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A review of the vertical constructed wetland ecological system as tertiary wastewater treatment: setup, performance, efficiency

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Abstract

Disposal of untreated wastewater from households as well as institutions and industrial areas is causing deterioration of water bodies in urban areas in developing countries. Therefore a high level of responsibility towards water usage is required and must be recycled according to pollutant content to maintain water quality and protect our environment. One of the sustainable and efficient methods of treatment is the ecological system as well as a constructed wetland. Constructed wetlands (CWs) have a great potential for wastewater treatment. These systems consist of beds or channels which have been planted with helophytes (water-loving plants), which rely upon physical, chemical, and biological processes to remove wastewater contaminants. CWs are generally classified into two categories, surface flow, and subsurface flow. Both of the systems are capable of removing nitrogen, phosphorus, biochemical oxygen demand, chemical oxygen demand, total suspended solids, metals, and pathogens from different types of domestic and industrial wastewaters.

The paper provides a review of the vertical constructed wetland system setup and the removal mechanisms of contaminants in this system which includes many processes such as aerobic, anaerobic, microbiological conversions, sedimentation, chemical transformations, physicochemical adsorption, and chemical precipitation. This review paper presented the vertical constructed wetlands as tertiary wastewater treatment systems with high efficiency, sustainability, and effective cost.

Keywords: Constructed wetlands, Mechanism, contaminants, wastewater treatment, and vertical constructed wetland.

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I. INTRODUCTION

Constructed wetlands (CW) are engineered wetland ecosystems that have been designed and constructed to use natural wetland processes for the removal of pollutants . These systems mimic marshes with aquatic plants, soil, and associated microorganisms but take advantage of a controlled environment to treat wastewater.

The concept of constructed wetlands was given by Kathe Seidel in the early 1950s. She studied the CW system for the treatment of different types of wastewater at Max Planck Institute in Poln, Germany]. The first full-scale free water surface (FWS, surface flow) CW was built in the Netherlands to treat wastewater from a camping site during the period 1967-1969s This system had a star-shaped layout and was called a "planted sewage farm, However, FWS CWs did not spread substantially in Europe where subsurface flow constructed wetlands prevailed in the 1980s and 1990s].

In the 1980s, treatment technology of constructed wetlands rapidly spread around the world. In the 1990s, increased demand for nitrogen removal from wastewater led to more frequent use of vertical flow (VF) CWs which provided a higher degree of filtration bed oxygenation and consequent removal of ammonia via nitrification]. In the late 1990s, the inability to produce simultaneously nitrification and de-nitrification in a single HF or VF CWs and thus remove total nitrogen led to the use of hybrid systems which combined various types of CWs.

CW is usually considered to be one of the most promising technologies to treat wastewater due to its low cost, simple operation and maintenance (O/M), little secondary pollution, and favorable environmental appearance. In general, CWs can be grouped into two categories of free water surface and subsurface-flow.

Free water surface wetlands can be sub-classified according to their dominant type of vegetation: Emergent macrophyte, free-floating macrophyte, or submerged macrophyte. Subsurface flow wetlands can best be sub-classified according to their flow patterns: Horizontal flow or Vertical flow. A classification system is shown in Fig.1.

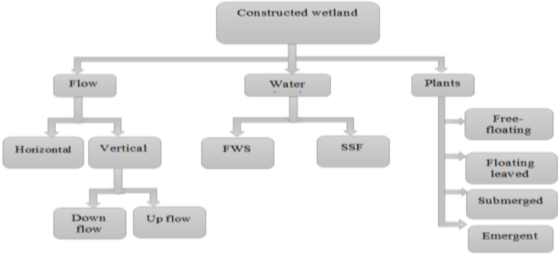

Fig.1. Types of constructed wetlands for wastewater treatment [5].

A vertical flow constructed wetland is a planted filter bed that is drained at the bottom. Wastewater is poured or dosed onto the surface from above using a mechanical dosing system [6]. The water flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe.

A. Vertical flow constructed wetland types

1) down flow type

The earliest form of down flow VFS is that of Seidel in Germany in the 1970s, sometimes called the Max Planck Institute Process (MPIP) or the Krefeld Process. Similar systems in the Netherlands were called "infiltration fields" [7]. Interest in the particular process has been revived in the last decade because of the need to produce beds that nitrify and overcome the problem of HF beds. The typical arrangement of down flow VFS is shown below in Fig .2.

