IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Various Types of Constructed Wetland for Wastewater Treatment-A Review

To cite this article: Arvind Kumar Swarnakar *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1032** 012026

Various Types of Constructed Wetland for Wastewater Treatment- A Review

Arvind Kumar Swarnakar[1], Dr. Samir Bajpai[2], Dr. Ishtiyaq Ahmad[3]

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 (BOD_5), 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,

1. Introduction

Natural wetland comprises of vegetation, soil and either water or wastewater. There are different conventional methods for wastewater treatment such as sand traps (grit chamber), septic tanks, Imhoff tank, baffled reactor (Anaerobic Baffled Reactor, ABR), anaerobic filter, green filters, Soil BioTechnology (SBT) or Constructed Soil Biofilter (CSB) or Constructed Soil Filter (CSF), anaerobic stabilization ponds, aerobic stabilization pond (Maturation Ponds/Oxidation Pond), Rotating Biological Contactor (RBC), Active Sludge Process (ASP), Upflow Anaerobic Sludge Blanket (UASB), Trickling Filter (TF), and micro-algae techniques etc. CWs are the manmade system with combination of base material, vegetation, and organic matter to provide wastewater treatment [1]. CWs require less infrastructure, investments, raw materials, energy consumption, operation, staff during operation, maintenance, odors, insects, flow variations, toxic substances, and by-products [2]. Categorization of CWs depends on flow direction, macrophytic growth and hydrology [3]. CWs are typically used as a secondary treatment unit. The CWs are used for treatment of domestic wastewater, animal wastewater, mine water, leachate remediation, industrial wastewater, urban stormwater and field runoff [4]. The main part of the CWs are aggregate, soil and gravel used as filter media and macrophytes (vegetation) such as Typha, Canna indica, Flax Lily, Banksias, Bottlebrush, P. australis, common rush, tapered rosette grass, Phragmites australis, common reed, Club-rush, Cattail, Common water plantain, Reed canary grass, Meadowsweet, Yellow flag, Compact rush used as vegetation [5]. According to water flow in substrate UN- HABITAT has divided CWs in three categories – 1. Vertical Flow Constructed Wetland (VFCW) 2. Horizontal Flow Constructed Wetland (HFCW) 3.

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.

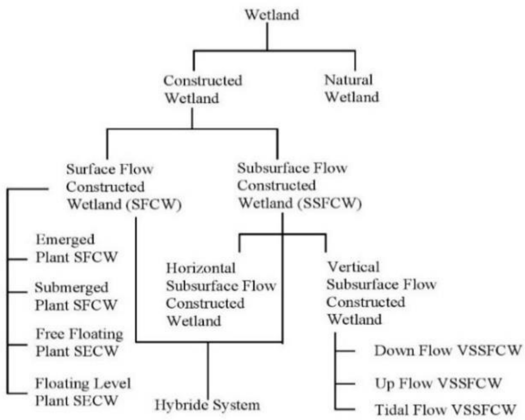

Figure 1. Various types of wetlands

2. Removal Mechanisms in Constructed Wetland

The main mechanism of treatment through CWs comprises biogeochemical transformation with solid and liquid separations. Macrophytes plays 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 phytostablization. Plant enzymes break down the contaminants through phytodegradation. Plants and algae remove the contaminants from soil and sediments through phytoextraction. Plants release the contaminates 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.

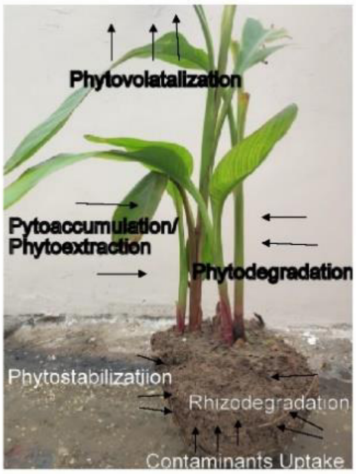

Figure 2. Macrophytes mechanism for contaminant removal

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 dissolve 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% BOD_5, 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.

