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CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2022; 32 (3): 0260-0284
DOI: 10.2478/ceer-2022-0040
Original Research Article

A CRITICAL REVIEW ON ECONOMICAL AND SUSTAINABLE SOLUTIONS FOR WASTEWATER TREATMENT USING CONSTRUCTED WETLAND

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Abstract

Pollutant removal by the mechanism of constructed wetland has led to low cost, highly efficient wastewater treatment technology. Constructed wetlands (CWs) are artificial engineered systems that mimic like natural wetlands. CW's have been used in previous research to treat a broad range of waste streams at large-scale for low-cost application in wastewater management. Generally, the most literature has targeted a particular class of mechanism or the other due to lack of generalized techniques for wastewater management using CWs. This work focuses on to introductory information and review on concept of CWs based on the latest mechanisms for the wastewater treatment to inspire economical and sustainable solutions to water based environmental problems. This research emphasis CW mechanism, construction, design, and applications of CWs as well as optimization of CWs for the treatment of wastewater. This review also highlights the study with different treatment stages of CWs for removing pollutants from different types of wastewaters.

Keywords: constructed wetland, economical, wastewater, recycle, reuse

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1. INTRODUCTION

Currently, India is facing water scarcity problem (Rijsberman et al. 2006, Mishra, V et al. 2021). It takes over millions of lives every year affected by water scarcity (Mekonnen, M. M. et al.2016, Dolan, F. et al. 2021). Hence the immediate need arises to save the water resources and find ways for reclamation or reuse of water. Due to untreated waste disposal into natural water resources results in rapid increase of pollution in water resources and which has been doubled in the recent years (Chakraborti t al. 2019, Shannon et al. 2008, Bhardwaj RM. 2005). Industrial development has also gained a rapid growth due to its increased demand and due to urbanization but because of water contamination and degradation of natural water resources. The treatment of wastewater ought to be the top priority for the country to put a stop to the proliferation of water environment problems (Kalbar, P. P et al. 2012, Asano, T. et al. 1996, Boller, M. 1997). Reclamation of wastewater is the priority for the ecologists after looking at the current scenario. Aquatic systems are contaminated with heavy metals have high density ($\geq$ 5 g/ cm^3), due to agricultural seepage or runoff and industrial discharge. Increased level of contamination of heavy metals in water has negative impact on ecological function of water (Bashir, I. et al. 2020). Typically, the wastewater contains pathogens, total solids, nutrients, other organic elements and few traces of heavy metals. It is reported that the rivers are polluted due to the industrial waste disposal because of the presence of high BOD (Biochemical Oxygen Demand) and ammoniac nitrogen (NH_3- N). These pollutants are out of their permissible limit which makes the wastewater contaminated (Chinnusamy, C. 2019, Abowei et al. 2005). They can be brought under their permissible limit before their disposal to prevent the contamination. To comply with maximum permissible discharge limits for different pollutants a proper treatment of wastewater is mandatory before discharging into the surface waters. However, in majority of the developing countries like India, Pakistan etc. it has not yet been accomplished, partly due to power outages or poor maintenance (Rai et al., 2015; Carty et al., 2008). Regarding this water it requires suitable water standards. Now looking at the situation the question arises whether to find technologies that is economical to treat the contaminated water for irrigation and cultivation purposes. We must find efficient ways to safeguard our water resources. Waste-water treatment plays a predominant role to reduce the level of contamination into the water sources. Elimination of the harmful pollutant form contaminated water and reuse for various purpose is a possible key to the water based environmental problems. Now surface quality is degrading days due to negative impact. Pollutants originating from wastewater are characterized differently which affects the ecosystem. It results in the alterations of flora and fauna of the community (Donde, O.O. 2017). The Economical and Sustainable Solutions to water based environmental problems is wastewater treatment. Various treatments methods are found and are still in progress to find a best, is Constructed Wetlands (CW) (Thorslund, J et al. 2017). In the few decades, artificial engineered wetlands known as CWs, has established a strong ground for treatment of wastewater in comparison conventional treatment systems. CWs is the cheaper alternative for treatment of different kind of wastewater such as domestic, agricultural, industrial etc . (Vymazal, J. 2011; Omondi, D.O et al. 2020, Yalcuk and Ugurlu, 2009; Vymazal, J et al. 2021; Almuktar et al. 2018). Currently, focus of researchers have been shifted towards understanding of better design, evolution, and performance of CWs, and numerous studies focuses on efficient use of CWs for removing pollutants such as organic matter, nutrients, heavy metals, trace elements, pharmaceutical contaminants, pathogens, etc. from wastewater (Langergraber, G., & Dotro, G. (2019); Ji, Z et al. 2021; Christofilopoulos, S et al. 2019; Nivala, J 2013). CWs are a sustainable and more environment friendly approach for reducing environmental pollution and use of local resources. CWs can be adopted in small towns and villages as being simple in installation and operation. Due to the high level of the removal efficiency of dyes, heavy metal, micropollutants, bacteria, nutrients and organic pollutants constructed wetlands (CW) has invited interests of many researchers in the field of wastewater treatment. Constructed wetlands act like an estuary and serve as biofilters to eliminate pollutants from wastewater (Pawęska, K et al. 2011). In the work presented in (Bruch, I et al. 2011; Perdana, M.C et al. 2018; Zhao, Y.J. et al. 2011; Ávila, C. 2014; Khalifa, M. E. 2020), authors have examined the efficiency of CWs based on the various treatment stages and use of different media type. Subsequently, research contribution published on pollutant removal efficiency and overall performance of CWs based on several factors such as substrate, vegetation, pH, temperature, substrate, vegetation, hydraulic loading rates (HLR), hydraulic retention time (HRT), dissolved oxygen (DO), and mode of feeding etc. (Jain, M. et al. 2020; Wu, H et al. 2015; Lim, P.E et al. 2003). CWs have many leads over the traditional sewage treatment method due to low cost, easy to maintain, and eco-friendly. Many mechanisms and generalized techniques for wastewater treatment based on CWs have been studied in the past few years, the detail of which can be found in (Gunes, K. et al. 2011; Kumar, S and Dutta, V 2019; Qasaimeh, A. et al. 2015; Verlicchi, P. 2014). The constructed wetland appeared to be a more cost-effective alternative to conventional treatment modalities which involve huge energy and cost. However, major key issues such as long-term effective treatment process, sustainable operation are still remained open. Over the years, process of CWs has made great advancement, but still a gap in better understanding of cost and optimization of CWs. Therefore, it is necessary to carry out a study to inspire economical and sustainable solutions for the enhancement of Constructed Wetland with the help of in-depth review of previous studies while acknowledge the detected gaps. Generally, the most literature is targeting a particular class of mechanism or the other due to lack of generalized techniques for wastewater management using CWs. Hence this paper focuses on providing and inspiring economical and sustainable solutions for the enhancement of constructed wetland based on the latest mechanisms for the wastewater treatment.