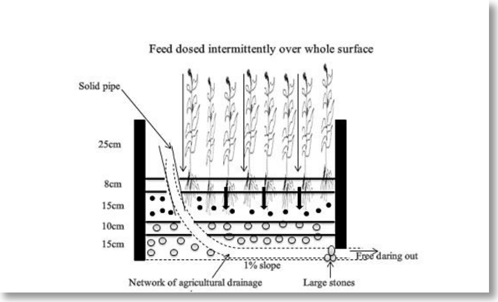

Fig. 2. Typical arrangement of a down flow vertical flow constructed wetland [8].

Vertical flow constructed wetlands (VF CW) comprise a flatbed of graded gravel topped with sand planted with macrophytes. The size fraction of gravel is larger in the bottom layer (e.g. 30-60 mm) and smaller in the top layer (e.g., 6 mm). VFCW are fed intermittently with a large batch thus flooding the surface. The wastewater then gradually percolates down through the bed and is collected by a drainage network at the base. The bed drains completely free and it allows air to refill the bed, this kind of dosing leads to good oxygen transfer and hence the ability to nitrify [9].

2)up flow

In vertical-up flow CW the wastewater is fed on the bottom of the filter bed. The water percolates upward and then it is collected either near the surface or on the surface of the wetland bed. These systems have commonly been used in Brazil since the 1980s [10]. The beds are filled with crushed rock on the bottom, the next layer is coarse gravel and the top layer is soil planted with Rice (Oryza sativa).

This treatment system is called in Brazil "filtering soil" Fig .3. However, outside Brazil, the layer of soil is usually not used and beds are filled with gravel and usually planted with common species such as Phragmites Australia.

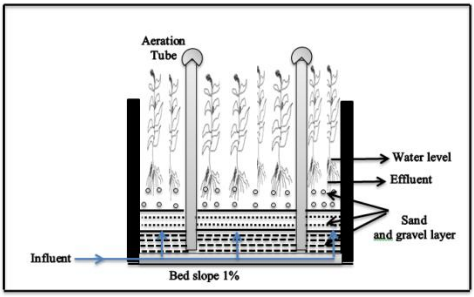

Fig.3. Typical arrangement of an up-flow vertical flow constructed wetland. [11]

B. Set-up and operational parameters of vertical flow constructed wetlands

1) System set-up

A full-scale VFCW system usually consists of several similar beds in parallel operation for each treatment stage (usually, two or three treatment stages in series are used as shown in Fig.4. Before the VFCW bed, a pretreatment stage is usually present, which serves as the primary treatment stage. The second treatment stage contains several parallel units depending on the wastewater volume and load to be treated [12].

The number of parallel beds in the third stage is usually smaller since they receive the treated effluent from the second stage. Respectively, smaller is the area required for the beds of the third stage. The third stage may be an HSF or an FWS CW, or even a different natural treatments system (e.g., a stabilization pond). This configuration is usually applied for large full-scale facilities.

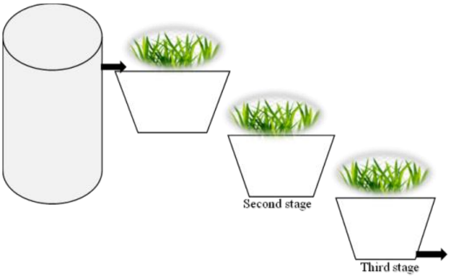

Fig.4. Typical layout of a full-scale VFCW facility: pretreatment stage followed by two to three VFCW stages [12].

