Various Types of Constructed Wetland for Wastewater Treatment - A Review

Arvind Kumar Swarnakar¹, Dr. Samir Bajpai², Dr. Ishtiyaq Ahmad³
1. Research Scholar, Department of Civil Engineering, National Institute of Technology Raipur, Chhattisgarh, India akswarnakar@nitrr.ac.in
2. Professor, Department of Civil Engineering, National Institute of Technology Raipur, Chhattisgarh, India
3. Assistant Professor, Department of Civil Engineering, National Institute of Technology Raipur, Chhattisgarh, India

Abstract. As per the World Health Organization 80% of wastewater is released to the environment without satisfactory treatment. Constructed Wetlands (CWs) are one of the natural wastewater (WW) treatment methods. CWs have been recommended as a low technology, low maintenance, low operation cost, and green technology wastewater treatment system. Many types of CWs are currently in use. This paper studies these different types based on the climate, area, base materials, temperature, contaminant removal efficiency, removal mechanism and physicochemical analysis of various wastewater parameters. It is found that wetlands are successful in removing organic matter – Biochemical Oxygen Demand (BOD₅), Chemical Oxygen Demand (COD) and suspended solids and nutrients – total Nitrogen (TN) and total Phosphorus (TP). CWs need to be studied as a promising solution not only for effective treatment of wastewater but also as an economical method to improve the fertility of soil. Further, the paper discusses the scope of future research in CW to further improve the wastewater treatment technology.

Keywords: Constructed wetland, soil, gravel, wastewater, treatment,
Hybrid Flow Constructed Wetlands (HyFCW). Most of the natural wetlands are Free Water Surface (FWS). Further subdivision is shown in fig.1. This paper briefly describes all types of CWs.

![Figure 1. Various types of wetlands](image)

### 2. Removal Mechanisms in Constructed Wetland

The main mechanism of treatment through CWs comprises biogeochemical transformation with solid and liquid separations. Macrophytes play a very important role in removing various types of contaminants. The removal mechanism by macrophytes is shown in fig. 2. Contaminants uptake by root zone involves rhizodegradation process by microbial activity. The heavy metals are reduced through phytostabilization. Plant enzymes break down the contaminants through phytodegradation. Plants and algae remove the contaminants from soil and sediments through phytoextraction. Plants release the contaminants from soil and sediments in atmosphere through phytovolatalization process [6, 7, 8, 9]. Removal of various contaminants involves various operations and process in CWs. Organic material (BOD) is removed by biological degradation, sedimentation, and microbial uptake – organic contamination including pesticides are removed by adsorption, volatilization, photolysis, and biotic degradation, suspended solids are removed by sedimentation and filtration, Nitrogen is removed by plant uptake, sedimentation, nitrification/denitrification, microbial uptake, volatilization, Phosphorus is removed by sedimentation, filtration, adsorption, plant and microbial uptake, pathogens are removed by natural die-off, sedimentation, filtration, UV degradation, adsorption, heavy metals are removed by sedimentation, adsorption by vegetation and substrate and plant uptake process.
2.1 Role of plants in CWs

Different types of CWs plants are – free floating, rooted floating, emergent, submerged, shrub and trees. Most commonly, emergent herbaceous plants are used in CWs. Phragmites, phragmites australis, cattail, reeds, vetiver grass, typha latifolia, water grass and canna indica are some wetland plants. Selection of plants depends on type of constructed wetland systems, substrates, type of wastewater, viability of local plants and temperature [11]. Soil organic matter plays important role in plant growth in HFCWs [12]. The vegetation density (numbers in per sq-m area) depends on available filter media area [5-11]. Due to easy availability, Typha latifolia is a common plant for CWs and it also generates the higher biomass.

2.2 Selection of wetland

Selection of the wetland depends on type of pollutants, material of substrates, local available vegetations, temperature, Hydraulic Retention Time (HRT= Volume (Area x Water Depth x Porosity) / Discharge) and Hydraulic Loading Rate (HLR) [10]. As per the United State Environmental Protection Agency (USEPA) performance of constructed wetland depends on depth of water, slope of ground, and flow velocity. Table 1, 2 and 3 shows the efficiency of the HFCWs with various vegetation, HRT and HLR. Geo physicochemical parameters of filter media are necessary parameters for selection of CWs [7-49].