Figure 3. Vertical Type Constructed Wetland

Table 1. Removal efficiencies (%) for VFCWs

S. No.	Type of WW	TSS	BOD_5	COD	NH_4-N	NO_3-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 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. 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	BOD_5	COD	NH_4-N	NO_3-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.

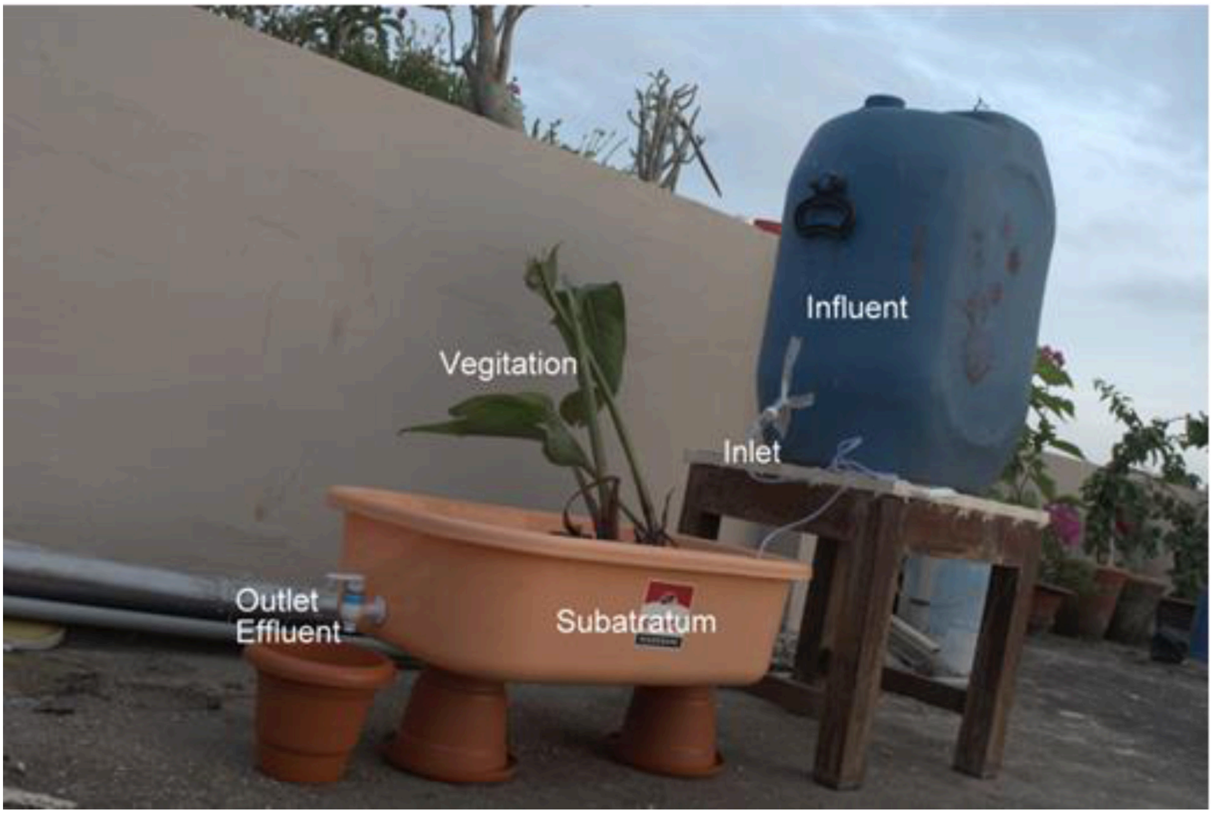

Figure 4. Horizontal Flow Constructed Wetland (HFCWs)

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.