A general vertical section of a VF down flow CW cell is presented in Fig.5. AFCW typically consists of:

a) ***Inlet devices (feeding and distribution system)***

Depending on the terrain different options are given: the high difference between the pretreated wastewater and the bed allows for the use of mechanical devices without the need for electrical, fossil, or solar energy. This energy-less system are siphon or tipping buckets. The intermittent feeding device may be switched either by quantity, time or both. Water is then usually distributed by networks of perforated pipes [13].

b) ***Drainage pipes***

Drainage pipe networks, which are perforated and spread over the whole bed of the cell, end into the effluent pipe.

c) ***A basin***

A basin (cell) made of either reinforced concrete or, most often, earth covered by High-density polyethylene (HDPE) membrane (for waterproofing).

d) ***Filter media***

There are many variations in the configuration of the filter layers. Filter materials specified include sand (0.2-0.6mm d_{50}), fine gravel (6-16mm d_{50}), medium gravel (24-32 mm d_{50}) and coarse stone (60-130mm d_{50}). The number of materials or manufactured materials is sometimes specified as filter media, including expanded clay aggregate, shells, iron, and zeolite.

e) ***Plants***

The function of plants can provide support for microbes for biofilm development and increase the contact time between wastewater and microbes; through their movement by the wind, they increase the hydraulic conductivity of the substrate and reduce the risk of clogging; they insulate the substrate reducing the risk of ice formation; they transfer oxygen from the atmosphere to the substrate, thus creating aerobic conditions around the roots; and they uptake nutrients.

CW plants are emergent macrophytes that can grow in saturated or semi-saturated conditions. The most commonly used species in Europe include the common reed (Phragmites australis) and the cattail (Typha latifolia), while other species used are the bulrushes (Scirpus spp.), rushes (Juncus spp.), and sedges (Carex spp.).

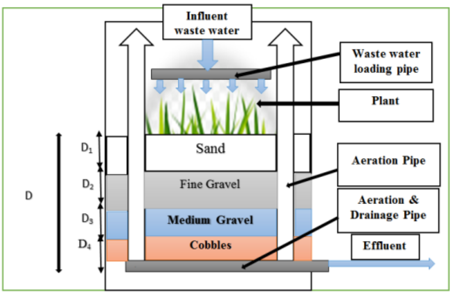

Fig.5. Vertical section of a VF CW cell [14]

2) Operational parameters

a) Hydraulic load (HL)

HL or hydraulic loading rate (HLR) is the flow applied to the surface of the filter per unit time. It is normally expressed in m/day or cm/day. The HL is inversely proportional to the hydraulic retention time for a given SSFCW depth, and it varies from site to site and depending on wetland configuration [13].

b) Organic loading rate (OLR)

Organic load or OLR depends on the inlet quality and the HL. OLR in SSFCWs is expressed in grams of COD or BOD$_5$ per area (m^2) per time (day). The US EPA itself, in its manual on CWs for municipal wastewater treatment (USEPA, 2000), recommends the use of area per gram of COD as a "conservative" approach to ensure reliable functioning and to respect the established concentration limits. VFCWs can accept higher OLR than HFCWs.

c) Dosing and feeding regime

SSFCWs can operate continuously usually by gravity or intermittently (doses). The HFCWs usually operate continuously and the VFCWs are often intermittently loaded. This may influence the hydraulics of the beds as well as the oxygenation, thereby affecting the removal processes .when intermittently feeding the VFCWs, the number and quantity of doses per day may also affect the performance [13]. SSFCWs can also be operated with a feeding resting period. The application of resting periods (as explained for the IP technology) can also affect the oxygenation in the bed as well as the biomass growing.

II. GENERAL POLLUTANT REMOVAL MECHANISMS

Based on the functions and biogeochemical processes occurring within wetlands as a result of long-term saturation, constructed wetlands have the ability to remove or filter pollutants from the water directed through them. Removal mechanisms can act uniquely, sequentially, or simultaneously on each contaminant group or species. As Fig.6 illustrates, processes taking place in a constructed wetland may be a biotic (physical, chemical) or biotic (microbial, phytological). The mechanisms used for treatment/removal of a contaminant depend on the specific contaminant, site conditions, remedial objectives, and regulatory issues. [15]

Treatment processes in wetlands incorporate several physical, chemical, and biological processes. The major physical process is the settling of suspended particulate matter which is a major cause of BOD reduction. The chemical processes involve adsorption, chelation, and precipitation, which are responsible for the major removal of phosphorus and heavy metals. In terms of biological processes, the treatment is achieved by microorganisms [2] [16]. Due to fixed film or a free bacterial development, biological processes allow the degradation of organic matter, nitrification in aerobic zones, and denitrification in anaerobic zones. The microbiological activity is the key parameter for their performance. The overall processes taking place in subsurface flow constructed wetlands for the removal of contaminants are summarized in Table .1.