2. CONCEPT OF CONSTRUCTED WETLAND

A wetland is a transitional land that are adapted to soaked with water, either permanently or seasonally. The definition of wetland can be reformulated based on the different purpose and can be characterised into many forms. The primary characteristics such as vegetation of aquatic plants distinguish wetlands from other landforms or water bodies. Generally, wetland is of two types (i) Natural and (ii) Constructed as shown in figure 1.

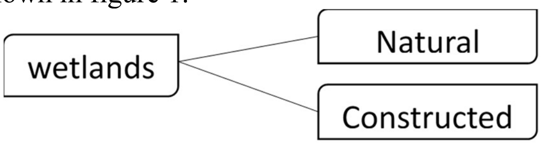

Fig. 1. Wetland classification

Natural wetland systems are natural purifiers of wastewater treatment which contribute to water absolution, water regulation and recreation.

Constructed wetlands are artificial engineered systems that are used to remove contaminants from wastewater. They consist of wetlands, soil or channels that have aquatic plants planted in them, and utilizing natural process such as microbial, biological, physical, and chemical processes to treat the wastewater. These systems, which are primarily made up of vegetation, substrates, soil, gravel, microorganisms, and water, employ complex processes that involve physical, chemical, and biological mechanisms to get rid of various contaminants or improve the quality of the water. Constructed wetlands are most economical as compared to conventional treatment units as they need more energy for its process and the following methods require cheaper available materials.

The following five major components for a Constructed Wetland

- Basin
- Substrate
- Vegetation
- Liner
- Inlet/Outlet arrangement system.

Constructed Wetlands are efficient wetlands that are acknowledged as effective wastewater treatment method. They can be used to treat different wastes generating from sewage, paper mill industry, pulp, glass, petrochemical, greywater, effluent from dairy, brewery and many more industries. These are eco-friendly and are economically sustainable. It had multiple advantages like raising the importance of wastewater, habitat enrichment, use in various fields etc. These are economically cheap as they are easy to operate, they require less labor, cheaper instrument requirements. Plants are used in the wetlands which are selected according to the prevailing environmental conditions and availability. HRT and HLR is an important and practical criterion for optimizing the performance of a wetland system (Kataki, S. et al. 2021, Zhao, Y. et al. 2020; Reed, S. C. 1992).

3. EVOLUTION OF CONSTRUCTED WETLAND

Historically, Käthe Seidel from Germany conducted the first experiment of wastewater treatment using macrophytes and in the 1960s he invented the concept of vertical subsurface flow constructed wetland which was previously called as the "root zone" method. Since then, the constructed wetland (CW) concept becomes efficient and environment friendly technology for the treatment of wastewater. Typical reasons for using constructed wetlands are water and wastewater quality improvement, flood control prepares water for reuse and creation of habitat to compensate for natural wetland converted for agricultural or urban development (Sim et al. 2013). CWs have also emerged as a promising technique to remove nutrients and pollutants from various wastewaters (Cui, L.F. 2012). These systems have a simple construction, large buffering capacity, little extra sludge production, self-adaptive treatment process, as well as low operation and maintenance cost (Ye and Li, 2009).