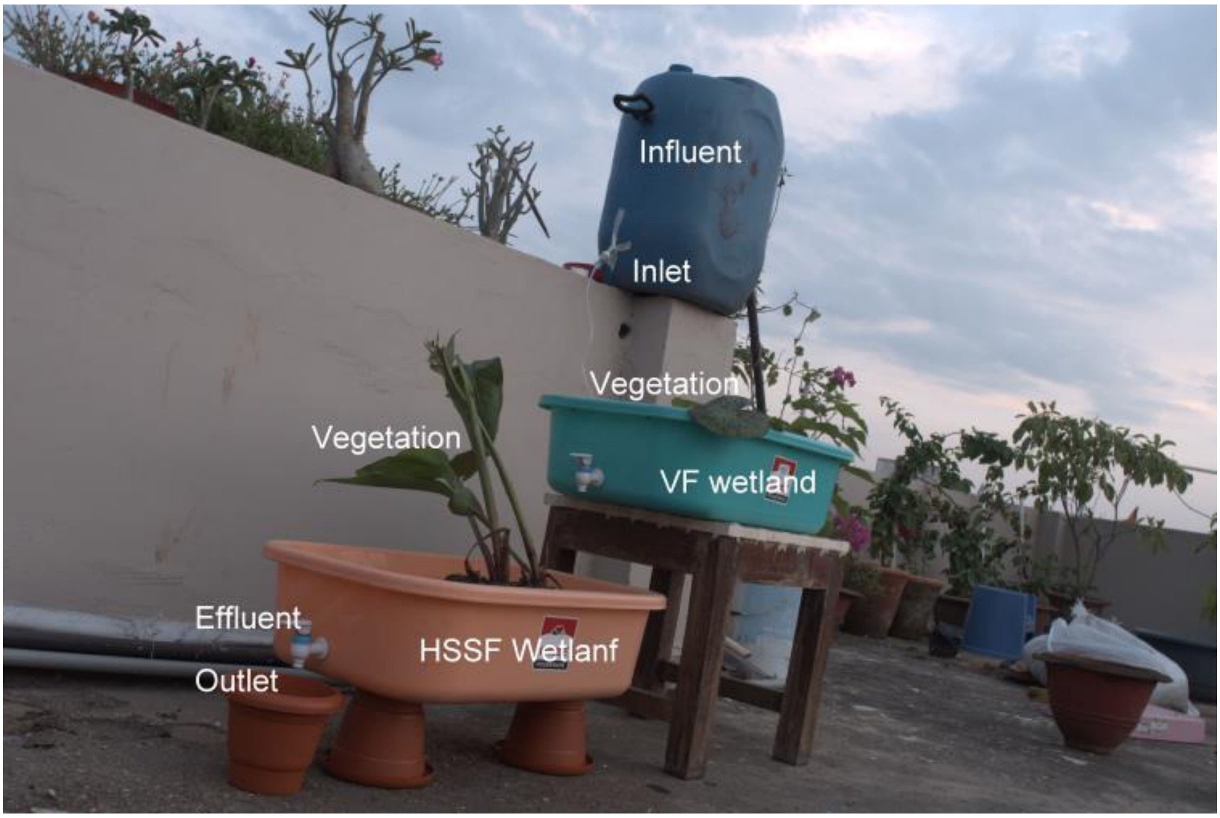

Figure 5. Hybrid Constructed Wetland (HCWs)

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	BOD_5	COD	NH_4-N	NO_3-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	[1][32]
5.	Anaerobic baffled reactor(ABR)-HSSF-VSSF	95.9	90.1	90.0	-	69.5	-	26.1	[33]

[1]99.7% 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 dominensis , 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 filer 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, domestic wastewater 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. Phytoremidiation in various types of CW is a well stablished 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 BOD5, 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 the 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 a 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.

REFERENCE

[1] Kirby, J.A. (2000). Constructed wetland: Tertiary Treatment of Wastewater. Wastewater treatment symposium, A ssociation of Professional Engineer and Geoscientists of newfoundland, Corner Book, NF.

[2] Stefanakis, A.I., Akratos, C.S., & Tsihrintzis, V.A. (2014). Vertical flow constructed wetlands: Ecoengineering systems for wastewater and sludge treatment (1st Ed.). Amsterdam, The Netherlands: Elsevier Publishing.

[3] Vymazal, J. (2011). Plants used in constructed wetlands with horizontal subsurface flow: A review. *Hydrobiologia*, *674*, 133–156.

[4] Kadlec R.H, Wallace S.D. (2009). Treatment wetlands, Second edition. CRC Press, Page 10.