3. Vertical Flow Constructed Wetland (VFCWs)

In VFCWs the wastewater in flow is above the substrate. The wastewater is treated through percolates in root zone. Higher concentration of polluted water can be treated by VFCWs. The major parts of the VFCWs are shown in figure 2. The inlet of influents flows either by pump or by gravity. Oxidizing of ammonia is done quite well by VFCWs hence used in food proceeding and landfill leachates as shown in previous studies by Kadlec R.H. & Wallace S.D. (2009) [4]. The removal efficiency of vertical flow CWs is shown in table 1. It is used for continuous flow and good n utrient removal as compare to organic matter. It is less capable of removing total dissolved solids. Water stagnation, mosquitoes and aquatic animals are the
problem with VFCWs. It has studied the textile waste with sugar bagasse and sylhet sand with plantation P.australis, D. sanderina and observed 79.2% BOD₅, 69.0-89.0% COD, 67.6-89.0% turbidity removal efficiency in VFCW [13]. It has been observed in pharmaceutical compounds in wastewater removal by pilot-scale VFCW by using scirpus grossus plants and sand, gravel as media. They practiced with different HRT (3, 4, and 5 days) and has been observed that 99% ibuprofen, 88% COD, 99% ammonia and 83% orthophosphate are effectively removed (HRT 5 days and 2 L/min aeration) [14]. Soil base constructed wetlands can also use for VFCWs.

![Vertical Type Constructed Wetland](image)

**Figure 3. Vertical Type Constructed Wetland**

**Table 1. Removal efficiencies (%) for VFCWs**

| S. No. | Type of WW     | TSS | BOD₅ | COD | NH₄-N | NO₃-N | TN  | TP  | Reference |
|-------|----------------|-----|------|-----|-------|-------|-----|-----|-----------|
| 1.    | Household      | 97.0 | 96.0 | -   | 88.4  | -     | -   | -   | [16]      |
| 2.    | STP            | -   | -    | 85.0| 77-100| -     | 64-80| 90.0| [17]      |
| 3.    | Municipal      | 89.4 | 41.5 | 55.8| 73.0  | 34.6  | -   | 67.8| [18]      |
| 4.    | Domestic       | 90.0 | -    | 84.0| 92.0  | -     | -   | -   | [19]      |
| 5.    | Landfill Leachate | -  | -    | 78.0| 87.0  | -     | -   | -   | [20]      |
4. Horizontal Flow Constructed Wetland (HFCWs)

HFCWs comprise of soil or gravel bed with vegetation. The wastewater flows below the top surface around the root of vegetation. Such wetlands can be called Sub Surface Flow Constructed Wetland system (SSFCWs). HSFCWs are used as secondary system for small community system [4]. Pretreated wastewater flows by gravity, horizontally or vertically, through the bed substrate where it contacts a mixture of facultative microbes living in association with the substrate and plant roots resulting in effective removal of \( \text{BOD}_5 \) and suspended solids (USEPA, 2000). Small scale HFCWs are shown in fig.3. The aerobic zones occur around roots and rhizomes that leak oxygen into the substrate. Organic compounds are very effectively degraded aerobically around roots and rhizome bacteria. As per the table 2, good efficiency for removing total suspended solid (TSS), organic matter (BOD) and COD as compared to nutrients. Mosquitoes and aquatic animal issues are limited in this CWs. HFCWs are used for all types of wastewaters. The various materials can be used for substrates like shale, soil sediments, zeolite, limestone, volcanic mineral, alum sludge, oyster shell, wood chip, plant waste, fly ash, slag, construction waste, ceramsite and activated carbon. Sewage with high \( E. \text{ Coli} \) bacteria and suspended solids pit soil can be used [15]. Fecal coliform (FC) can effectively remove (82%) by HFCWs under 4.5 mg/L Dissolved Oxygen (DO) and temperatures 25 °C [21]. Soil base subsurface constructed wetland enhanced the potential for removing wastewater pollution [11-49].

