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Constructed Wetlands – Natural Treatment of Wastewater Using Aquatic Plant

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ABSTRACT: Constructed wetlands are engineered and managed wetland systems that are increasingly receiving worldwide attention for wastewater treatment and reclamation. Compared to conventional treatment plants, constructed wetlands are cost-effective and easily operated and maintained, and they have a strong potential for application in a small community. Constructed wetlands for wastewater treatment have substantially developed in the last decades. As an eco-friendly treatment process, constructed wetlands may enable the effective, economical, and ecological treatment of agricultural, industrial, and municipal wastewater. In this paper the inlet and outlet wastewater physico-chemical parameters were analysed during the retention period. The parameters studied were pH, BOD, COD, DO, Total Suspended Solids, Total Dissolved Solids, Nitrogen and Phosphorus. The percentage removal of the parameters were analysed and studied until the percent removal rate gets stabilized.

KEYWORDS: Constructed wetland, Wastewater treatment, Nitrification, Denitrification, Phosphorus removal, Heavy metals removal, Aquatic plant, BOD, COD, pH

I. INTRODUCTION

1.1 GENERAL

Globally, most of the developing countries are geographically located in those parts of the world that are or will face water shortages in the near future. Moreover, the existing water sources are contaminated because untreated sewage and industrial wastewater is discharged into surface waters resulting in impairment of water quality. The treatment of wastewater using Constructed Wetland (CW) is one of the suitable treatment systems, used in many parts of the world. Wetlands are defined as land where the water surface is near the ground surface long enough each year to maintain saturated soil conditions, along with the related vegetation. Marshes, bogs, and swamps are all examples of naturally occurring wetlands.

A “constructed wetland” is defined as a wetland specifically constructed for the purpose of pollution control and waste management, at a location other

than existing natural wetlands. Wetlands can be used for primary, secondary, and tertiary treatments of domestic wastewater, storm wastewater, combined sewer overflows (CSF), overland runoff, and industrial wastewater such as landfill leachate and petrochemical industries wastewater. The most common systems are designed with horizontal subsurface flow (HF CWs) but vertical flow (VF CWs) systems are getting more popular at present. The most commonly used species are robust species of emergent plants, such as the common reed, cattail and bulrush.

1.2 ADVANTAGES OF CONSTRUCTED WETLANDS

- Wetlands can be less expensive to build than other treatment options
- Utilization of natural processes,
- Simple construction (can be constructed with local materials),
- Simple operation and maintenance,
- cost effectiveness (low construction and operation costs),

- Process stability.
- Low energy demand.
- Low environmental impact

1.3 LIMITATIONS OF CONSTRUCTED WETLANDS

- large area requirement
- wetland treatment may be economical relative to other options only where land is available and affordable.
- Design criteria have yet to be developed for different types of wastewater and climates.

1.4 NATURAL WETLANDS VS. CONSTRUCTED WETLANDS

A natural wetland is an area of ground that is saturated with water, at least periodically. Plants that grow in wetlands, which are often called wetland plants or saprophyte, have to be capable of adapting to the growth in saturated soil.

Constructed wetlands, in contrast to natural wetlands, are man-made systems or engineered wetlands that are designed, built and operated to emulate functions of natural wetlands for human desires and needs. Engineered to control substrate, vegetation, hydrology and configuration. It is created from a non-wetland ecosystem or a former terrestrial environment, mainly for the purpose of contaminant or pollutant removal from wastewater (Hammer). These constructed wastewater treatments may include swamps and marshes. Most of the constructed wetland systems are marshes. Marshes are shallow water regions dominated by emergent herbaceous vegetation including cattails, bulrushes, and reeds.