[5] Jethva K., Bajpai S., Chaudhari P.K., Swarnakar A.K. (2017). Wastewater nutrient removal through phytoremidiation: a review. 49th Annual Convention of IWWA on "Smart Water Management" January 19-21.

[6] United Nations Human Settlements Programme (UN-HABITAT), (2008). Constructed Wetland Manual. P-8.

[7] USEPA, Design Manual, Constucted Wetlands and Aquatic Plant system for Municipal Wastewater Treatment. EPA/625/1-88/022;1988

[8] Srivastava J, Gupta A, Chandra H. Managing water quality with aquatic macrophytes. Rev Environ Sci Biotechnol. 2008;7:255–266.

[9] Odinga C.A., Swalaha, F. M., Otieno F. A.O., Kumar R. Ranjith, and Bux. F., (2013). Investigating the efficiency of constructed wetlands in the removal of heavy metals and enteric pathogens from wastewater. Environmental Technology Reviews. DOI:https://doi.org/10.1080/21622515.2013.865086.

[10] Cooper,P.F., Job G.D., Green M.B. and Shutes R.B.E.(1996). Reed Beds and constructed wetland for wastewater treatment.WRc Swindon, UK.

[11] Jethwa K., Baipai S., (2016). Role of plants in constructed wetlands (CWS): a review. Journal of Chemical and Pharmaceutical Sciences. Issue 2: August 2016, P;1-10.

[12] Bajpai, S. & Swarnakar, A., (2021). Role of soil organic matter in plant growth for horizontal flow subsurface constructed wetlands for waste water treatment. EM International. https://doi.org/10.1080/09593330.2016.1273396.

[13] Saeed, T., Sun G., (2012). A review on nitrogen and organic removal mechanism in subsurface flow constructed wetland: depend on environmental parameters, operating condition and supporting media. J. Environ.Manag. 112, 429-448.

[14] Falahi, O. A. A., Abdullah, S. R. S., Hasan, H. A., Othman, A. R., Ewadh, H. M., Al-Baldawi, I. A., & Imron, M. F. (2021). Simultaneous removal of ibuprofen, organic material, and nutrients from domestic wastewater through a pilot-scale vertical sub-surface flow constructed wetland with aeration system. *Journal of Water Process Engineering*, *43*, 102214.

[15] Wang Y., Cai Z., Sheng S., Pan F., Chen F., Fu J., (2020). Comprehensive evaluation of substrate materials for contaminants removal in constructed wetlands. Sci Total Environ.701:134736. doi: 10.1016/j.scitotenv.2019.134736. Epub 2019 Oct 31. PMID: 31715485.

[16] Wu, S., Austin, D., Liu, L., Dong, R., (2011). Performance of integrated household constructed wetland for domestic wastewater treatment in rural areas. Ecol. Eng. 948-954.

[17] Cui, Y.B., Jiang, T.L., Guo, Z.Q., (2008). Nutrient removal mechanism and performance of constructed wetland in cold climate.J. Xi'an univ. Archit.Techno. 40, 121-125.

[18] Sani, A., Scholz, M., Bouillon, L., (2013), Seasonal assessment of experimental vertical- flow constructed wetlands treating domestic wastewater. Bioresour. Technol. 147, 585-596.

[19] Sklarz, M.Y., Gross, A., Yakirevich, A., Soares, M.I.M., (2009). A recirculating vertical flow

constructed wetland for the treatment of domestic wastewater. Desalination. 246 (1e3), 617e624.

[20] Lavrova, S., Koumanova, B., (2010). Influence of recirculation in a lab-scale vertical flow constructed wetland on the treatment efficiency of landfill leachate. Bioresour. Technol. 101, 1756e1761.

[21] Fahim. R., Xiwu L., Hussain I., Jilani G., Hussain J.,(2019). Inactivation Of Faecal Coli Form Indicator Microorganisms In A Constructed Wetland Under Diverse Environmental Conditions. International Journal of Advances in Science Engineering and Technology, Vol. 7, Issue -2 ISSN(p): 2321 –8991

[22] Hayward, J., Jamiesoon, R., Boutilier, L., Goulden, T., Lam, B., (2014). Treatment performance assessment and hydrological characterization of an arctic tundra wetland receiving primary treated municipal wastewater. Ecol. Eng. 73, 786-797.

