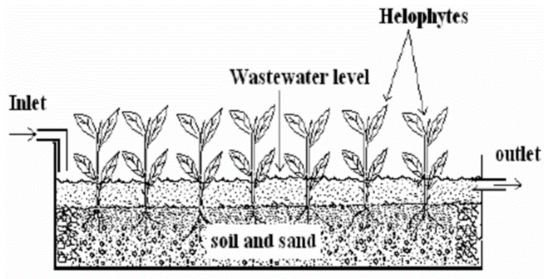

Fig no 3. Surface flow wetland (Choudhary *et al*., 2011)

In surface flow CWs, the pollutant removal (Vymazal, 2010) is achieved by

- Microbial degradation of organic material and settling of colloidal particles
- Suspended solids are removed through settling and filtration when flowing through dense vegetation.
- Nitrogen removal through nitrification.
- Higher pH values and algal photosynthesis cause ammonia volatilization.

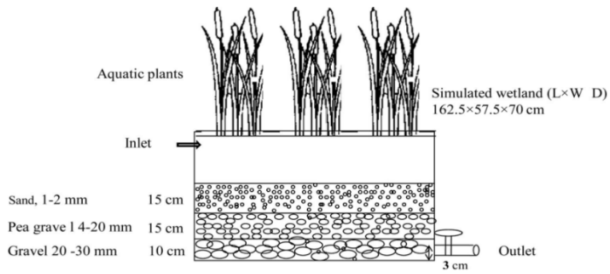

Fig. no. 4. Schematic diagram of Horizontal flow constructed wetlands (Upadhyay *et al*., 2017)

Subsurface flow wetland: A subsurface flow (SSF) wetland consists of a sealed basin with a porous substrate of rock, gravel, and soil, or a combination of these. The water level is designed to remain below the top of the substrate. It is most commonly used to reduce biochemical oxygen demand, chemical oxygen demand, suspended solids, metals, nitrogen, phosphorus, and pathogens from domestic and industrial wastewaters (Choudhary *et al*., 2011). According to the flow of wastewater, SSF CWs are further subdivided into two types: horizontal flow (HF) and vertical flow (VF).

Horizontal Flow (HF): In the horizontal flow CWs, wastewater moves under the surface of the bed in a horizontal path till it reaches the outlet zone where it has been collected and discharged. This system consists of gravel or rock beds sealed by an impermeable layer and planted with wetland vegetation (Fig. 4). HF CWs are used to treat domestic and municipal wastewater around the world. However, at present, HF CWs are used to treat many other types of wastewater, including industrial, agricultural, landfill leachate, and runoff waters.

In HF CWs, the pollutant removal is achieved by (Vymazal, J., 2010).

- Organic compounds are degraded by microbial degradation under anoxic/anaerobic conditions because the concentration of dissolved oxygen in the filtration beds is very limited.
- Suspended solids are retained by filtration and sedimentation.
- Nitrogen removal is by denitrification.
- Ammonia removal is limited due to insufficient oxygen in the filtration bed.
- P removal is usually low in HF CWs.

In horizontal wetlands, increased bacterial biofilm enhances treatment efficiency and biodegradation capacity. Plastic media have exhibited better performance in the reduction of pollutants than gravel and rubber (Zidan *et al*., 2015). Plants play an important role in the uptake and retention of different contaminants present in the water. The presence of *Typha domingensis in* horizontal flow wetland enhances the efficiency of the system and also contributes to the removal of phosphorus, organic matter, and nitrogen present in the wastewater. The final effluent from this technique improves the water quality and could be an alternative for treating tertiary wastewater (Schierano *et al*., 2020).

Vertical Flow: Vertical flow constructed wetlands (VF CWs) are provided with substrates like coarse sand or fine gravel (60 to 100 cm deep) and planted with aquatic vegetation (Fig. 5).

