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CONSTRUCTED WETLAND SYSTEM AS A NATURAL TECHNOLOGY TO REMEDIATE WASTEWATER

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Abstract

Constructed wetlands (CW) is a natural technology having eco-friendly technique of treatment of wastewater and it has been applied to various kind of wastewater like industrial wastewater, municipal wastewater, agriculture drainage, acid mine drainage, etc. In last decades, Constructed wetlands are being applied for treating many classes of Pollutants present in wastewater such as heavy metals, textile dyes, pesticides, petroleum hydrocarbons, explosives, radionuclides, etc. This treatment method overcomes the shortcomings of conservative wastewater treatment method as it is a cost-effective, non-intrusive and eco-centric technology.

In addition, an attempt has been taken to project future advances in the field of CW and facilitate these advances by framing key unsolved problems in CW. This review covers the evaluation of the current status-of-the-art of CW technology and provides definitions and performance metric nomenclature in an effort to unify the fast-growing CW community. It also contains an outlook on the emerging trends in CW and proposes future research and development directions. Wetland behavior and efficiency concerning wastewater treatment is mainly linked to macrophyte configuration, substrate, hydrology, surface loading rate, influent feeding mode, microorganism availability, and temperature.

Keywords: Constructed wetland, wastewater, macrophytes, microorganisms, wastewater treatment, Substrates

Introduction:

The environmental awareness has been increased during last decade and many of the governmental bodies around the world made the agenda for the treatment of environmental pollution and to reduce the contamination which is increasing to the high pick now a day *(6).* Generally, an appropriate environmental remediation method should be selected based on the effectiveness of the reduction & degradation process and the cost of applied method according to the type of particular wastes *(16)***.** Mainly, the performance of the selected Environmental clearance method or Pollution control methods through their environmental impact is special concern because in some degradation methods the daughter product of the remediation process is more toxic than the original pollutant *(6).* Many of the Researchers and Scientists believe that there is no single worldwide degradation method suitable for all types of pollutants present in their respective sources. Instead of that, the effective remediation process may be applied by involving the collective implementation of two or more methods *(6)*. The major problem throughout the world is the generation of wastewater as wastewater is triggering severe environmental problems in many of the urban areas. The efficient treatment of wastewater, both municipal and industrial, is the environmental management method (Bhat et al. 2018) which aims to avoid any sort of pollution to receiving waters by reducing the organic load and recovery of nutrients (Queiroz et al. 2019). In small-scale industries, due to operational, economical, and regulation issues, the conventional treatment methods for effluents are hardly used. The implementation of any treatment process should be cost-effectiveness, ease of maintenance and operation and also should be highly efficient in removing major contaminants. The deduction of undesirable components present in wastewater can be done by various processes like filtration, sedimentation, adsorption, precipitation, microbial application and phytoremediation (Hammer, D.A. and Bastian, R.K. (1989)). The Wetlands are one of the effective degradation technologies which now attracts environmentalist for the removal of wastewater pollutants as it is a natural process. As the word indicates 'Wetland" is the wet land with soil which is more or less water saturated, at least periodically. For the implementation of the consortia of effective Microbial – Macrophytes, the establishment of Constructed Wetland is required. The rising interest in wetland system is because of the fact that natural systems deal advantages over conservative activated sludge and trickling filter systems *(13)*.

The Constructed Wetland as Wastewater Treatment Facility:

The Constructed wetlands (CWs) are designed by creating natural atmosphere for utilizing natural factors like macrophytes, soil and associated microorganisms to remove unwanted elements from wastewater. CWs are engineered systems having eco-technology that are created to optimally utilize natural processes for the treatment of wastewater. The wastewater treatment efficiency depends on many factors i.e. Type of wetland, Type of operation (continuous, batch or intermittent flow) and Hydraulic loading rate, Hydraulic retention time, selection of macrophytes and characteristics of wastewater etc. *(2)*. The Constructed wetlands were studied by Keathe Seidel, in Germany, in early 1950s at first for treatment of different types of wastewater using macrophytes. Then, in late 1960s, North America used constructed wetlands for treating wastewater by method of ecological engineering of natural wetlands. Correspondingly, some pilot scale projects of surface flow CWs operated for treatment of municipal wastewater in Australia however, this technology did not get much support by public sector and the Australian government, hence, the use of this technology reduced till 1990s in Australia. The main reason was low rate of phosphorus removal and high health risk of public because of mosquito breeding places availability in surface flow CW which was the inadequacies of this technology *(5)*. However, then after it was shown that, to minimize the health risk, an adequate design and management of vegetation can enrich the efficiency of constructed wetlands. At present, many constructed wetlands are working on treatment of various kind of wastewater because of their effective low cost alternative method to treat the wastewater in construction, operation and maintenance *(5)*. The major function of wetland plants to provide a suitable environment by creating attachment sites for microorganisms and release oxygen. Suitable plant species selection improves the rate of the desired treatment.