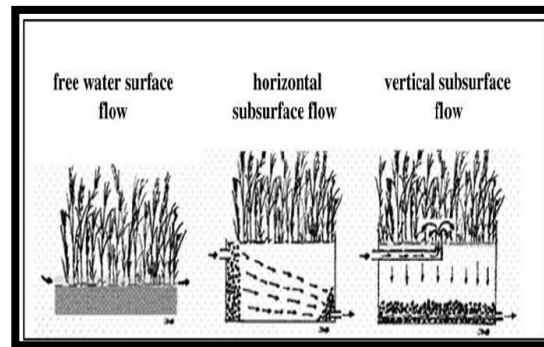


(Fig.1 A natural wetland)



(Fig.2 A constructed wetland)

1.5 CLASSIFICATION OF CONSTRUCTED WETLANDS

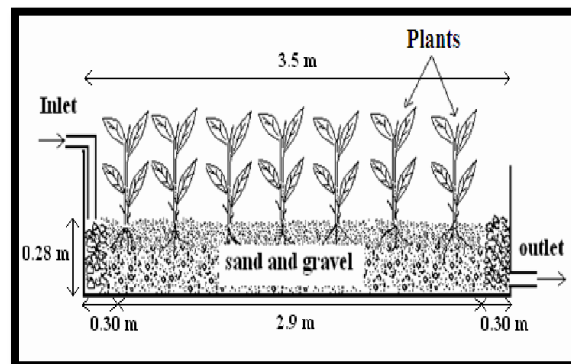


(Fig.3 Types of Wetlands)

- FSFCW: Free surface flow constructed wetland
- SSFCW: Subsurface flow constructed wetland
- HFSSCW: Horizontal flow Subsurface constructed wetland.
- VFSSCW: Vertical flow Subsurface constructed wetland.

1.6 PLANTING TECHNIQUE

- Plants can be introduced to a wetland by transplanting roots, rhizomes, tubers, seedling or mature plants;
- by importing substrate and seed bank from nearby wetlands or;
- by relying completely on seed bank of the original site;
- choosing plants from wild stock is more desirable than nurseries as they are better adapted to environmental conditions in constructed wetlands;
- plants collected from nearby area must be planted within 36 hrs. If nursery plants are used, they should be from similar climatic conditions & should be shipped rapidly to minimize losses;
- if seed are used, they should be evaluated for the species present and their viability.



(Fig.4 Planting Technique)

The macrophyte planting density can be as close as 0.3 m (1ft) centre or as much as 1 m (3ft). The higher the density, the more rapid will be the development of a mature and completely functional wetland system. However, high density plantings will increase construction costs significantly. FWS wetlands should be planted more densely owing to the role of the plants in the treatment process, whereas subsurface systems can be planted less densely.

If mechanical equipment is used for planting, the unplanted areas should be kept dry until planting is complete. Since the bottom is sloped toward the discharge end, planting should start at the outlet and proceed toward the inlet. Sprinklers and shallow flooding have been used to keep the planted areas wet. If the FWS wetland is designed to treat a high-strength influent such as primary treated wastewater, a cleaner water source or diluting the wastewater with storm water or well water is recommended for the initial planting and growth period so the plants are not overly stressed.

In subsurface systems, it is typical practice to flood the wetland cell to the surface of the media prior to planting and to maintain that level until significant growth has occurred. Later, the water level is lowered to the intended operating

level. A layer of straw or hay mulch 15 to 20 cm (6–8 in) in thickness should be placed on the gravel surface to protect the new plants from the high summer surface temperatures that can occur on bare gravel surfaces. The mulch also is useful for providing thermal insulation during the first winter of operation in northern climates.