All CW systems have been proved to be capable of removing a variety of pollutants present in wastewater such as organic matter (biological oxygen demand (BOD_5) and chemical oxygen demand (COD)), suspended solids, nitrogen, phosphorus, heavy metals, and pathogenic microorganisms.

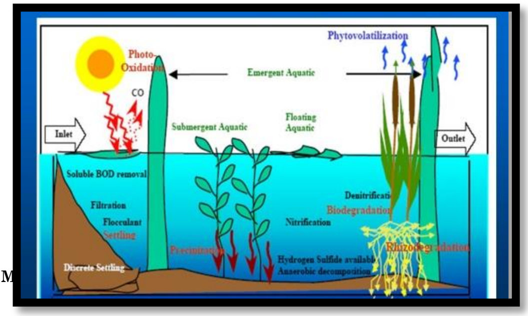

Fig.6. Processes Occurring in Constructed Wetland [17]

A. Total Organic Carbon and Oxygen Demand

Wastewaters contain a wide variety of organic compounds, which are measured as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). The main routes for organic carbon removal include volatilization, photochemical oxidation, sedimentation, sorption, and biodegradation. Organic contaminants sorbed onto particles flowing into the wetlands settle out in the quiescent water and are then broken down by the micro biota in the sediment layer [18].

The basis for the COD test is that nearly all organic compounds can be fully oxidized to carbon dioxide with a strong oxidizing agent under acidic conditions. The COD value is always measured by the acidic potassium permanganate method and potassium dichromate method and could reflect the pollution degree of reducing matter in water, including ammonia and reducing sulfide, so in wastewater with a high quantity of reducing matter, the COD value will overestimate the organic pollutants in the water.

BOD value is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at a certain temperature over a specific period. The BOD value is most commonly expressed in milligrams of oxygen consumed per liter of the sample during 5 days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water. This is not a precise quantitative test, although it is widely used as an indication of the organic quality of water. [19]

TOC value is the amount of total carbon (water-soluble and suspended in water) in the water. Using combustion during the assessment, this method could oxidize all the organic pollutants, and value reflects the amount of organic matter more directly than BOD_5 or COD.

The COD, BOD, and TOC tests could quickly reflect the organic pollution in the wastewater, however, they can't reflect the kinds of organic matter and composition of the water, and therefore cannot reflect the total amount of the same total organic carbon pollution caused by different consequences.

B. Total Suspended solids (TSS)

Inorganic and suspended solids are removed by physical processes. The main removal mechanism for total suspended solids (TSS) in VFCWs is gravitational settling (sedimentation) and filtration. As the wastewater drains vertically, it passes through the pores of the substrate media, and the velocity of the water current is decreased. The solids are trapped within the pores either mechanically or by adhesion [20]. A gradual accumulation of solids is probably the main parameter affecting substrate clogging. Solids accumulate on top of the bed (usually above the sand layer), creating a sludge-litter layer (also known by its German term“schmutzdecke”), as also within the substrate pores (physical blocking) and onto the surface of the media grains. In VFCWs, intermittent loading and application of resting periods between loadings allow for the good aeration of the bed and the oxidation of the accumulated organic solids, which also prevents bed clogging.

C. Nitrogen Removal

As we know that high concentration of nitrogen in domestic and industrial wastewater causes a very serious problem of eutrophication in wastewater receiving bodies. On the other hand, a variety of inorganic and organic nitrogen forms is essential for all living organisms. Nitrogen may be removed from wastewaters by several processes in CWs like adsorption, volatilization, plant adsorption & uptake, ammonification, and nitrification-denitrification complex are the most important removal pathways around the root zone. The inorganic forms of nitrogen present in wastewater are ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). All these inorganic forms of nitrogen are significantly removed by the plant uptake at low hydraulic loading rates [21].