4. TYPES OF CONSTRUCTED WETLAND

Figure 1 illustrates a several various type of CWs that exist. The primary distinctions between the three categories of constructed wetlands for the treatment of wastewater are as follows: There are Traditional CWs, Enhanced CWs, and Integrated CWs. Further subdivided into free water surface (FWS) CWs and subsurface flow (SSF) CWs in accordance with the hydrology of the wetland. (Saeed and Sun, 2012). Free water surface is like natural wetlands and the subsurface constructed wetland can be classified as: vertical (VSSF) and horizontal sub-surface flow (HSSF) which encounter the process based on the flow of horizontally or vertically (Sylla, A. 2020; Shukla, R. et al. 2021; Galve, J. C. A. et al. 2021; Khan, N. A. et al. 2020). Integrated CWs are well known with the combination of various wetland systems, such as (VF–HF CWs, HF–VF CWs, HF-FWS CWs and FWS-HF CWs) (Vymazal, 2013; Rani, N. et al. 2021; Kiflay, E 2021).

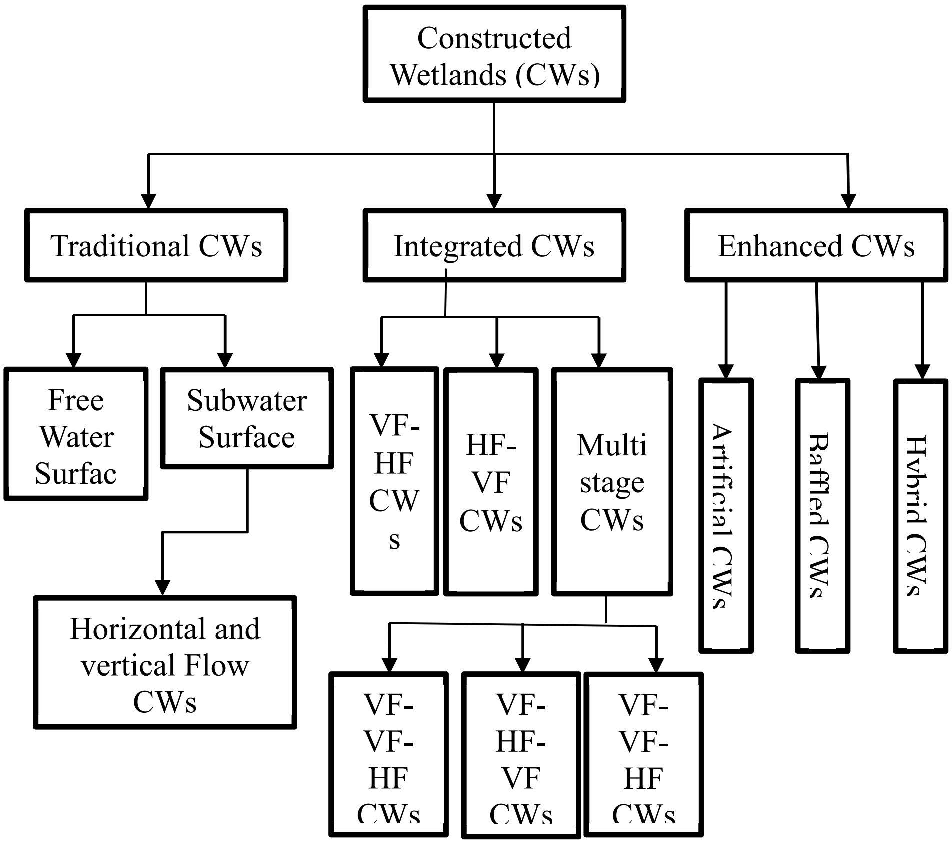

Fig. 2. The classification of CWs used in wastewater treatment

Generally, the design combination consisted of two stages in parallel and series. In addition to that, the multi-stage CWs utilizes more no. stages of CWs (Kadlec and Wallace, 2009). In Recent years no. of research carried out based on artificially aerated CWs, hybrid towery CWs, and other forms of enhanced CWs to boost the efficacy of wastewater treatment systems (Wu et al., 2014).