(Table 1: Major roles of macrophytes in constructed wetlands)

| Wetland part | plant | Role |
|------------------------|-------|---|
| Aerial tissues | plant | <ul style="list-style-type: none"> ➤ Light attenuation → reduced growth of phytoplanktons ➤ Influence on microclimate → insulation during winter ➤ Reduced wind velocity → reduced risk of resuspension of settled solids ➤ Aesthetic appearance ➤ Nutrient storage |
| Plant tissues in water | | <ul style="list-style-type: none"> ➤ Filtering effect → filter out large debris ➤ Reduced current velocity → increased rate of sedimentation, reduced risk of resuspension of settled solids ➤ Surface area for attached microorganisms ➤ Excretion of photosynthetic oxygen → increased aerobic degradation ➤ Nutrient uptake |
| Roots and rhizomes | | <ul style="list-style-type: none"> ➤ Stabilising the sediment surface → less soil erosion ➤ Release of oxygen increase organic degradation and nitrification ➤ Nutrient uptake ➤ Release of antibiotics |

II. LITERATURE REVIEW

ATIF MUSTAFA(2013) conducted treatment performance of a pilot-scale constructed wetland (CW) commissioned in in Karachi, NED University of Engineering & Technology, was evaluated for removal efficiency of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonia-nitrogen (NH₄-N), ortho-phosphate (PO₄-P), total coliforms (TC) and faecal coliforms (FC) from pretreated domestic wastewater. Monitoring of wetland influent and effluent was carried out for a period of 8 months. NED wastewater treatment plant

(WWTP) treats wastewater from campus and staff colony. The wastewater contains domestic sewage and low flows from laboratories of various university departments. The constructed wetland is planted with 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; BOD (50%), COD (44%), TSS (78%), NH₄-N (49%), PO₄-P (52%), TC (93%) and FC (98%).

YADAV and JADHAV (2011) construct wetland unit combined with surface flow and planted with *Eichhornia crassipes* was built near Technology Department, Shivaji University, Kolhapur (Latitude 16° 40' N, Longitude 74° 15' S). Maharashtra situated in 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 in the months of December and January respectively. The parameters analysed for the study were pH, Dissolved Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand, Total Suspended Solids, Total Dissolved Solids, Nitrogen and Phosphorus. Only quality of wastewater was analysed during the study period of 2 months i.e. December and January. The sampling took place daily at both inlet and outlet of constructed wetland system. Treatment effectiveness was evaluated which indicated good mean removal efficiencies; BOD (95%), COD (97%), TSS (82%), NH₄-N (43%), PO₄-P (49%).

III. WETLAND CONSTRUCTION

Wetlands, either constructed or natural, offer a cheaper and low-cost alternative technology for wastewater treatment. A constructed wetland system that is specifically engineered for water quality improvement as a primary purpose is termed as a 'Constructed Wetland Treatment System' (CWTS). In the past, many such systems were constructed to treat low volumes of wastewater loaded with easily degradable organic matter for isolated populations in urban areas. However, widespread demand for improved receiving water quality, and water reclamation and reuse is currently the driving force for the implementation of CWTS all over the world. The ability of wetlands to transform and store organic matter and nutrients has resulted in a widespread use of wetland for wastewater treatment worldwide.

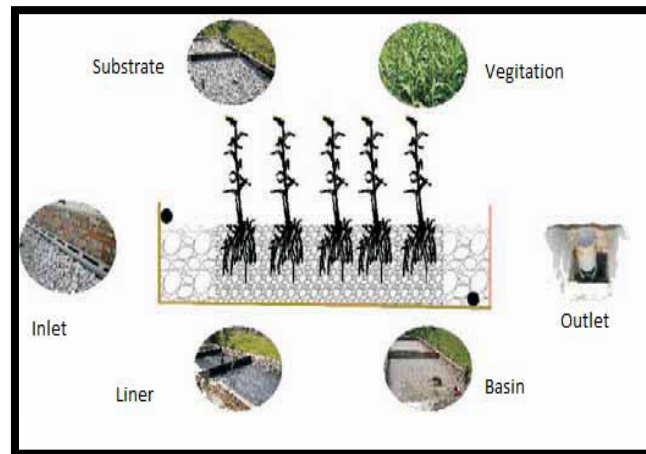
Recent concerns over wetland losses have generated a need for the creation of wetlands, which are intended to emulate the functions and values of natural wetlands that have been destroyed. Natural characteristics are applied to CWTS with emergent macrophyte stands that duplicate the physical, chemical and biological processes of natural wetland systems. The number of CWTS in use has very much increased in the past few years. The use of constructed wetlands in the United States, New Zealand and Australia is gaining rapid interest. Most of these systems cater for tertiary treatment from towns and cities. They are larger in size, usually using surface-flow system to remove low concentration of nutrient (N and P) and suspended solids. However, in European countries, these constructed wetland treatment systems are usually used to provide secondary treatment of domestic sewage for village populations. These constructed wetland systems have been seen as an economically attractive, energy-efficient way of providing high standards of wastewater treatment.