[23] Jenssen, P.D., Maehlum, T., Krogstad, T., vrale. L. 2005. High performance constructed wetlands for cold climate. environ. Sci. Health 40, 1343-1353.

[24] Rai, U.N., Upadhyay, A.K. Singh, N.K., Dwivedi, S., Tripathi, R.D., 2015. Seasonal applicability of horizontal sub surface flow constructed wetland for trace elements and nutrient removal from urban wastes to conserve Ganga river quality at Haridwar, India. Ecol. Eng. 81, 115-112.

[25] Thalla A.K., Devatha C.P., Anagh K., Sony E., (2019), Performance evaluation of horizontal and vertical fow constructed wetlands as tertiary treatment option for secondary effluents. Applied Water Science 9:147.

[26] Raphael. O. D., Ojo S. I. A., Ogedengbe K., Eghobamien C., and Morakinyo A. O. (2018). Comparison of the performance of horizontal and vertical flow constructed wetland planted with Rhynchospora corymbosa. International Journal Of Phytoremediation. Https://Doi.Org/10.1080/15226514.2018.1488809.

[27] Sayadi, M. H., Kargar, R., Doosti, M. R., & Salehi, H. (2012). Hybrid constructed wetlands for wastewater treatment: A worldwide review. Proceedings of the international academy of ecology and environmental sciences, 2(4), 204

[28] Haydar, S., Anis, M., & Afaq, M. (2020). Performance evaluation of hybrid constructed wetlands for the treatment of municipal wastewater in developing countries. Chinese Journal of Chemical Engg. 28(60), 1717-1724.

[29] Mander U, Tooming A, Mauring T, et al. (2007). Performance dynamics of a LWA-filled hybrid constructed wetland in Estonia. Ecohydrol. Hydrobiol, 7: 297-302.

[30] He, S.,Wang, Y., Li, C., Li, Y., Zhou, J., (2018). The nitrogen removal performance and microbial communities in a two-stage deep sequencing constructed wetland for advanced treatment of secondary effluent. Bioresour. Technol. 248, 82–88.

[31] Gholipour, A., & Stefanakis, A. I. (2021). A full-scale anaerobic baffled reactor and hybrid constructed wetland for university dormitory wastewater treatment and reuse in an arid and warm climate. Ecological Engineering, 170, 106360.

[32] Melian JA, Rodríguez AJ, Arana J, et al. (2010). Hybrid constructed wetlands for wastewater treatment and reuse in the Canary Islands. Ecological Engineering, 36: 891-899.

[33] Singh SH, Haberl R, Moog O, (2009). Performance of an anaerobic baffled reactor and hybrid constructed wetland treating high-strength wastewater in Nepal—A model for DEWATS. Ecological Engineering, 35:654-660.

[34] Dires, S., Birhanu, T., & Ambelu, A. (2019). Use of broken brick to enhance the removal of nutrients in subsurface flow constructed wetlands receiving hospital wastewater. Water Science and Technology, 79(1), 156-164.

[35] Ilyas, H., & Masih, I. (2017). The performance of the intensified constructed wetlands for organic matter and nitrogen removal: A review. Journal of environmental management, 198, 372-383.

[36] Lu, H., Xiao, L., Wang, T., Lu, S., Wang, H., Guo, X., & Li, J. (2021). The application of steel slag in a multistage pond constructed wetland to purify low-phosphorus polluted river water. Journal of Environmental Management, 292, 112578.

[37] Agarry, S. E., Oghenejoboh, K. M., Latinwo, G. K., & Owabor, C. N. (2018). Biotreatment of petroleum refinery wastewater in vertical surface-flow constructed wetland vegetated with Eichhornia crassipes: lab-scale experimental and kinetic modelling. Environmental technology.

[38] Hadad, H. R., Maine, M. A., & Bonetto, C. A. (2006). Macrophyte growth in a pilot-scale constructed wetland for industrial wastewater treatment. Chemosphere, 63(10), 1744-1753.