5. MECHANISM IN CONSTRUCTED WETLAND

A constructed wetland is a wastewater treatment system which improves the efficiency of the processes that help to treat the water similar to naturally occurring wetlands. The system includes plants, weeds, substrates, micro-organisms, water, different filters (sand, gravel, soil etc.) It has a lot of extensive options in design. The microbiological activity is the key parameter for their performance. In general, the mechanism which takes place in the constructed wetland system is that there is a combination of filter and purification system in which the plants, microorganisms and substrates play a vital role. plants in constructed wetland, contribute to nutrient transformation, provides mechanical resistance to flow, increase the retention time, facilitate settling of suspended particulates, and improve conductance of water through the media as the roots grow. A typical CW consists of a pond with substrate, media, and vegetation. Influent flows in the CW and gets treated by physical, chemical, and biological means aerobic respiration, denitrification, sulphate reduction, acid fermentation, and methanogenesis. CWs improve wastewater quality through various processes such as physical, chemical, and biological (Kadlec et al. 2009, Garcia et al. 2010). The mechanism involved in the EC process generally consists of various stages mainly listed as below:

1. At First, water is allowed to enter the wetland, sedimentation of solid takes place. As the water flows through the constructed wetland, the rhizomes of the plant roots and the substrate remove the larger particles present in the wastewater.
2. Pollutants and nutrients present in the wastewater naturally break down and get consumed up by the bacteria and plant, hence remove them from the water.
3. The Hydraulic retention time (HRT) in the wetland is an important factor to consider, which varies according to the design and desired quality level of the treatment system.
4. After the treatment using constructed wetland, water can be safely released into surface waters or used for different purposes according to the safety standards.

Table 1. Constructed Wetland treatment mechanism

Process	Factor affecting	Mechanism	Pollutants
Physical	Water flow, Retention time, Vegetation, Surface area	Sedimentation filtration	Suspended solids, pathogens
Chemical	pH, Temperature, Surface area	Precipitation/ Coagulation, Adsorption	Colloids, Dissolved nutrients, metals, soluble organics
	Cation exchange capacity, pH, Temperature	Ion Exchange	Dissolved metals
	Light, Temperature, Aeration	Photolysis Oxidation, Volatilization	COD, Hydrocarbons, Synthetic Organics, volatile matters
Biological	Substrate organics, pH, Temperature	Decomposition,	BOD, COD, Organics
	Type of plant, Uptake Capacity, Surface area	Plant uptake	Soluble metals, P, N, Organic matters
	pH, Temperature	Fermentation Methanogenesis	Organic Matters

In this paper, the main mechanisms that takes place in CWs are (i) the transformations i.e. Chemical reactions which includes precipitation, flocculation, oxidation/reduction reactions, acid/ base reactions, and biochemical reactions occurring both under aerobic or anaerobic conditions and (ii) the solid liquid separations which includes gravity separation, ion exchange, filtration, absorption, Uptake by the helophytes and microorganisms and adsorption. These both the processes together lead to the pollutant and contaminant removal in Constructed Wetlands. (EPA 2000). The processes that take place in the removal of pollutants are physical, chemical, and biological (Choudhary et al. 2011).

6. APPLICATION OF CWs FOR WASTEWATER TREATMENT

At the early stage, the application of CWs was mainly focused on treating of traditional domestic and municipal wastewater. Due to the consequence of water pollution caused by industries, agriculture fields, mines, river, lakes and runoff and degradation of natural water resources the application of CWs has been crucially expanded to decontaminate agricultural effluents, industrial effluents, and so on (Wang, M. et al. 2018; Cronk, J.K. 1996; Ignatowicz, K 2020). (Kadlec and Wallace, 2009) investigated that the free water surface CWs are the most efficient type in removal of suspended solids and organics as compared to surface flow CWs. But SSFs CWs are the most effective in removal to microbial pollution and heavy metals. This types of CWs depends on the treatment stages, variation of grading material and media can be used in different wastewater treatment applications. Table 2 provides a summary of the studies that were carried out on the various stages of treatment of CWs in order to treat different types of wastewaters, such as domestic sewage, agricultural wastewater, and industrial effluent, amongst others.

Table 2. Summary of studies on stages of treatment of CWs for wastewater treatment

No.	Treatment Stage	Sewage Type	Range of Parameters	References
1.	hybrid VFCWs	Synthetic WW	(COD) 507.38±6.94 mg/L and high N loading 121.37±3.08 mg/L	[97]
2.	IVFCWs	Artificial WW simulating to domestic & secondary WW	HLR- 250 and 150 mm/d.	[19]
4.	HSSF CWs	Synthetic WW	HRT varying from 2hrs to 100 hrs.	[62]
5.	Subsurface vertical flow CW	Synthetic WW	HRT- 12 to 14 Hrs	[13]
6.	vertical up- flow columns	Synthetic WW	HRT varying from 15 hrs to 180 hrs	[14]