Typically, wetlands are constructed for one or more of four primary purposes: creation of habitat to compensate for natural wetlands converted for agriculture and urban development, water quality improvement, flood control, and production of food and fiber (constructed aquaculture wetlands).

Constructed wetlands are based upon the symbiotic relationship between the micro organisms and pollutants in the wastewater. These systems have potential to treat variety of wastewater by removing organics, suspended solids, pathogens, nutrients and heavy Metals.

A constructed wetland is a shallow basin filled with some sort of filter material (substrate), usually sand or gravel, and planted with vegetation tolerant of saturated conditions. Wastewater is introduced into the basin and flows over the surface or through the substrate, and is discharged out of the basin through a structure which controls the depth of the wastewater in the wetland. A constructed wetland comprises of the following five major components:

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



(Fig.5 Components of constructed wetland)

Basin

Systems have been designed with bed slopes of as much 8 percent to achieve the hydraulic gradient. Newer systems have used a flat bottom or slight slope and have employed an adjustable outlet to achieve the hydraulic gradient.

Substrate

Many different media sizes have been tried for the bed, but gravel less than 4 cm diameter seems to work best. Larger diameters increase the flow rate, but result in turbulent flow. Smaller media gives a reduced hydraulic conductivity, but has the advantage of more surface area for microbial activity and adsorption. Soil is sometimes used to remove certain materials due to the ability of reactive clays to adsorb heavy metals, phosphates, etc.

Vegetation

Three types of plants are normally used

- Cattails, which are a favorite food of muskrats and nutria.
- Bulrush is also high on the mammals food list, but they should not be attracted to the wetland if the water surface is kept below the media.
- Reeds are used most often in Europe because they are not a food source for animals. However, they are not allowed in some areas due to their tendency to spread and push out native vegetation.

The type used will also depend on the local climate and the substances to be removed. In some instances decorative plants are used, but results show them to be less effective and require more maintenance. Control of the water level can be used to increase root penetration and control weeds.

Liner

The liner goes under the entire system and can be a manufactured liner or clay. This prevents the wastewater from infiltrating into the ground before it is treated. A berm around the system prevents runoff from entering the system.

Inlet

The inlet can be a manifold pipe arrangement, an open trench perpendicular to the flow, or weir box. The manifold arrangement can be a pipe with several valve outlets or a simple perforated pipe. Coarse gravel allows rapid infiltration of the water. The inlet purpose is to spread the wastewater evenly across the treatment bed for effective treatment.

Outlet

The outlet structures used are similar to the inlet structures. One preferred addition is making the outlet adjustable to allow the control of water level. The level could be lowered when a large amount of rainfall is expected or raised for maximum cross-sectional use of the media.

IV. PLANTS IN WETLANDS

The larger aquatic plants growing in wetlands are usually called macrophytes. The term includes aquatic vascular plants (angiosperms and ferns), aquatic mosses, and some larger algae that have tissues that are easily visible. Although ferns like *Salvinia* and *Azolla* and large algae like *Cladophora* are widespread in wetlands, it is usually the flowering plants (i.e. angiosperms) that dominate. Macrophytes, like all other photoautotrophic organisms, use the solar energy to assimilate inorganic carbon from the atmosphere to produce organic matter, which subsequently provides the energy source for heterotrophs (animals, bacteria and fungi). As a result of the ample light, water and nutrient supply in wetlands, the primary productivity of ecosystems dominated by wetland plants are among the highest recorded in the world. Associated with this high productivity is usually a high heterotrophic activity, i.e. a high capacity to decompose and transform organic matters and other substances.