[39] Lim, P. E., Tay, M. G., Mak, K. Y., & Mohamed, N. (2003). The effect of heavy metals on nitrogen and oxygen demand removal in constructed wetlands. Science of the total environment, 301(1-3), 13-21.

[40] Liu, M., Li, X., He, Y., & Li, H. (2020). Aquatic toxicity of heavy metal-containing wastewater effluent T reated using vertical flow constructed wetlands. Science of The Total Environment, 727, 138616.

[41] S. Dires, T. Birhanu, A. Ambelu, Use of broken brick to enhance the removal of nutrients in subsurface flow constructed wetlands receiving hospital wastewater, Water Sci. Technol. 79 (2019) 156–164, https://doi.org/10.2166/WST.2019.037.

[42] Kumari A., Mourya N.S., Tiwari B., Hospital wastewater treatment scenario around the globe. Current Developments in Biotechnology and Bioengineering. DOI: https://doi.org/10.1016/B978-0-12-819722-6.00015-8.

[43] N.A. Khan, R. El Morabet, R.A. Khan, S. Ahmed, A. Dhingra, M. Alsubih, A.R. Khan, Horizontal sub surface flow Constructed Wetlands coupled with tuben settler for hospital wastewater treatment, J. Environ. Manag. 267 (2020), 110627, https://doi.org/10.1016/j.jenvman.2020.110627.

[44] Nan, X., Lavrnić, S., & Toscano, A. (2020). Potential of constructed wetland treatment systems for agricultural wastewater reuse under the EU framework. Journal of Environmental Management, 275, 111219.

[45] Wang, M., Zhang, D., Dong, J., & Tan, S. K. (2018). Application of constructed wetlands for treating agricultural runoff and agro-industrial wastewater: a review. Hydrobiologia, 805(1), 1-31.

[46] Kadam, S. K., Tamboli, A. S., Chandanshive, V. V., Govindwar, S. P., Choo, Y. S., & hong Pak, J. (2022). Construction and implementation of floating wetpark as effective constructed wetland for industrial textile wastewater treatment. Journal of Hazardous Materials, 424, 127710.

[47] Bakhshoodeh, R., Alavi, N., Majlesi, M., & Paydary, P. (2017). Compost leachate treatment by a pilot-scale subsurface horizontal flow constructed wetland. Ecological Engineering, 105, 7-14.

[48] Corbella, C., Garfí, M., & Puigagut, J. (2016). Long-term assessment of best cathode position to maximise microbial fuel cell performance in horizontal subsurface flow constructed wetlands. Science of the total environment, 563, 448-455.

[49] Villasenor, J., Capilla, P., Rodrigo, M. A., Canizares, P., & Fernandez, F. J. (2013). Operation of a horizontal subsurface flow constructed wetland–microbial fuel cell treating wastewater under different organic loading rates. Water research, 47(17), 6731-6738.

[50] Saeed, T., Yadav, A. K., & Miah, M. J. (2022). Influence of electrodes and media saturation in horizontal flow wetlands employed for municipal sewage treatment: A comparative study. Environmental Technology & Innovation, 25, 102160.

[51] Hassan, I., Chowdhury, S. R., Prihartato, P. K., & Razzak, S. A. (2021). Wastewater Treatment Using Constructed Wetland: Current Trends and Future Potential. Processes, 9(11), 1917.

[52] Upadhyay, K., & Bajpai, S. (2021). Transport of Microplastics from Municipal Solid Waste Landfills to Aquatic system: An Overview. AIJR Proceedings, 222-227.

[53] Meera, S. P., Bhattacharyya, M., Nizam, A., & Kumar, A. (2021). A review on microplastic pollution in the mangrove wetlands and microbial strategies for its remediation. Environmental Science and Pollution Research, 1-15.

[54] Hsieh, C. Y., Yang, L., Kuo, W. C., & Zen, Y. P. (2013). Efficiencies of freshwater and estuarine constructed wetlands for phenolic endocrine disruptor removal in Taiwan. Science of the total environment, 463, 182-191.

[55] Swarnakar, A. K., Bajpai, S., & Ahmad, I. (2021). Geo Physicochemical Properties for Soil Base Subsurface Constructed Wetland System. AIJR Proceedings, 228-233.