7.	HSSF CWs	Synthetic	The supply rate of 3L/d with an average contact time of 12 hrs	[30]
8.	VSSFCW	Diluted dairy farm WW	HLR 1.7m^3/m^2/d	[7]
9.		Tap water	HLR of 240ml/d HRT: 12-14 hrs	[3]
10.	unplanted CWs	Secondary sewage effluent	Flow rate @ 0.28-0.8 ML/ha-d and HRT 3 days to 8 days	[56]
11.	barrels planted with Phragmites australis	Synthetic sewage solution	HLR m^3/m^2 phosphorus loading rate 1.33 mg/m^3/m^2	[65]
12.	VFCW	Municipal WW	HRT varying from 1d to 2d	[9]
13.	Hybrid tidal flow CW	Septic tank effluent	HLR (m/d) Varying from 0.5 to 1.5	[26]
14.	VFCW	Synthetic high strength WW	High C loading with 500 g/m^3 glucose dose and high N loading with 200 g/m^3 glucose and 250g/m^3 arbamide dose	[98]
15.	HCW	Domestic WW	HRT of 4,8, 12,18,20 days	[75]
16.	Rectangular planted CW	Municipal sewage water	BOD, NO_3- N, NH_4-N, PO_4-P	[67]
17.	Sub surface vertical flow CW	Pre-treated eutrophic WW	HRT: 1,4,8,16,24, 48 hrs	[88]
18.	CW tanks with common reeds	Domestic WW	HRT (days), Soil:Sand ratio HRT- 3d Soil:Sand– 3:1 HRT- 1.5d Soil:Sand- 1:1 HRT- 0.75d Soil:Sand- 1:3	[79]
19.	Pilot-scale constructed wetland	Urban Sewage	HRT- 1.5 to 2 days HLR- 0.2 to 0.4 m/d	[8]
20.	Primary treatment	Municipal Wastewater	HLR- 0.6-9.89 m^3/m^{2}day; OLR- 0.12- 2.12 kg COD/ m2 day HRT of BBHCW- 1.7 h	[49]
21.	Secondary	Primary treated Domestic sewage	12, 24, 36 and 48h HLR- 250 L h-1	[77]
22.	Secondary	Dairy wastewater	HLR- 4h	[31]
23.	Primary hybrid sub-surface CW	Domestic Wastewater	HRT-24,30,36h	[68]
24.	Primary (HRBCW)	Domestic Wastewater	HRT- 3 days	[39]
25.	Secondary	Domestic wastewater	HRT- 11.8 and 12.5 day	[16]
26.	Primary	Domestic	HRT -5days	[91]
27.	Primary	domestic wastewater	HRT-2.7 days, 5 days	[74]
28.	Tertiary	industrial wastewater	HRT- 3, 5, and 7 d	[21]

29.	Primary	domestic wastewater	15 days for a period of 7 months	[33]
30.	Secondary hybrid-CW	Domestic wastewater	HRT- 120 &160 Hrs	[87]
31.	Primary	Industrial wastewater	HRT- 2.7, 5 days	[55]
32.	Secondary	Domestic Wastewater	HRT -8h	[46]
33.	BSFCWs	Synthetic wastewater	HRT-48 Hrs	[94]
34.	SFCWs	Synthetic wastewater	HRT - 3days	[54]
35.	Secondary	domestic wastewater	HRT-11.8 and 12.5 day	[93]
36.	Primary	Blackwater	HRT - 3, 5, 7 days	[92]

7. BENEFITS AND LIMITATION OF CONSTRUCTED WETLAND PROCESS

Constructed wetlands are of the advantage that they are easily operated, low cost and maintenance compared to the conventional systems. CWs coupled/ integrated with other treatment technologies have been investigated to make the system more efficient and to overcome the shortages of individual CWs systems. The combined system maximizes the advantages and constructs a combined win-win system. Additional pros and cons of Constructed wetland process are given in the Table 3.

Table 3. Advantages and disadvantages of Constructed Wetland

Pros	**Cons**
1. Easily operated, low cost and maintenance. 2. It is a green technology. 3. Its applications are formation of habitat, flood control and wastewater treatment. 4. Are particularly useful for impoverished countries, especially those in tropical areas. 5. Provides multiple benefits in economic, ecological, and technical sectors. 6. Easy site selection, sizing can vary, and most importantly, hydraulic pathways and retention time can be controlled. 7. Sludge production is less 8. It is a self-adaptive treatment unit with a large buffering capacity.	1. Seasonal characteristics of the plant used could restrict CW performance owing to the decreased removal ability. 2. Requires more land area. 3. Biological clogging and Organic Matter clogging. 4. As the substrate media has a low phosphorus adsorption capacity, less phosphorus is removed. 5. The requirement of long hydraulic retention time. 6. Treatment efficiency for a single unit is low.