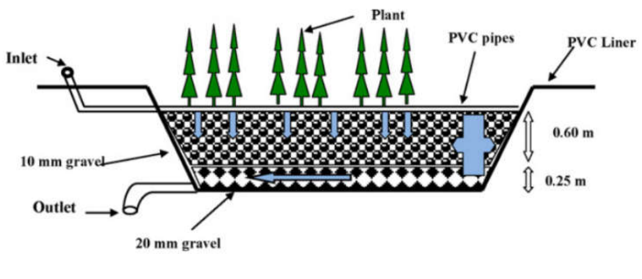

Fig no. 5. Layout of a vertical flow constructed wetland system (Abou Elela and Hellal, 2012)

The water is fed in large batches and the water percolates through the sand medium. The new batch of water is introduced only when all the water has percolated and the bed is free of water. This enables the diffusion of oxygen from the air into the bed. It also provides good oxygen transfer, and hence nitrification occurs. Higher organic removal was achieved in vertically constructed wetlands. In addition to this, it is also effective in removing organics and suspended solids, and media with high sorption capacity are used for the removal of phosphorus (Tsihrintzis, 2017). Abdelhakeem *et al*., (2016) showed that this method was efficient in removing different kinds of pollutant characteristics, including BOD, COD, NH_4, TSS, and TP, but ineffective in removing nitrates. It is often used to treat domestic and municipal wastewater, especially when discharge limits are set for ammonia-nitrogen. Vertical flow constructed wetlands with *Canna sp* and the substrates of gravel and sand were suggested as suitable techniques for treating secondary effluents. This treatment method offers high removal of nitrogenous compounds like nitrogen, ammonia, and nitrate. It also further reduces the microbes and organic matter from the wastewater and also provides an oxygenated environment (Sharma *et al*., 2014). Arivoli *et al*., (2015) reported that vertical flow constructed wetlands with aquatic plants like *Typha angustifolia, Erianthus arundinaceus, and Phragmites australis* were suggested as suitable methods for treating heavy metals from pulp and paper industry effluents.
This technology is eco-friendly, cost effective, and efficient in removing nutrient loads from wastewater. This has great potential in treating domestic and municipal wastewater and also offers low operation and construction costs. It is a feasible technique for treating wastewater, particularly in rural areas (Perdana *et al*., 2018 and Kulshrestha *et al*., 2020).

Constructed Wetlands for wastewater treatment in India: India is a developing country facing a burgeoning population, which leads to industrial growth and agricultural expansion. This has resulted in an increased demand for water. Contamination of groundwater due to partially treated and untreated wastewater from urban settlements, industrial establishments, etc. causes an increase in water demand and results in the generation of waste. Currently, in India, 1.3 billion people's wastewater is untreated and released into the environment, or it is reused in agricultural irrigation without treatment. Constructed wetlands in rural India have the potential to reduce disease and environmental degradation. The conventional methods adopted in developing countries to treat the generated waste include septic tanks, oxidation ponds and ditches, activated sludge processes, anaerobic systems, and trickling filters. The operation and maintenance cost for a typical sewage treatment plant is very high, which makes developing countries search for other suitable techniques for treating wastewater. As a result, constructed wetlands find application in developing countries due to their low operation and maintenance costs (Arceivala and Asolekar, 2012). For improving the sustainability of constructed wetlands, three factors should be considered: 1) Design and operation; 2) Upkeep; 3) New technologies. Further, new studies are required for successful application and to maintain the sustainability of constructed wetlands (Gorgoglione and Torretta, 2018). India's first constructed wetlands were constructed at Sainik School, Bhubaneshwar, Orissa. The bottom was lined with a polyethylene sheet filled with 30% soil, 70% sand and planted with *Typha latifolia* and *Phragmites carca*. The constructed wetlands in this area showed significant removal of BOD, nitrogen, and phosphate from the wastewater with a percentage of 65-75%, 30-50%, and 75-85%, respectively. *Phragmites carca* was efficient in the removal of N when compared to *Typha latifolia* (Juwarkar *et al*, 1995). Horizontal flow constructed wetlands were implemented in the EPCO at Ekant Park and Ujjain Charitable Trust Hospital and Research Centre in Madhya Pradesh. This system showed good removal of COD (77%), TSS (79%), and coliform bacteria (99%) (Vipat *et al*., 2008) and also showed significant removal of BOD (75%), TSS (78%), and NH4 (68%) (Diwan *et al*. 2008). The degradation of a high concentration of waste was achieved after treating domestic wastewater in horizontal sub-surface flow constructed wetlands planted with *Phragmites spp. and Typha spp.* These wetlands mainly act as biological filters and significantly reduce BOD, COD, TSS, and organic nitrogen (Sudarsan *et al*., 2014). Shukla *et al*., (2021) concluded that horizontal sub-surface constructed wetlands contributed to the significant removal of various physico-chemical and biological parameters.