Table -2. Removal efficiencies (%) for HFCWs

| S.No. | Type of WW | TSS  | \( \text{BOD}_5 \) | COD  | \( \text{NH}_4^+\text{N} \) | \( \text{NO}_3^-\text{N} \) | TN  | TP  | Reference |
|-------|------------|------|----------------|------|----------------|----------------|-----|-----|-----------|
| 1.    | Domestic   | 95.0 | 85.5           | 80.0 | 29.5           | -              | 42.0| 19.5| [22]      |
| 2.    | Municipal  | -    | 84.0           | 69.0 | -              | -              | 41.0| 96.0| [23]      |
| 3.    | Urban Sewage | 82.7 | 91.6           | -    | 55.3           | -              | -   | 58.2| [24]      |
| 4.    | Sewage Treatment Plant | - | 77.0 | 60 | 67.0 | 69.0 | - | 85.0 | [25] |
| 5.    | Graywater  | 86.0 | 35.0           | 61.9 | -              | -              | 87.0| 95.0| [26]      |

Fig 4 shows the layout of the HFCWs. Influents flow under gravity. Table 2 shows the comparative performance for wastewater treatment in HFCWs.
5. Hybrid Flow Constructed Wetlands (HCWs)

HFCWs are the combination of VFCWs and HFCWs. HFWS is effective for reduction of pathogens, ammonia and TN [9]. The various types of CWs can be arranged together to create a combined system, which is called hybrid constructed wetlands. Such mixed CWs are utilized to accomplish higher effectiveness of wastewater treatment as opposed to single CW. Investigation of HCWs was initiated by Seidel in Germany in 1980 [27] – ammonia was oxidized to nitrate, and in the following anoxic HF beds nitrate was reduced via denitrification [3]. Using a similar setup for the municipal wastewater, using the gravel, sand and soil with typha plant, the removal efficiency for BOD$_5$ 78%, TKN 66%, TSS 74% and P 86% while pilstia stratiotes removed BOD$_5$ 84%, TKN 76%, TSS 82% and P 83% [28]. Fig. 5 shows the layout of HCWs.
HFCWs has some disadvantages like space consuming, capital cost, pretreatment, high supervision and not extremely lenient to cold atmospheres.

Table 3. Removal efficiencies (%) for HCWs

| S.No. | Type of WW                  | TSS | BOD₅ | COD  | NH₄-N | NO₃-N | TN   | TP   | Reference |
|-------|-----------------------------|-----|------|------|-------|-------|------|------|-----------|
| 1     | Domestic                    | 89.0| -    | 85.0 | 83.0  | -     | 83.0 | 64.0 | [29]      |
| 2     | Domestic                    | -   | -    | 59.0 | 79.2  | -     | 79.7 | -    | [30]      |
| 3.    | Dormitory wastewater        | 92.2| 88.9 | 86.0 | 66.5  | 65.7  | -    | 63.5 | [31]      |
| 4.    | Urban Wastewater            | 96.0| 86.0 | 80.0 | 88.0  | -     | -    | 24.0 | [32]      |
| 5.    | Anaerobic baffled reactor(ABR)-HSSF-VSSF | 95.9| 90.1 | 90.0 | -     | 69.5 | -    | 26.1 | [33]      |

¹99.7% for fecal enterococci
6. Current scenario in Constructed wetland research

Various researchers have studied performance improvement of CWs by manipulating various parts and parameters such as, substrate, plants, Hydraulic Retention Time (HRT), Loading Rate (LR), aeration system, flow pattern, recirculation pattern, various combination for wetlands and plant density [USEPA]. For example, the locally available broken brick used for substratum in SSFCW for removal of nutrients, plants such as the typha domenisis, cyperus papyrus and dark green bulrush used for treatment for hospital wastewater resulting in 93% TSS, BOD$_5$ 90%, COD 83%, TKN 64%, and 56% phosphate removal [35], different aeration methods like tide flow (TF), effluent recirculation (ER) and artificial aeration for all type of CW (VFCW, HFCW and HCW) improving the removal efficiency 89% TSS, 84% COD, 63% total Nitrogen (TN) and 81% ammonia nitrogen [35]. Recently, steel slag size 10 to 20 mm used as filter media in multistage pond CWs for removal of contamination in river water resulting in increase in total phosphorus (TP) reduction for first level HFCW by 151% [36].