The presence or absence of aquatic macrophytes is one of the characteristics used to define wetlands, and as such macrophytes are an indispensable component of these ecosystems. In spite of the fact that the most important removal processes in constructed treatment wetlands are based on physical and microbial processes, the macrophytes possess several functions in relation to the water treatment.

Vegetation and its litter are necessary for successful performance of constructed wetlands and contribute aesthetically to the appearance. The vegetation to be planted in constructed wetlands should fulfill the following criteria:

- Application of locally dominating macrophyte species;
- Deep root penetration, strong rhizomes and massive fibrous root;
- Considerable biomass or stem densities to achieve maximum translocation of water and assimilation of nutrients;
- Maximum surface area for microbial populations;
- Efficient oxygen transport into root zone to facilitate oxidation of reduced toxic metals and support a large rhizosphere.

Two species, *Phragmites* sp. and *Typha* sp., widely used vegetation in constructed wetlands. *Phragmites* sp. and *P. australis* (Common Reed) is one of the most productive, wide spread and variable wetland species in the world. Due to its climatic tolerance and rapid growth, it is the predominant species used in constructed wetland.



(Fig.6 *Phragmites karka* (common reed))



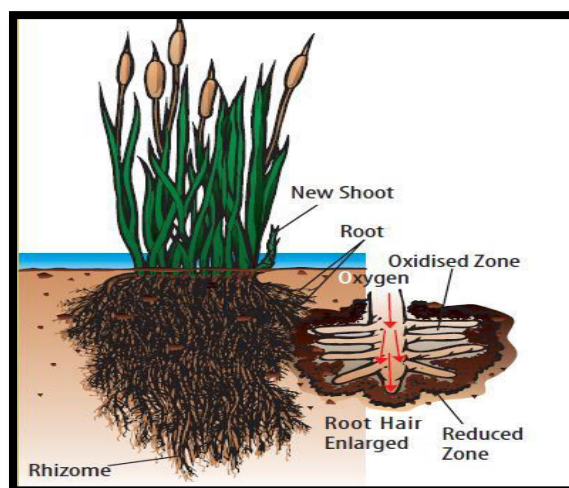
(Fig.7 Cattail-*typha angustifolia*)

IV. PROPOSED METHODOLOGY

4.1 REMOVAL MECHANISMS

A constructed wetland is a complex assemblage of wastewater, substrate, vegetation and an array of microorganisms (most importantly bacteria). Vegetation plays a vital role in the wetlands as they provide surfaces and a suitable environment for microbial growth and filtration. Pollutants are removed within the wetlands by several complex physical (sedimentation, filtration, adsorption and volatilisation) chemical (precipitation, adsorption hydrolysis, oxidation/reduction) and biological (bacterial metabolism, plant metabolism, plant absorption, natural die-off) processes as depicted.

Settleable and suspended solids that are not removed in the primary treatment are effectively removed in the wetland by filtration and sedimentation. Particles settle into stagnant micro pockets or are strained by flow constrictions. Attached and suspended microbial growth is responsible for the removal of soluble organic compounds, which are degraded biologically both aerobically (in presence of dissolved oxygen) as well as anaerobically (in absence of dissolved oxygen). The oxygen required for aerobic degradation is supplied directly from the atmosphere by diffusion or oxygen leakage from the vegetation roots into the rhizosphere, however, the oxygen transfer from the roots is negligible.