Sudarsan *et al*., (2015) stated that constructed wetland can act as a better eco-friendly method and it can be used for commercial biological treatment of wastewater with average removal efficiencies of 75.99 % for BOD, 76.16 % for COD, 57.34 % for TDS, 62.08 % for Nitrate, 58.03 % for Phosphate, and 57.83 % for Potassium. The Ganga, an important river system in India, gets deteriorated due to direct discharge of sewage into the river without any kind of treatment, contributing to 75% of the river pollution (Rai *et al*., 2013). Constructed wetlands play an important role in removing high loads of nutrients and other pollutants efficiently from the sewage water, with an increase in DO levels from nil to 4.71 mg/l at 36 h followed by a 90% reduction in BOD. Thus, constructed wetlands act as an eco-friendly system to treat sewage water before discharging it into the Ganga river. The concept of constructed wetlands has been successfully implemented in urban regions of India by the joint initiative of the European Commission and the Indian government (DST) under the project of SWINGS (Safeguarding water resources in India with green and sustainable technologies). Under this project, constructed wetlands were setup at Aligarh Muslim University (AMU), Aligarh, Uttar Pradesh, at Indira Gandhi National Technical University (IGNTU), Amarkantak, Madhya Pradesh, and Kalyani University, Kalyani, West Bengal. Seeing the success of SWINGS in its projects, the Indian government has also taken an initiative for the development of constructed wetlands in rural areas, especially regions along the ghats of the Ganga and Yamuna rivers (Khan and Khalil, 2017). Constructed wetlands are used for treating wastewater from dairy and heavy metal industries. Through this process, a high rate of disinfection can be achieved, and the effluent water can be used for agricultural purposes. But, this application suits well for grey water treatment when compared to black water because the biodegradation rate is much higher in greywater than in blackwater. The final treated water is used for irrigation and laundry purposes and reduces the dependence on freshwater usage by about 35% (Gupta and Khare, 2018). Constructed wetlands with aquatic plants like *Typha latifolia* and *Canna indica* were used for treating wastewater generated by households. This methodology was successfully implemented in Kothapally, Telangana. Total coliform bacteria were consistently reduced to about 80%, followed by a significant reduction in inorganic nitrogen (67%), COD (65%) and sulphate (60%). The treated water was finally used for irrigation in agricultural fields, which helped the farmers to cultivate additional crops and was also useful in generating income (Datta *et al*., 2021). This technology does not find widespread application in India due to a lack of awareness and local expertise in developing the technology (Friedrichsen *et al*., 2021), and there is a need for creating awareness among the general public and private sector to adopt this eco-friendly approach to treating domestic sewage in India.

CONCLUSION

A constructed wetland is an environmentally friendly and effective method for treating wastewater, particularly greywater or domestic wastewater. The nutrients present in the greywater include nitrate, nitrite, phosphate, ammonia, and the other physical-chemical characteristics of greywater, especially COD and BOD, are considerably reduced when greywater is treated in the constructed wetlands. The treated wastewater is used for domestic purposes, which includes watering of plants, lawns, and other recreational activities. For successful operation of constructed wetlands, certain components should be taken into account, including the type and loading rate of wastewater, substrate, vegetation, climatological, hydrological, and climatological factors. Proper monitoring and management are also a main factor needed for good operation of constructed wetlands. It is gaining popularity among the developing countries like India, since this technology offers a lowest operation and maintenance cost when compared to the other conventional methods for treating wastewater.

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