8. RECENT TRENDS OF WASTEWATER TREATMENT USING CONSTRUCTED WETLAND

Our main objective is to discuss the knowledge on the sustainability of CWs and to discuss the recent development of CWs in the wastewater treatment. Treatment of wastewater to be adopted should be ecofriendly where special equipment and electricity is not required. There are systems for the treatment that constitutes an interface between terrestrial system and the aquifer systems. Today the wastewater requires high level of treatment so as to get rid of the contaminants and to be safe for further use. Wastewater can be reclaimed and reused at home easily like using the bathing water for flowering and planting purpose, any liquid which will be discarded after boiling like boiling pasta or noodles, water used for washing clothes may be recycled as water for plants rather than wasting it. There are many other wastewater treatment techniques, including filters and chemical treatments, activated sludge and oxidation ponds but the setup is costly and is difficult to operate. There are innumerable processes for the treatment of wastewater such as activated sludge process (ASP), membrane bioreactor (MBR), moving bed bio reactor (MBBR), membrane sequencing batch reactor (MSBR), photo catalysis, electro- Fenton (EF), membrane filtration, hybrid anaerobic reactor, micro aerobic hydrolysis acidification (MHA), up- flow anaerobic sludge blanket (UASB), etc. which might reduce the practicability and economic feasibility of the treatment processes. CWs are known to be a reliable wastewater treatment technology which has its own benefits good purification effect, low construction and operation cost, energy consumption, maintenance and, as well as astounding ecological benefit. They are used as a suitable solution for the treatment of various types of wastewaters around the world, such as, municipal sewage, domestic sewage, industrial wastewater, non-point source agricultural pollution and polluted surface water.

There are different treatment stages like primary, secondary and tertiary. These are carried out according to the characteristics of wastewater. The primary system occurs in which its function is to reduce Oil & Gas, suspended solids and turbidity. After which further biological treatments takes place. Amongst all Activated Sludge Process (ASP) is found the most effective mainly in the removal of chemical oxygen demand (COD) from 70-80%. The pollutants removal efficiency depends on the composition of wastewater. The amalgamation of two or more biological processes can be more effective in treating wastewater. Hence the integration of various processes mechanical, physical, chemical and biological treatments has been found effective in achieving higher removal efficiency. Advanced oxidation processes (AOPs) may be considered as a better alternative than adsorption. They have a tendency to break the parent compound into their non-harmful or non-toxic forms and the organics use adsorption to turn over from one medium to other i.e., from aqueous to a solid medium (Doherty, L. et al. 2015).

8.1. Anaerobic Treatment Followed by Constructed Wetland

Systems combining constructed wetlands with anaerobic bioreactors have proved to be efficient and adequate for wastewater treatment. Anaerobic treatment consists of Up-flow Aerobic Sludge Blanket (UASB), continuously stirred tank reactor/digester/Up-flow Anaerobic Filters, ultrahigh rate fluidized bed reactors, two-stage UASB reactor along with constructed wetlands. Wastewater consists of Parameters such as Biological Oxygen Demand (BOD_5), chemical oxygen Demand (COD), pH, total Kjeldahl nitrogen (TKN), organic matter, NH_3, NO_2^-, NO_3^- and Total suspended solids (TSS) which are measured by laboratory methods (Alberto Fernández del Castillo et al.) Anaerobic Reactors and CW complements each other with simple design, operation, reduced cost and low energy input (Alvarez, J.A et al).Treatment of wastewater using Anaerobic filters are more preferable than conventional treatment methods it consumes less time and has the potential to treat wastewater containing high COD loads (M. K. Daud et al.). In the study an integrated system is made which consists of horizontal subsurface flow constructed wetland (HSSFCW), anaerobic baffled filter (ABR) and floating constructed wetland (FCW). In this Anaerobic conversion of organic nitrogen to ammonium takes place and nitrate reduces to ammonium, the amount of ammonium in ABR gets increased and it gets decreased in HSSFCW and FCW stages. Due to the good removal efficiency of the parameters TSS, COD, BOD_5, and phosphate, the integrated system consisting of horizontal subsurface flow constructed wetland (HSSFCW), anaerobic baffled filter (ABR) and floating constructed wetland (FCW) is considered efficient (Kifaly, E. 2021).

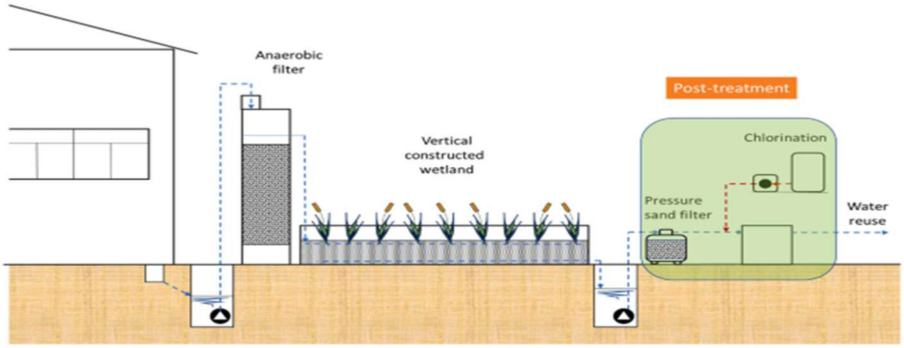

Fig. 3. Flow diagram depicting a pumping station, anaerobic filter(UAF), a vertical constructed wetland (VFCW) and a post treatment unit

8.2. Microbial Fuel Cell Incorporated with Hybrid Constructed Wetland (HCW-MFC)

Constructed wetland (CW) and microbial fuel cell (MFC) have an inherent characteristic that is they both depend on microbial conversion of organic and inorganic wastes. Because of which anode can be incorporated in the anaerobic section and cathode in the aerobic section of Constructed wetland system and hence Constructed wetland- microbial fuel cells (CW-MFCs) be created. This technology can generate bio-energy and can enhance treatment efficiency at the same time and can be proved efficient. Hybrid constructed wetland-microbial fuel cells (HCW-MFCs) should be paid more attention and should be expanded for large and practical purpose. For this, inlet strategies and flow regimes should be looked into to improve the efficiency of the treatment system (Ren, B. et al. 2020). CW-MFC system simultaneously along with the production of bioelectricity and it treats organic compounds, phosphorus and nitrogen depends.