1) Nitrification

Nitrification is the oxidation of ammonium to nitrate mediated by nitrifying bacteria. This process is only operational under aerobic conditions and is divided into two steps: first is the conversion of ammonium to nitrite by Nitrosamines bacteria and second is a conversion of nitrite to nitrate by Nitrobacteria bacteria. In this process, the nitrifying bacteria drive energy from the oxidation of ammonia and nitrite while carbon dioxide is used as a carbon source [22]. The overall reactions for these two steps are:

$$\mathrm{N}H_4{}^{+} + \ 1.5O_2 \rightarrow \mathrm{N}O_2{}^{-} + \ H_2\mathrm{O} + 2H^{+} \qquad (1)\ [22]$$

$$\mathrm{N}O_2{}^{-} + \ 0.5O_2 \rightarrow \mathrm{N}O_3{}^{-} \qquad (2)\ [22]$$

2) Denitrification

Denitrification is an anaerobic decomposition process in which organic matter is broken down by microorganisms (such as Pseudomonas, Micrococcus, and Bacillus) using nitrate instead of oxygen as an electron acceptor [23]. The process occurs in two steps: the first nitrate is reduced to nitrous oxide, which is subsequently further reduced to atmospheric nitrogen. Denitrification is illustrated by the following equation. [23]

$$2NO_3^- \rightarrow 2NO_2^- \rightarrow 2\,NO \rightarrow N_2O \rightarrow N_2 \qquad (3)$$ [23]

Denitrification contributes to 60-70% of the total nitrogen removal in CWs. The rate of denitrification is influenced by many factors such as nitrate concentration, microbial flora, type and quality of organic carbon source, hydroperiods, different plant species residues, the absence of O_2, redox potential, soil moisture, temperature, pH value, presence of denitrifies, soil type, water level, and the presence of overlying water.

3) Ammonification

Ammonification represents the first step in the N transformation chain. The organic nitrogen contained in the influent wastewater is converted to ammonia, as Equation (4) depicts [20].

$$\text{Amino acids} \rightarrow \text{Imino acids} \rightarrow \text{Keto acids} \rightarrow NH_3 \quad (4)$$ [20]

$$\text{E.g. .: amino acid: } RCH\,(NH_2)\,COOH + H_2O \rightarrow NH_3 + CO_2 \quad (5)$$ [20]

$$\text{Urea: } CO\,(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2 \quad (6)$$ [20]

Usually, most of the organic N is transformed to ammonia by microbes. This process takes place in both aerobic and anaerobic areas of the bed but proceeds rapidly in the oxygen-rich layers. Ammonification takes place faster than nitrification in terms of kinetics [24]. This process is affected by temperature, pH, C/N ratio, nutrient content, and soil conditions. The optimum pH area is between 6.5 and 8.5 and temperature between 40 and 60°C, while it is reported that the ammonification rate doubles with a 10°C temperature increase. Ammonification has not been investigated at the same level, compared to other processes, while various rates have been reported in the literature up to 0.53 g N/m^2/d.

In VFCWs, the ammonification rate decreases with substrate depth, thus higher rates are observed in the upper aerobic zone. Practically, N is not removed by this process but converted to ammonia, which is then subjected to other removal processes. Due towel-aerated conditions, the ammonification rate is at high levels in VFCWs compared to other CW types.

D. Phosphorus removal

Phosphorus (P) is a macronutrient of special importance for all biological organisms. It is present in various wastewater types. High P content, together with nitrogen, in surface water, contributes to eutrophication which favors algal and plant growth and results in the depletion of the oxygen amount in the water column with negative impacts on the aquatic organisms. Major sources of P are untreated or insufficiently treated wastewater; agricultural practices; domestic, urban, and industrial runoff.

P, like nitrogen, is a useful nutrient for plants, which utilize it for their growth. P in wastewater appears in various organic and inorganic forms [22].