Functions of Macrophytes in Constrcuted Wetlands:

The plants which are growing in wetlands are often called as Macrophytes which are adapted to grow in wetland soil which is water saturated.

Generally, there are three types of macrophytes i.e.

(1) Floating Macrophytes – The entire wetland plants are above the water surface except roots,
(2) Submerged Macrophytes – The entire wetland plants submerged in water, and
(3) Emergent Macrophytes – The plants' roots embedded in soil but they are emerged to significant heights above the water.

Almost all types of wetland plant are used for wastewater treatment including rooted floating plants, shrub and trees and the most commonly macrophytes used in constructed wetland are emergent herbaceous plants *(16)*.

Each type of macrophyte works with various potential to perform in different types of wetlands depending upon their morphology. The roots oxygen releasing through floating and submerged vascular plants play vibrant role in wastewater quality improvement during treatment. It is documented that the roots of *Eichhornia crassipes* and *Cymodocea rotandata* do not increase the soil oxygen level substantially but it sustains a thick biofilm of aerobic bacteria by releasing oxygen through the roots which support degradation of organic matter *(6).*

According to many literatures, all types of macrophyte like free floating, submerged and mostly the emergent macrophytes are using worldwide in surface water constructed wetlands. Among the emergent macrophytes in these wetlands are Typha, Phragmites, Scirpus, Juncus, and Eleocharis. These systems are used for the treatment of all types of wastewater with the help of microbial growth and work on the degradation, filtration, settling, nitrification, denitrification, and volatilization, etc.

Moreover, there is a variation in amounts of oxygen released by various types of macrophytes in their rhizosphere due to their difference in morphology and oxygen transport mechanisms. All different types of macrophyte play a significant role in wastewater treatment in constructed wetlands. However, the role and the importance of emergent macrophytes in all types of constructed wetlands for their ability to release oxygen through their deep rooting systems are valuable *(20).*

Many research articles indicated commonly used plants in subsurface constructed wetlands are *Phragmites australis*, *Typha latifolia*, *T. angustifolia*, *T. domingensis*, *T. orientalis*, *T. glauca*, *Scirpus lacustris*, *S. validus*, *S. californicus*, and *S. acutus.* These plants were planted in systems used for the treatment of industrial, domestic, and agricultural wastewater as well as landfill leachate by the processes of aerobic and anaerobic degradation of contaminants by microorganisms, filtration and uptake by the plant roots and adsorption *(7).*

Role of Microorganisms in Constructed Wetland System:

The presence of various microorganisms like bacteria, fungi and algae is abundant in wetlands and they increase the organic pollutant removal in subsurface flow wetland systems. Microorganisms play a key role in the biogeochemical cycles of the wetland systems and each species of microbes has its own contribution towards the treatment of wastewater received from various sources having different pollutant loads *(8).*
The below table shows microbes present in constructed wetland system,

Sr. No.	Microorganisms studied	Treatment efficiency (% removal)	Wastewater studied	Type of Wetland
1	Total coliform, Escherichia coli (E. coli) and Helminth eggs	90%	Domestic wastewater	Hybrid systems (train with vertical and horizontal systems)
2	Fecal coliforms and total coliforms	99%	Septic wastewater effluent	Pilot-scale combined CW system
3	Salmonella, fecal coliforms and E. coli	96, 98 and 99 % respectively	Swine wastewater	Two-cellfield scale surface flow constructed wetland
4	Fecal coliforms and enterococci, Salmonella, Giardia cysts, Cryptosporidium oocysts	>99%, 93-96%, 88 % and 69 % respectively	Domestic wastewater	Horizontal subsurface flow constructed wetland
5	E. coli, Salmonella and helminth eggs	99.5% for E. coli, Salmonella and helminth eggs - 100% in all samples	Domestic wastewater	Horizontal subsurface flow constructed wetland
6	Coliphage, total coliforms, fecal coliforms, Giardia and Cryptosporidium	Giardia and Cryptosporidium (duckweed pond at 98 and 89%), coliphage, total and fecal	Secondary unchlorinated wastewater	Three types: duckweed-covered pond, a multi-species subsurface flow (SSF) and a multi-species surface flow (SF) wetland were studied