The design of MFC-CW system shown in figure 4 (Yaqian Zhao et al. 2013) depends on substrate material, electrode material, wetland plant, hydraulic retention time, flow regime, and microbial activities. For the enhancement of CW-MFC, different packing layers of CW and electrode material of different kind could be used so that there could be diversity, richness and different microbial composition. Role of Plants is to promote richness of the electrode surface and electrode surface affects the microbial community. Environment condition is also a key factor in microbial decomposition (Xiao Huang et al.) (2021).

For high strength wastewater, novel stacked system could be developed in which stacks are vertically arranged which helped in enhancement of wastewater technique and electricity generation. It takes less space and is economical. For the removal of organics and nitrogen from wastewater Microbial fuel cell integrated with an HF-VUF-CW (horizontal flow- vertical up flow constructed wetland) has been proven to be an efficient technology. MFC-CW can improve efficiency in a better way than the other conventional constructed wetland systems. For example, Lei xu et al. made a multiple-cathode MFC-CW and found removal efficiency of NH_4–N which increased from 44.63 to 81.10. He compared the integrated system to conventional CW and showed removal percentage. It had 5% higher COD and 22% NH_4–N, respectively. More importantly, MFC-CW (microbial fuel cell-constructed wetland) provides electrochemically active bacteria (EAB) for good and healthy environment (Sun, G et al. 2005; Pratiksha Srivastava et al. 2020).

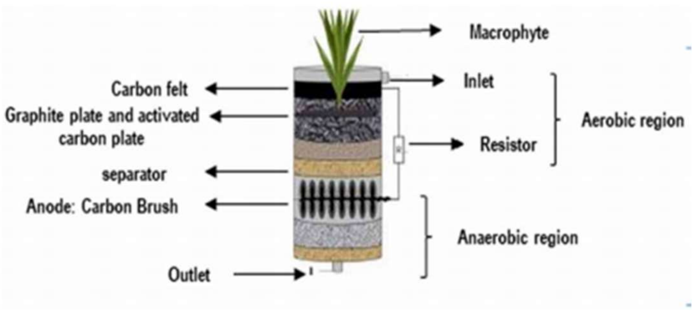

Fig. 4. Schematic description of the CW-MFCs configuration

8.3. Alum Sludge –CW

Alum sludge-based CW is considered as a recent trend in today's development. "Alum sludge" means "aluminium-based residual" obtained from wastewater treatment. It is an unavoidable waste material in the treatment process. Aluminium-salt is used as coagulant. Alum sludge is used as a substrate in the working of Constructed Wetland in which aluminium salts are used as coagulant. Alum sludge is a low-cost substrate material and has great working features due to which is proposed (1) high content of Aluminium ion for Phosphorus immobilization, which makes sludge a reliable, cost-effective and environment friendly adsorbent for P removal; (2) is easily available (Ren, B. et al. 2020). The study has demonstrated that the system is a cheap wastewater treatment system in achieving the efficiencies in removing pollutants, especially Phosphorus. It obtained 57–83%- BOD_5, 36–83% - COD, 11–77 % TN, 49–93% NH_4-N, 75–94% TP, 73–97% P (inorganic phosphorus) and 46–83% for SS, respectively. A Conceptual illustration of beneficial integration of alum sludge into a wastewater treatment shown in figure 5 (Hu, Y et al.2012). A multi-stage constructed wetland system can be made in which alum sludge is used as substrate which enhances the efficiency and removal of phosphorus and organic matter from the wastewater (Babatunde, A. O. et al. 2010) For treating low concentration wastewater, a dewatered alum sludge-based constructed wetland system was designed which was planted with Phragmites Australis and was efficient in the TN and phosphate removal regardless of the value of HRT (Kang, W. et al. 2022)