Free orthophosphate (OP: $PO_4^{-3} - P$) is a common form in wastewater and exists in ionic equilibrium.

$$H_3PO_4 \leftrightarrow H_2PO_4^{-} \leftrightarrow HPO_4^{-2} \leftrightarrow PO_4^{-3} \qquad (7)$$ [22]

Under pH values between 5 and 9, H_2PO_4 and HPO_4^{-2} are abundant. Polyphosphates (cyclic, linearly condensed) are another inorganic form, while organically bound compounds can also be found, like phospholipids, nucleic acids, and phosphorylated sugars, among others. Dissolved phosphates are the most reactive and result in hydration change with pH variations. In wetland environments, many transformations of P forms take place Figure .7. Dissolved organic P and insoluble organic and inorganic P have to be converted into soluble inorganic forms, in order to be subjected to biological consumption. Plants take up soluble reactive P to cover their growth needs and convert it to tissue P, while P is also sorbed to wetland substrate.

The main transformation/removal mechanisms of P in CWs include adsorption-desorption, precipitation, plant microbial uptake, and mineralization. As mentioned previously, VFCWs are capable of removing high amounts of nitrogen and OM, as a result of various processes. On the other hand, P removal is more problematic compared to other pollutants, i.e., organic matter or nitrogen Rousseau et al [25].

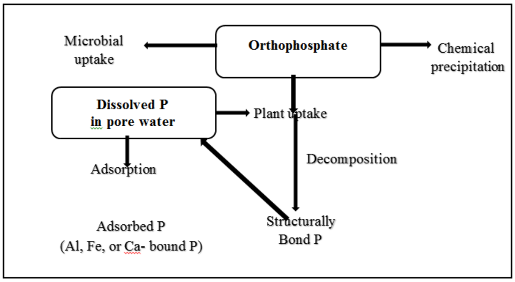

Figure 7.Phosphorus transformation and removal processes in VFCWs [25].

Table. 1. Contaminant removal mechanisms in constructed wetlands [25].

Parameters	Physical	Chemical	Biological
Suspended solids	Sedimentation Filtration		Biodegradation
Biochemical oxygen demand	Sedimentation	Oxidation Reduction	Biodegradation
Chemical oxygen Demand.	Sedimentation	Oxidation Reduction	Biodegradation Phytodegradation Phytovolatilization Plant uptake

Nitrogenous Compounds	Sedimentation Volatilization	Adsorption	Bio-denitrification-nitrification Plant uptake
Phosphoric Compounds	Sedimentation	Adsorption Precipitation	Microbial uptake Plant uptake
Metals	Sedimentation Filtration	Adsorption Precipitation	Plant uptake
Pathogens	Filtration UV ray action	Adsorption Oxidation	Natural death Exposure to natural toxins Bacteriophage attack

III. AQUATIC PLANT SYSTEMS

Aquatic plant systems are shallow ponds with floating or submerged aquatic plants. The most thoroughly studied systems are those which use water hyacinth or duckweed. These systems include two types based on the dominant plant types.

The first type uses floating plants and is distinguished by the ability of these plants to derive their carbon dioxide and oxygen needs from the atmosphere directly. The plants receive their mineral nutrients from the water. The second type of system consists of submerged plants and is distinguished by the ability of these plants to absorb oxygen, carbon dioxide, and minerals from the water column. Submerged plants are relatively easily inhibited by high turbidity in the water because their photosynthetic parts are below the water [26].

In general, the most significant functions of wetland plants (emergent's) concerning water purification are the physical effects brought by the presence of the plants. The plants provide a huge surface area for attachment and growth of microbes. The physical components of the plants stabilize the surface of the beds, slow down the water flow thus assist in sediment settling and trapping process and finally increasing water transparency. Wetland plants play a vital role in the removal and retention of nutrients and help in preventing the eutrophication of wetlands [27]. A range of wetland plants has shown their ability to assist in the breakdown of wastewater. Table.2 has shown the Brief summary of plant roles in constructed wetlands (CWs).

The roles of wetland plants in constructed wetland systems can be divided into five categories:

A. Physical

Macrophytes stabilize the surface of plant beds, provide good conditions for physical filtration, and provide a huge surface area for attached microbial growth. Growth of macrophytes reduces current velocity, allowing for sedimentation and increase in contact time between effluent and plant surface area, thus, to an increase in the removal of Nitrogen. Furthermore, the soil hydraulic conductivity is improved in an emergent plant bed system. Turnover of root mass creates macropores in a constructed wetland soil system allowing for greater percolation of water, thus increasing effluent/plant interactions.