Table 1: *Rajitha J. Rajan, J. S. Sudarsan, S. Nithiyanantham, Microbial population in constructed wetlands – Review of recent advancements for water treatment, Environmental Engineering Research, 2019.*

Construction of constructed wetland system:
The constructed wetland is needed to be designed with specific size, capacity and material of container to be used and called as modelled constructed wetland system. Researches had worked on CW models made up of PVC Drums / Containers, basins made up of Cement and Cement Bricks etc. *(4)*

Substrate Selection in Constructed Wetlands:
The Bed media used in constructed wetlands is named as aggregate or substrate. These substrates could be sand, gravel, rock or organic material such as soil and compost, which provide the primary support for the wetland plants and microorganism growth, enhancing biodegradation of wastewater pollutants in addition to its impact on system hydrology mechanisms (Tietz et al. 2007; Meng et al. 2014). Moreover, wetland substrates remove contaminants from the wastewater performing ion exchange, adsorption, precipitation and complexation (Dordio and Carvalho 2013; Ge et al. 2015). Mostly in CWs and subsurface CWs, the rock layer is the significant layout parameter, since it can include an adequate growth medium for plants and also enable efficient wastewater movement. Additionally, substratum sorption can perform a major part in removing various contaminants like phosphorus *(15)*.

Substrates Utilized for Constructed Wetlands:
Substrate choice is measured on the basis of the hydraulic conductivity and the absorption potential of contaminants. Weak hydraulic conductivity would lead to major blockage which significantly reduces process capacity, and low substrate biosorption which may also affect CW's long-term extraction efficiency *(15)*. Moreover, the size and shape of substrate have an important role in the wetland system as it controls the surface area available for growing a biofilm and the system's media pore blockage probability. It was reported that very large substrate size will reduce the surface area available for microorganisms to grow (Meng et al. (2014)), on other hand it was also reported that, small-sized media will support the growth of biofilms by increasing the available surface area supporting the microorganisms for better wastewater treatment biologically, resulting in better effluent quality after treatment (Scholz and Xu (2002)). Furthermore, Hoffman et al. (Hoffmann et al. 2011) and Meng et al. (2014) determined that the hydraulic loading rate in constructed wetland systems, mainly subsurface flow types, can be directly affected by wetland substrate porosity, as the clogging of wetland media is a common problem in such systems affecting the treatment system, especially when selecting unsuitable media pores for the applied organic load. Numerous experiments have been performed on the selection of wetland substrates, in specific for effective phosphorus elimination from wastewater and the frequently utilized substrates involve predominantly natural substance, artificial media along with industrial by-products like gravel, sand, clay, calcite, marble, vermiculite, slag, fly ash, bentonite, dolomite, calcite, stone, zeolite, and activated carbon. *Cao Shiwei, Jing Zhaoqian, Yuan Peng, Wang Yue and Wang Yin at al. (2019)* conducted the experiment by performing the wetland systems by using various substrates like Plastic Ring, Fly ash and zeolite substrate as combinatorial substrate and Fly ash ceramsite substrate and concluded that, the efficiency of CW model with Fly ash ceramsite substrate was slightly higher than the other two CWs specially for the abatement of NH_4^+-N, NO3 – -N, and TN.

Types of Constructed Wetland Systems designed for the Wastewater Treatment:
The Wetland Treatment Systems generally, constructed wetlands are classified according to different principles such wetland's hydrology as per water flow (surface-flow and subsurface-flow), macrophyte types (free-floating, emergent, and submerged) and path of water flow (horizontal or vertical). There are many types of constructed wetlands including surface flow (SF) wetlands, subsurface flow (SSF) wetlands and hybrid wetlands, which is a mixture of surface and subsurface flow wetlands. The hybrid system is a multistage system in which the treatment is performed in different units which are designed for specific functions *(18)*.
The hybrid CW is usually composed of two phases of multiple models parallel CWs, like VF-HF CWs, HF-VF CWs, and HF-FWS CWs, as well as FWS-HF CWs. Moreover, multiple stage CWs consisting of more than three CW steps. Amplified CWs like manmade ventilated CWs, baffled flow CWs, hybrid tower CWs, step feeding CWs together with circular flow corridor CWs have been presented in current years to improvement of wastewater efficiency and treated wastewater recycling processes *(7)*.