Researchers have also studied different types of wastewaters such as removal of petrochemical waste through HFCW by using gravel and sand media, plants typha and phragmites, removing the BOD$_5$ (85%), COD (89%) and turbidity (66%). Similarly study on different plant species, like acacia nilotica, cotton, brassica napus carried out for decontaminating oilfield wastewater. BTEX (benzene, toluene, ethylbenzene and xylene), PAH (Polycyclic Aromatic Hydrocarbons) and aliphatic/aromatic petroleum hydrocarbon can be removed by CW for refinery wastewater [37]. Heavy metals like Cu, Zn, Ni, Fe, Pb, Cd, B, Cr, Al, Co, As and Se from industrial wastewater, mine tailing waste, tannery wastewater, oil refinery waste can be removed from SFCW. Media used for removal of heavy metals from CW are sediments, compost, gravel, soil, ash with plants macrophyte, typha latifolia, macrophyte myriophyllum spicatum and algal species [38,39]. The removal efficiency of heavy metal from CW are reported as 69%-96% [38,39,40]. Pharmaceutical, hospital and personal care products (PPCB), medical waste and cosmetic waste has been seen effectively removed by CWs. Phytoremediation in various types of CW is a well established treatment method now [39,40,41]. The removal of various PPCB was observed to be in the range of 70% to 90% by various CWs [42,43].

Agro based synthetic fertilizer, pesticides, fungicides, insecticides and herbicides leach with soil and contaminate the river, lakes, ponds, and ground water. CW removal efficiency for agricultural wastewater for COD (92%), BOD$_5$ (98%), TN (91%), TP (96%), TSS (96%), 94-99% E.Coli, Fecal Coliform (FC), and Total Coliform (TC) from single stage CWs in various conditions has been reported [44]. The researchers attributed the contribution of CW for treating agro-base runoff and industrial wastewater [45].

Group of researchers [46] recently observed that wastewater from textile dyeing process can be effectively treated by CW resulting in removal efficiencies–COD (87%), BOD$_5$ (86%), TSS (49%), TDS (46%), Orange3R (84%), alcohol oxidase (85%), lignin peroxidase (150%) and color (75%).

Compost and landfill leachates have a high amount of organic matter and it can be treated by CW [47]. A pilot-scale study was done in Iran where HSSFCW planted with vetiver grass and fine gravel is used as filter media. It is observed that 75% of BOD$_5$, 53% of COD and 74% of TN were removed successfully [47]. Microbial fuel cell (MFC)-based horizontal flow (HF) constructed wetlands are novel systems that use interconnected electrodes (cathode and anode), saturated media, plant, and electrochemically active microbial population for wastewater polishing [48,49]. One study reported that the Microbial Fuel Cell (MFC) HFCW with aluminum plates anode and cathode in HFCW with stone aggregate as filter media and vetiver grass planted in CW, has 93% phosphorus, 83% coliform, 55-92% nitrogen and 80-100% organic impurities removal [50].
Microplastics (MP) are emerging as one of the major environmental pollutants on the earth. In MP, Synthetic Organic Polymer Plastics (SOPP) have been used majorly in households, clothing, agriculture, personal care products [51]. The increased dependency on plastic material has skyrocketed the demand for plastic products which eventually end up as waste in the environment. The research shows that MPs travel from municipal solid waste landfill to aquatic systems [52]. Natural wetlands are also proving to be effective in removing MPs, a pollutant of emerging concern. Mangrove wetlands are proving to be effective in removing MPs from aquatic streams [53]. CWs can be a suitable treatment strategy in removing MPs before they reach natural water sources.

7. Conclusion and further directions

Due to a small pollution load in domestic and municipal wastewater, CWs can be an effectively part of treatment. CW provides high removal efficiency for organic contaminants, nutrients—nitrogen and phosphorus, and pathogenic microorganisms. Highly toxic contaminants and heavy metals from industrial wastewaters can also be effectively treated by CWs. Toxic heavy metals removal like lead, cadmium, iron, mercury, arsenic, copper, chromium, zinc, nickels, silver and manganese through CWs have been reported by many researchers. CWs provide many advantages over conventional wastewater treatment systems. CWs provide an economical, low technology, less expensive and high energy-saving treatment technology. CWs also show promise in providing effective treatment not only for the domestic, municipal wastewater but also for difficult to treat industrial wastewaters. Waterborne pathogens can also be reduced by wetland systems. CWs are environmentally friendly and natural resource treatment systems that contribute to the public health. CWs also show potential in removal of emerging contaminants of concerns that are difficult to remove by conventional treatment methods. Recent research shows that some endocrine disrupting chemicals were reduced by 48 to 99% by CWs [54]. More research is also required for removal of MPs by CWs. A long term monitoring of geo-physicochemical properties of CW under various operating conditions will give further research for better understanding of the key factors responsible for the optimization of CW [55]. CW has great potential efficiency for removal of all types of water pollution and wetland technology has made great strides in the last few years.

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