B. Organic compound release

Plants have been shown to release a wide variety of organic compounds through their root systems, at rates up to 25% of the total photosynthetically fixed carbon. This carbon release may act as a source of food for denitrifying microbes [27]. Decomposing plant biomass also provides a durable, readily available carbon source for microbial populations.

C. Microbial growth

Macrophytes have above and below-ground biomass to provide a large surface area for the growth of microbial biofilms. These biofilms are responsible for a majority of the microbial processes in a constructed wetland system, including Nitrogen reduction.

Plants create and maintain the litter/humus layer that may be likened to a thin biofilm. As plants grow and die, leaves and stems fall to the surface of the substrate create multiple layers of organic debris (the litter/humus component). This accumulation of partially decomposed biomass creates highly porous substrate layers that provide a substantial amount of attachment surface for microbial organisms. The water quality improvement function in constructed and natural wetlands is related to and dependent upon the high conductivity of this litter/humus layer and the large surface area for microbial attachment.

D. Creation of aerobic phase

Macrophytes mediate the transfer of oxygen through the hollow plant tissue and leakage from root systems to the rhizosphere where aerobic degradation of organic matter and nitrification will take place. Wetland plants have adaptations with supersized and lignified layers in the hypodermis and outer cortex to minimize the rate of oxygen leakage.

The high nitrogen removal of Phragmites is most likely attributable to the characteristics of its root growth. Phragmites allocates 50% of plant biomass to root and rhizome systems. Increased root biomass allows for greater oxygen transport into the substrate, creating a more aerobic environment favoring nitrification reactions.

Nitrification requires a minimum of 2 mg O_2/l to proceed at a maximum rate. The rate of nitrification is most likely the rate-limiting factor for overall Nitrogen removal from a constructed wetland system.

E. Aesthetic values

The macrophytes have additional site-specific values by providing habitat for wildlife and making wastewater treatment systems aesthetically pleasing.

Table .2. A brief summary of plant roles in constructed wetlands (CWs) [28].

	Role of plants in a constructed wetland
Physical effects of root structure	Filtering effect. Velocity reduction, promotion of sedimentation, decreased re suspension. Prevention of medium clogging. Improved hydraulic conductivity. Macrophytes do not increase hydraulic conductivity and even contribute to clogging. No effect on removal of suspended solids.
Roots as a base for microorganisms	Provision of surface for microbial attachment. Root release of gas and exudates. Oxygen leakage addition of aerobic niches. Oxygen leakage increased aerobic degradation. Oxygen leakage supports precipitation of heavy metals. Oxygen leakage increased nitrification. Excretion of carbon increased denitrification. Aerobic dynamics are very limited in horizontal flow CWs.
Plant uptake	Storage and uptake of nutrients. Plant nutrient uptake is negligible. Metal phytoremediation. Salt phytoremediation.
Microclimatic conditions	Light attenuation reduces algal growth. Insulation from frost in the winter. Insulation from radiation in the spring. Reduced wind velocity. Stabilization of the sediment surface.
Other functions of plants in the CW	Elimination of pathogens. Insect and odor control. Enhanced mosquito reproduction. Wastewater gardens. Increased wildlife diversity. Aesthetic appearance of the system. Bio indicators.

IV. PERFORMANCE EFFICIENCY OF VFCWs IN BACKGROUND STUDIED

Sara G. Abdel Hakeem, designed vertical flow constructed wetland units located in Zenien wastewater treatment plant in Giza, Egypt. Common read plants (phragmites. Australia) were cultivated in this system. The performance of the system was operated during eight-month and the experiments were conducted under the presence and absence of plants.

The average removal efficiencies of chemical oxygen demand (COD), ammonium (NH_4), and total phosphorus (TP) were 75%, 32%, and 22% respectively for the planted beds compared to 29%, 26%, and 17% for unplanted beds [29].

Vertical flow constructed wetland for domestic wastewater treatment from family Subandi house was studied by Denny Kurniadie from Bandung, Indonesia [30]. The system was planted with phragmites KarKa. The filter bed was a multi-layer bed with sand as the main media. In this study, the average treatment efficiency for COD, PO_4, and NH_4 during the period of March 1999- January 2000 was 81.08%, 68.59%, and 90.54% respectively.