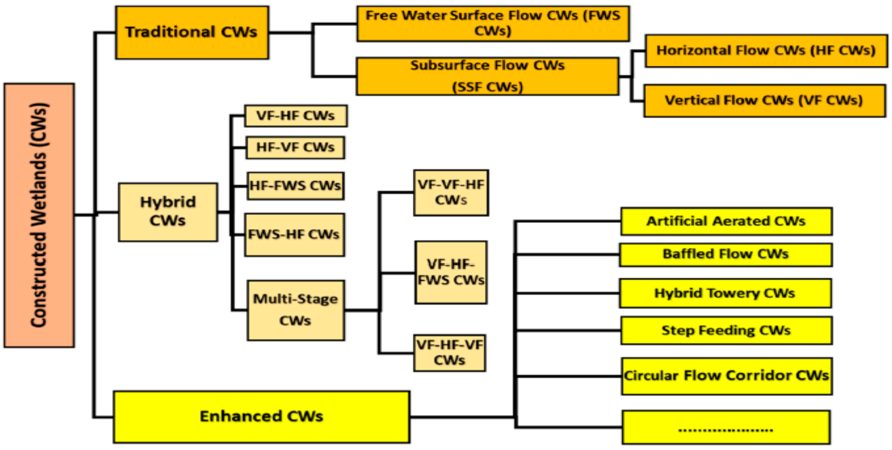

Fig. 1: Classification of Constructed Wetlands utilized in Wastewater Management, Md Ekhlasur Rahman, Mohd Izuan Eendi Bin Halmi, Mohd Yusoff Bin Abd Samad, Md Kamal Uddin 1, Khairil Mahmud, Mohd Yunus Abd Shukor, Siti Rozaimah Sheikh Abdullah and S M Shamsuzzaman, International Journal of Environmental Research and Public Health, 11th November 2020.

In wastewater treatment, some CW units are designed to promote aerobic reactions, while other units are planned for anaerobic conditions. The aerated wetland has improved nitrification / denitrification capacity as well as provided better biogeochemical conditions in the wetland subsurface and the macrophytes.

a) Horizontal type of Constructed Wetland

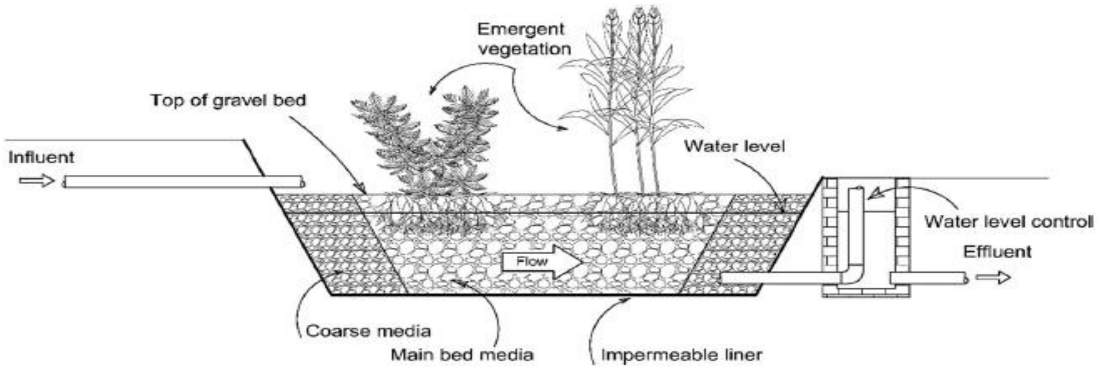

Fig. 2: Schematic of horizontal subsurface flow constructed wetland, Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review, Suhad A. A. A. N. Almuktar, Suhail N. Abed, Miklas Scholz, June 2018.