(Fig.8 Oxygen transfer from roots)

4.2 NITROGEN REMOVAL MECHANISMS

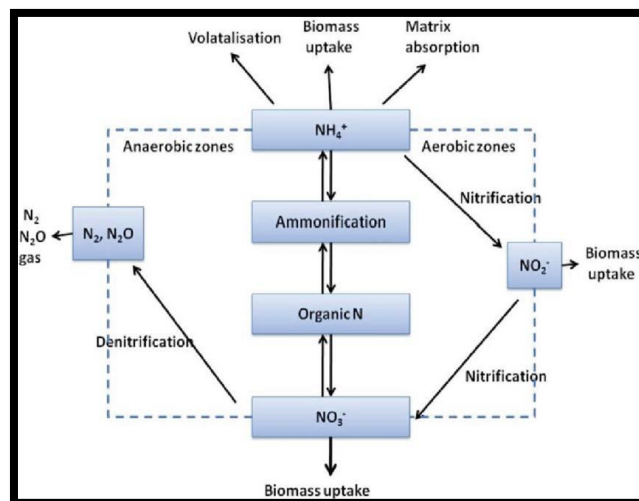
There are sufficient studies to indicate some roles being played by wetland plants in Nitrogen removal but the significance of plant uptake vis-à-vis nitrification/denitrification is still being questioned. Nitrogen (N) can exist in various forms, namely Ammoniacal Nitrogen (NH_3 and NH_4^+), organic Nitrogen and oxidised Nitrogen (NO_2^- and NO_3^-). The removal of Nitrogen is achieved through nitrification/denitrification, volatilisation of Ammonia (NH_3) storage in detritus and sediment, and uptake by wetland plants and storage in plant biomass (Brix, 1993). A majority of Nitrogen removal occurs through either plant uptake or denitrification. Nitrogen uptake is significant if plants are harvested and biomass is removed from the system.

At the root-soil interface, atmospheric oxygen diffuses into the rhizosphere through the leaves, stems, rhizomes and roots of the wetland plants thus creating an aerobic layer similar to those that exists in the media-water or media-air interface. Nitrogen transformation takes place in the oxidised and reduced layers of media, the root-media interface and the below ground portion of the emergent plants. Ammonification takes place where Organic N is mineralised to NH_4^+ -N in both oxidised and reduced layers. The oxidised layer and the submerged portions of plants are important sites for nitrification in which Ammoniacal Nitrogen (AN) is converted to nitrite N (NO_2^- -N) by the *Nitrosomonas* bacteria and eventually to nitrate N (NO_3^- -N) by the *Nitrobacter* bacteria which is either taken up by the plants or diffuses into the reduced zone where it is converted to N_2 and N_2O by the denitrification process.

Denitrification is the permanent removal of Nitrogen from the system; however the process is limited by a number of factors, such as temperature, pH, redox potential, carbon availability and nitrate availability. The annual denitrification rate of a surface-flow wetland could be determined using a Nitrogen mass-balance approach, accounting

for measured influx and efflux of Nitrogen, measured uptake of Nitrogen by plants, and sediment, and estimated NH_3 volatilisation.

The extent of Nitrogen removal depends on the design of the system and the form and amount of Nitrogen present in the wastewater. If influent Nitrogen content is low, wetland plants will compete directly with nitrifying and denitrifying bacteria for NH_4^+ and NO_3^- , while in high Nitrogen content, particularly Ammonia, this will stimulate nitrifying and denitrifying activity.



(Fig.9: Nitrogen transformations in a constructed wetland treatment system)

4.3 PHOSPHORUS REMOVAL MECHANISMS

Phosphorus is present in wastewaters as Orthophosphate, Dehydrated Orthophosphate (Polyphosphate) and Organic Phosphorus. The conversion of most Phosphorus to the Orthophosphate forms (H_2PO_4^- , PO_4^{3-}) is caused by biological oxidation. Most of the Phosphorus component may fix within the soil media. Phosphate removal is achieved by physical-chemical processes, by adsorption, complexation and precipitation reactions involving Calcium (Ca), Iron (Fe) and Aluminium (Al). The capacity of wetland systems to absorb Phosphorus is positively correlated with the sediment concentration of extractable Amorphous Aluminum and Iron (Fe). Although plant uptake may be substantial, the sorption of Phosphorus (Orthophosphate P) by anaerobic reducing sediments appears to be the most important process. The removal of Phosphorus is more dependent on biomass uptake in constructed wetland systems with subsequent harvesting.