S. MIMIS. et al., [31] have studied constructed wetland at the American farm school, Thessaloniki, Greece using two pilot-scale VF reed beds planted with native reeds. The wastewater fed to the VF reed beds was a pretreated mixture of municipal and animal farming liquid wastes. The experiments were carried out from April 2006 to July 2006.

Chemical oxygen demand removal efficiency was close to 95% an average out of the constructed wetland beds. The relatively small removal efficiency was observed for ammonia (NH_4-N) which was on average 20%.

Bhushan Tuladhar, et al., [32] have shown the importance of small-scale decentralized wastewater treatment using reed bed treatment systems (RBTS) in Nepal. The treatment plant has been constructed having the capacity to treat $50m^3$ of wastewater per day. The vertical flow and horizontal flow reed bed were constructed. A typical Vertical flow system can remove the BOD_5 of up to 96%; the Horizontal flow system can remove only up to 65%. The system is found to be highly effective in removing pollutants such as suspended particles, ammonia-nitrogen, BOD, COD, and pathogens. In general, the performance of the CWs has been excellent. Regular monitoring of the systems shows high pollutant removal efficiency achieving close to 100% removal of total coliforms and organic pollutants.

M C Perdana et.al [33] Designed vertical flow constructed wetland system located in Sewon District, Bantul, and Yogyakarta. The study was conducted in the Laboratory of Ecology of Duta Wacana Christian University (DWCU) for three months from March to May 2015. This experimental study applied four treatments control (unplanted), single species Iris pseudacorus, single species Echinodorus palaefolius, and combination (Iris pseudacorus and Echinodorus palaefolius) with three days of retention time.

The result showed that the best average value of effectiveness for each of the parameters: COD by combination treatment (50.76%),' Nitrate by single E. palaefolius (58.06%), and Phosphate by single E. palaefolius (99.5%).

Atif Mustafa [34] conducted treatment performance of a pilot-scale constructed wetland (CW) commissioned in Karachi, NED University of Engineering & Technology, was evaluated for removal efficiency of chemical oxygen demand (COD), ammonia-nitrogen (NH_4-N), ortho-phosphate (PO_4-P), from pretreated domestic wastewater. Monitoring of wetland influent and effluent was carried out for 8 months. NED wastewater treatment plant (WWTP) treats wastewater from campus and staff colonies. The wastewater contains domestic sewage and low flows from laboratories of various university departments. The constructed wetland is planted with a common wetland plant (Phragmites karka). The key features of this CW are horizontal surface flow. Treatment effectiveness was evaluated which indicated good mean removal efficiencies; COD (44%), NH_4-N (49%), and PO_4-P (52%).

Yadav, et al., [35] construct a wetland unit combined with the surface flow and planted with Eichhornia crassipes was built near Technology Department, Shivaji University, and Kolhapur. Maharashtra situated in the Western part of India. The campus wastewater was let into the constructed wetland intermittently over 30 days. The study was performed in two sets A and B which were run from December and January, respectively. The parameters analyzed for the study were pH, Dissolved Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand, Total Suspended Solids, Total Dissolved Solids, Nitrogen, and Phosphorus. Only the quality of wastewater was analyzed during the study period of two months from December and January. The sampling took place daily at both inlet and outlet of the constructed wetland system. Treatment effectiveness was evaluated which indicated good mean removal efficiencies; BOD (95%), COD (97%), TSS (82%), NH_4-N (43%), PO_4-P (49%).

V. CONCLUSION

Vertical constructed wetlands (VCW) have a great potential to treat contaminated wastewater from different origins. With careful designing and planning, a VCW can efficiently remove a variety of inorganic, organic, and biological contaminants from domestic and industrial wastewaters. The cost for design and construction can be considerably lower than other conventional wastewater treatment options. These systems also enhance the aesthetic value of the local environment.

In this paper provides a review of the vertical constructed wetland system setup and the removal mechanisms of contaminants in this system which includes many processes such as aerobic, anaerobic, microbiological conversions, sedimentation, chemical transformations, physicochemical adsorption, and chemical precipitation. This review paper presented the vertical constructed wetlands as tertiary wastewater treatment systems with high efficiency, sustainability, and effective cost.

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