b) Vertical type of Constructed Wetland

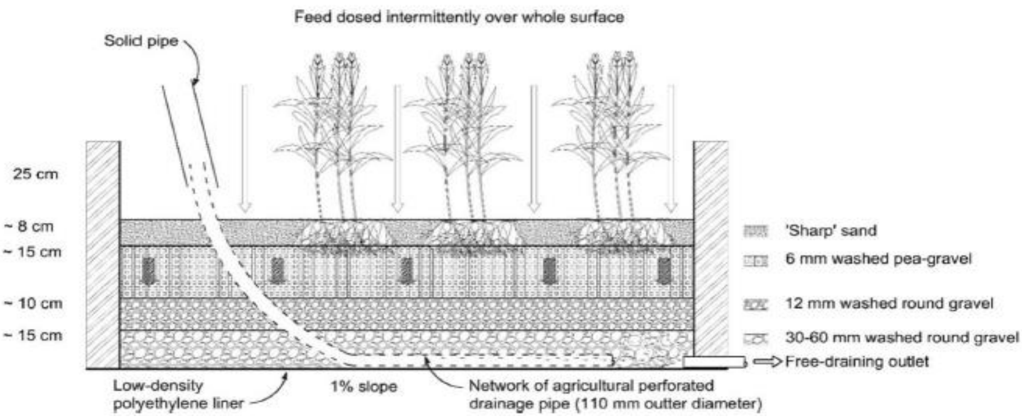

Fig. 3: Typical arrangement of a vertical – flow constructed wetland, Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review, Suhad A. A. A. N. Almuktar, Suhail N. Abed, Miklas Scholz, June 2018.

c) Hybrid type of Constructed Wetland

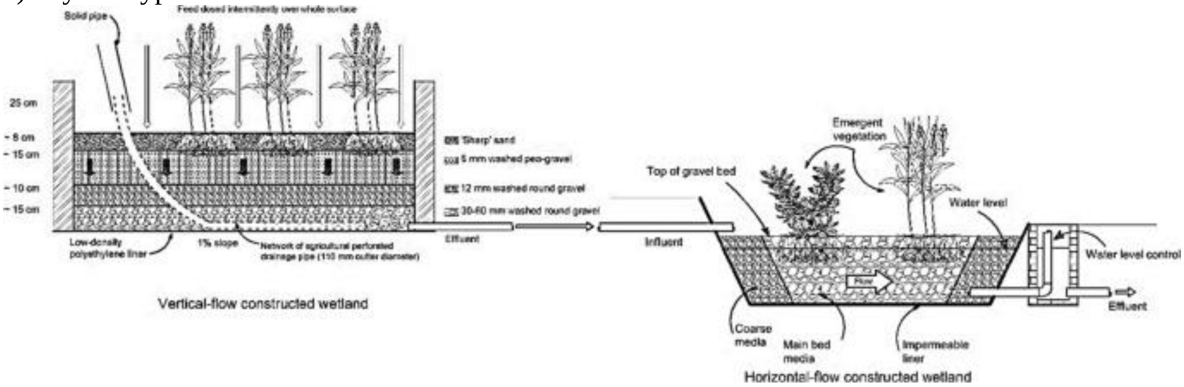

Fig. 4: Typical arrangement of hybrid constructed wetland, Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review, Suhad A. A. A. N. Almuktar, Suhail N. Abed, Miklas Scholz, June 2018.

Below table shows the Design, operation and maintenance of above mentioned types of Constructed Wetlands,

Type of Constructed Wetland	Design	Operation	Maintenance
Surface Flow (SF)	Simple, required a large land area, uses gravity flow	Low operation cost, simple operation procedure, high evapotranspiration, low temperature, affects the microbial activity	Greatly affected by temperature flocculation, odor and mosquito problems, low maaintenance cost
Surface Subsurface flow (SSF)	Complex, needs less area than SF, needs sedimentation tank, needs pumping	Provides more sorption sites than SF, relatively higher operation cost, flow should be uniform with low solid concentration, transpiration only.	Greater cold tolerance, less odor and pests, clogging problems, higher maintenance cost
Vertical Subsurface flow (VSF)	Complex, needs less area than SSF, need sedimentation pond, needs pumping	Provides more sorption sites than SF, relatively higher operation cost, flow should be uniform with low solid concentration, transpiration only.	Greater cold tolerance, less odor and pests, clogging problems, higher maintenance cost

Table: 1 Design, Operation and Maintenance of Constructed Wetlands, Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review, Suhad A. A. A. N. Almuktar, Suhail N. Abed, Miklas Scholz, June 2018.