4.4 BOD₅ REMOVAL

The physical removal of BOD₅ is believed to occur rapidly through settling and entrapment of particulate matter in the void spaces in the gravel or rock media. Soluble BOD₅ is removed by the microbial growth on the media surfaces and attached to the plant roots and rhizomes penetrating the bed. Some oxygen is believed to be available at microsites on the surfaces of the plant roots, but the remainder of the bed can be expected to be anaerobic.

4.5 PLANT UPTAKE

Nitrogen will be taken up by macrophytes in a mineralised state and incorporated it into plant biomass. Accumulated Nitrogen is released into the system during a die-back period. Plant uptake is not a measure of net removal. This is because dead plant biomass will decompose to detritus and litter in the life cycle, and some of this Nitrogen will leach and be released into the sediment. Johnston (1991) shows only 26-55% of annual N and P uptake is retained in above-ground tissue, the balance is lost to leaching and litter fall.

4.6 METALS

Metals such as Zinc and Copper occur in soluble or particulate associated forms and the distribution in these forms are determined by physico-chemical processes such as adsorption, precipitation, complexation, sedimentation, erosion and diffusion. Metals accumulate in a bed matrix through adsorption and complexation with organic material. Metals are also reduced through direct uptake by wetland plants. However over-accumulation may kill the plants.

4.7 PATHOGENS

Pathogens are removed mainly by sedimentation, filtration and absorption by biomass and by natural die-off and predation.

4.8 OTHER POLLUTANT REMOVAL MECHANISMS

Evapotranspiration is one of the mechanisms for pollutant removal. Atmospheric water losses from a wetland that occurs from the water and soil is termed as evaporation and from emergent portions of plants is termed as transpiration. The combination of both processes is termed as evapotranspiration. Daily transpiration is positively related to mineral adsorption and daily transpiration could be used as an index of the water purification capability of plants. Precipitation and evapotranspiration influence the water flow through a wetland system. Evapotranspiration slows water flow and increases contact times, whereas rainfall, which has the opposite effect, will cause dilution and increased flow.

Precipitation and evaporation are likely to have minimal effects on constructed wetlands in most areas. If the wetland type is primarily shallow open water, precipitation/evaporation ratios fairly approximate water balances. However, in large, dense stands of tall plants, transpiration losses from photosynthetically active plants become significant.

V. CONCLUSION

It is noted that CWs are now being increasingly used for environmental pollution control. Constructed wetlands were implemented in a wide range of applications, such as water quality improvement of polluted surface water bodies, wastewater on-site treatment and reuse in rural areas, campuses, recreational areas and green architectures, management of aquaculture water and wastewater, tertiary treatment, and miscellaneous applications.

Water monitoring results obtained from several demonstrations show that CWs could achieve acceptable wastewater treatment performances in removing major pollutants, including suspended solids, organic matters, nutrients, and indicating microorganisms, from wastewater influent. The results indicate that if constructed wetlands are appropriately designed and operated, they could be used for secondary and tertiary wastewater treatment under local conditions, successfully. Hence constructed wetlands can be used in the treatment train to upgrade the existing malfunctioning wastewater treatment plants, especially in developing countries. During hydraulic retention study, it was found that the BOD, COD was best removed in planted wetland than unplanted wetland. It is because of the oxygen diffusion from roots of the plants and the nutrient uptake and insulation of the bed surface. It is also found that the increases in the detention period of the wastewater the removal rate also increases.

- Economical alternative over conventional methods .
- Application of constructed wetland technology for commercial wastewater treatment signifies a step towards “green technology”.
- They provide a wide range of benefits in wastewater treatment and represent economic benefits in terms of energy consumption.
- They should be investigated and given a chance for use as an alternative technology in wastewater treatment by local municipalities and industries

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