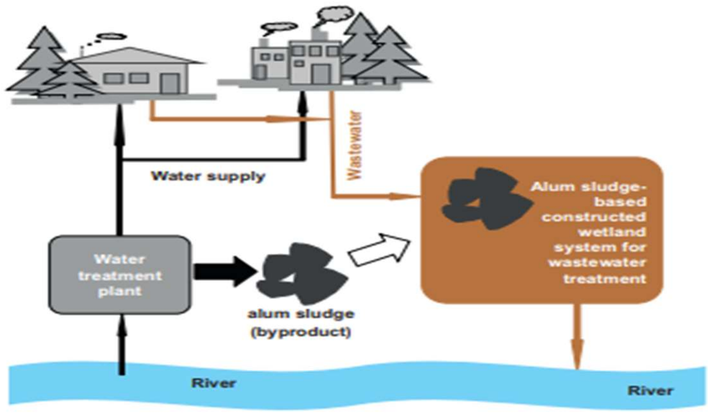

Fig.5. Conceptual illustration of beneficial integration of alum sludge into a wastewater treatment (Zhao, Y 2011)

8.4. CW with Activated Sludge Process (ASP)

CW technology is a sustainable and efficient wastewater treatment in today's world. Integration of constructed wetland with activated sludge process could be advantageous as they both have its own benefits. An emerging recent trend in this field consists of technique integrating CW into the main wastewater treatment process (activated sludge process) to setup a "Green-Bio-sorption Reactor" (GBR) in which "green" stands for plant or wetland and "sorption" represents the wetland substrate (Liu, R. et al. 2017). The Constructed wetland system is a wastewater treatment technology which is biofilm-based, i.e., biofilm and microorganism activities are the main framers for wastewater treatment and its purification. Ranbin Liu et al. studied that the integration of CW and sequencing batch reactor proved to be more advantageous than they work individually. A figure 6 from (Liu, R. et al. 2017) illustrate the conceptual application of CWs integrated with conventional activated sludge.

Fig.6. Conceptual application of CWs integrated with conventional activated sludge

8.5. Standard CW

Standard CW is also known as Modular CW. Construction of CW is very time consuming and also requires a lot of space. But CWs are being designed basis of rule-of-thumb. Therefore, it is highly desired that a real modular CW system should be designed in such a way that it allows rapid construction/assembling and increase in the flow. As such, in 2016 China developed a conceptual design of a real modular horizontal subsurface flow Constructed Wetland system (MHSSF-CW). It was in-situ and was constructed in a way that it can be assembled easily and quickly to form a good and efficient modular CW. The modular constructed wetland can be used for the treatment of domestic sewage. The sewage flow would be a factor in the construction and design of modular CW. The scale of the wetland would depend on the actual sewage flow. It has high applicability and feasibility. In addition, the efficiency of modular constructed wetland can be enhanced by integrating it with different treatment systems, such as advanced oxygen, Membrane Bio Reactor (MBR) and other treatment systems for a good and efficient wastewater treatment system. (Changsong, C. et al. 2021). The study made four types of CW which obtained good efficiency and pollutant removal which were (1) planted system with media layer of vertical woodchip (WP), (2) unplanted system along with vertical woodchip media layer (W), (3) unplanted with media layer of vertical bottom ash (B), and (4) planted with vertical bottom ash media layer (BP). They ranked as: BP > B > WP > W Constructed Wetland. The nutrient removal rate for reed and cattail growth was correlated. The study recommended a surface area of 0.26 to 0.9% for unplanted CW and 0.25 to 0.8% of catchment area for planted CW using the 7.5 to 10 mm design rainfall. (J. Y. Choi et al.).

Fig.7. Commercial wastewater constructed wetland wastewater treatment system

Perspectives of CW in India–India is one of the world's countries which suffer water-scarcity as a major problem. In 2019 India's wastewater treatment plants were USD 2.4 billion. By 2025, it is expected that water demand may reach USD 4.3 billion due to its increasing demand. Municipal water as well as sewage water treatment plant is setup across the country, according to Amitabh Kant, CEO, NITI Aayog. Central urban schemes such as Swachh Bharat Mission, Jal Shakti Abhiyan, Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Smart Cities Mission and Namami gange are the schemes which are started especially for the conservation of water by treatment of wastewater. They also lay stress on the reuse and recycle of wastewater (including blackwater and greywater) for its use in various sectors. An example of the commercial waste water constructed wetland wastewater treatment system is shown in Figure 7. (https://www.indiamart.com/proddetail/constructed-wetland-wastewater-treatment system-18009387855.html).

9. CONCLUSIONS

Substantial attempts have been made to expand the Constructed Wetlands technology as a green technology for treatment of wastewater. Use of this technology holds the aim for water protection and conservation for the habitat. The scope of the Constructed Wetland has been intensified and Constructed wetland systems have been integrated to give a more efficient system. In coming years, the constructed wetland system should be incorporated with the conventional CW and will be expanding more. These include Anaerobic Treatment followed by constructed wetland, aerated- CW, alum sludge- CW, activated sludge with CW, Microbial Fuel Cell-Constructed Wetland (MFC-CW) and the modular CW. Development of Constructed Wetland relies on the nature of its substrate and on many other factors. Further developments of the Constructed Wetlands should focus on it's the water recycling and reuse to maximum its purpose being an important part of green environment.

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Editor received the manuscript: 17.08.2022