Performance and Effectiveness Assessment of Constructed Wetland:

Growing success and operational efficacy of each technology is influenced by the strength and conditions of many variables and materials used during and after activity of the technology. In general, the variables like choice of plant and substrates, water depth, hydraulic loading rate, hydraulic retention time (HRT), feeding mode, microorganisms and physiochemical parameters like moisture, temperature (T), dissolved oxygen (DO), oxidation-reduction potential (ORP), pH as well as chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), concentrations of Heavy Metals may be vibrant to the success of established CW program and effective treatment efficacy. Overload hydraulic would result in insufficient retention times, which might inhibit the denitrification. However, because lower HLR corresponded to enough retention time for the bacteria, the dissolved oxygen in the system would be reduced. (C. Shiwei et al., 2019).

In the VSF systems, oxygen is partially transferred down into the root zone. Meanwhile, greater amount of oxygen is transferred through the wetland plants from the air to the root. On the basis of experiments conducted, it was marked that, the pollutants removal efficiency of the vertical wetland in terms of TSS, BOD, COD, TKN, Phosphates and Ammonia was 60 – 70%, 50 – 60%, 50 - 60%, 25 - 35%, 30 - 40% and 60 - 70% respectively and of the horizontal wetland in terms of 80 - 85%, 85 - 90%, 85 - 95%, 75 – 85%, 35 - 45%, and 70 - 80% respectively. However, it was worth reporting that, in HSF systems, the effluent is categorized by very low level of dissolved oxygen. Under this environment, the oxygen is remained at very low level to oxidize the ammonium nitrogen to nitrate. Thus, VSF system ensures high oxidation and efficient nitrification. On the other hand the overall pollutants removal by the HF–VF hybrid system reached 95 - 98%, 96 - 99%, 96 - 99%, 80 - 85%, 65 - 70% and 90 – 95 % for TSS, BOD, COD, TKN, Phosphate and NH3, respectively.

CWs also remove metals and pathogens present in wastewater. Filtration and sedimentation, Precipitation, Adsorption and Uptake by the helophytes and microorganisms are the main mechanisms for the removal of metal from industrial effluent in CW, (Stottmeister et al., 2003; Debusk, 1999). The metal removal efficiency was reported to be 70 – 99.7% cadmium, 22 - 28% lead, 73 - 77% silver and 62 - 68% zinc. In such way, Heavy metals are noted to be removed from wastewater and trapped in the wetland sediments and either may be adsorbed to soil or sediment or may be chelated or complexed with organic matter. Maximum concentration of metals in plants was observed in roots. Barley et al. (2005) also reported the highest metal concentrations in the roots of wetland plants.

Moreover CW systems have excellent pathogen removal efficiency as reported in different literatures (Stottmeister et al., 2003; Gersberg et al., 1987; Ottova et al., 1997). These systems act as biofilter through a combination of physical, chemical and biological processes which all participates in the reduction of the number of pathogens (Brix, 1993). Physical processes include aggregation, filtration, sedimentation and exposure to ultra-violet ray, chemical processes like adsorption, oxidative damage and exposure to toxins given off by other microorganisms and plants (Gersberg et al., 1989). Biological processes include natural death, ingestion by nematodes, protozoans, lytic bacteria and bacteriophages attacks (Ottova et al., 1997). It is reported that the elimination of coliforms (more than 90%) and streptococci (more than 80%) in various systems of constructed wetlands (Kadlec and Knight, 1996) and the reduction in faecal coliform populations up to 99% by CW (Neralla et al., 2000).

Conclusion:

This review paper explains various factors for constructed wetland wastewater treatment management design and operation such as plant choice, substrate choice, water depth, loading rate, hydraulic retention time and feeding mode are essential to achieve the sustainable treatment performance. Wetland macrophytes having presence of microorganisms and substrates characterize two factors that impact the efficiency of pollutant removal in CWs. More attention should be given to appropriate plant species selection for CWs. A serious evaluation of differences between plant species and season is also needed. In addition, some non-conventional wetland media, characterized by high sorption capacity, should be studied and used for CWs. Moreover, the review of the design and operating parameters shows that the best treatment performance is extremely dependent on environmental, hydraulic and operating conditions. Therefore, understanding how to achieve and optimize these conditions permits more exploration. Additional research on the critical pathways and mechanisms with some modification corresponding to pollutant removal should be taken into consideration. On the basis of earlier studies, the results revealed that the hybrid wetland systems boosted the effluent quality. This is mainly due to the relatively low velocity and high surface area of the hybrid system made up of HF–VF systems. To obtain efficiently treated effluent by using HSF or VSF CWs, separately, longer detention time is required which is further resulted in increasing water loss. Consequently, the hybrid CWs proved a promising technology for the treatment of wastewater.

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