Constructed Wetlands - Natural Treatment of Wastewater

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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. Constructed wetlands are very effective in removing organics and suspended solids, whereas the removal of nitrogen is relatively low, but could be improved by using a combination of various types of constructed wetlands meeting the irrigation reuse standards. The removal of phosphorus is usually low, unless special media with high sorption capacity are used. Pathogen removal from wetland effluent to meet irrigation reuse standards is a challenge unless supplementary lagoons or hybrid wetland systems are used. In this paper studies various case study related to Wetlands in Indian Cities and also described include systems involving both constructed and natural wetlands, habitat creation and restoration.**

Keywords- Natural Wetlands, Constructed Wetlands, Wastewater, Nitrogen, Phosphorous,Wastewater Treatment

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.

1.1.1 Objectives of study

- Removal of contaminants
- Phosphorus removal
- Suspended solids
- Pathogen removal
- Heavy metal removal
- BOD,COD Removal

1.2 Constructed 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.

(Fig.1 Constructed Wetlands)

1.2.1 ADVANTAGES

- 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

1.2.2 LIMITATIONS

- large area requirement

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- 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.

1.2.3 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.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.

1.3 Natural Wetlands

Similarly; to natural wetlands, constructed wetlands also act as a biofilter and/or can remove a range of pollutants (such as organic matter, nutrients, pathogens, heavy metals) from the water. Constructed wetlands are designed to remove water pollutants such as suspended solids, organic matter and nutrients (nitrogen and phosphorus).All types of pathogens (i.e., bacteria, viruses, protozoan and helminths) are expected to be removed to some extent in a constructed wetland. Subsurface wetland provide greater pathogen removal than surface wetlands.

As stated by Ramsar Convention, natural wetlands are those "areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters."

***As stated by National Wetlands Working Group,* (1988),** wetland are those areas which are generally found in waterlogged condition to enhance the wetland and aquatic growth as denoted by poorly drained soils, hydrophytic flora and different types of biological activities which are conditioned to be grow in wet environment.

(Fig.2 Natural Wetlands)

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 (NH_4-N), ortho-phosphate (PO_4-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 160 40' N, Longitude 740 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

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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.

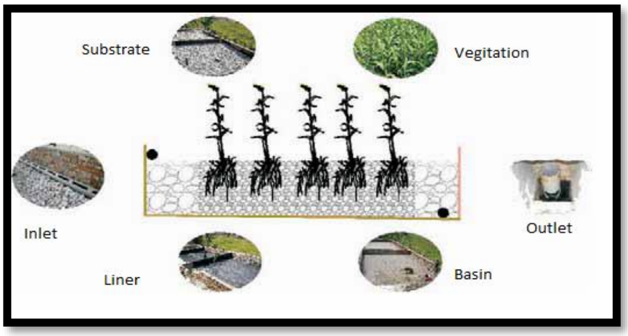
Recent concerns over wetland losses have generated a need for the creation of wetlands, which are intended to emulate the functions and values of natural wetlands that have been destroyed. Natural characteristics are applied to CWTS with emergent macrophyte stands that duplicate the physical, chemical 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 3 Components of constructed wetland)

IV. WETLAND PLANTS

The role of wetland vegetation as an essential component of CW is well established. Emergent plants contribute both directly and indirectly to the treatment processes. In spite of the fact that the most important removal processes in CW are based on microbial processes, the macrophytes posses several functions in relation to the water treatment. They influence treatment process in CW by their physical presence and metabolism. In general, the most significant functions of wetland plants (emergents) in relation to 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 stabilise the surface of the beds, slow down the water flow thus assist in sediment. Plants also provide microorganisms with a source of Carbon.

However, not all wetland species are suitable for wastewater treatment since plants for CW must be able to tolerate a combination of continuous flooding and exposure to wastewater or storm water containing relatively high amounts of pollutants. A portion of the nutrients is retained in the undecomposed fraction of the plant litter and accumulates in the soils. Plants oxygenate the root zone by release of oxygen from their roots, and provide aerobic microorganisms a habitat within the reduced soil. Plants have additional site-specific values by providing habitat for wildlife and making wastewater treatment systems aesthetically pleasing. Wetland species of all growth forms have been used in treatment wetlands. However, the most commonly used species are robust species of emergent plants, such as the common reed, cattail and bulrush. The larger aquatic plants growing in wetlands are usually called macrophytes.

Table 1: Role of plants

Macrophyte property	Role in treatment process
Aerial plant tissue	1. Light attenuation – reduced growth of phytoplankton 2. Reduced wind velocity – reduced risk resuspension 3. Aesthetic pleasing appearance of system 4. Storage of nutrients
Plant tissue in water	1.Filtering effect-filter out large debris 2. Reduced current velocity –Increase rate of sedimentation, reduced risk of

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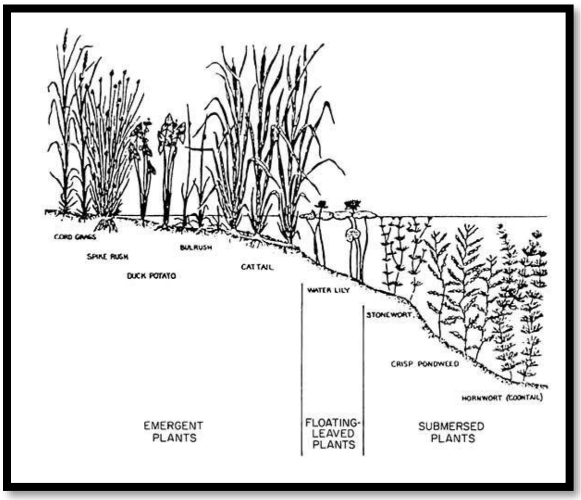
	suspension 3. Provide surface area for attached biofilms 4.Excretion of photosynthetic oxygen – Increases aerobic degradation 5. Uptake of nutrients
Roots and rhizomes in the sediment	1. Stabilizing the sediment surface-less erosion 2. Prevents the medium from clogging in VFS 3. Release of oxygen increase degradation(nitrification) 4. Uptake of nutrients

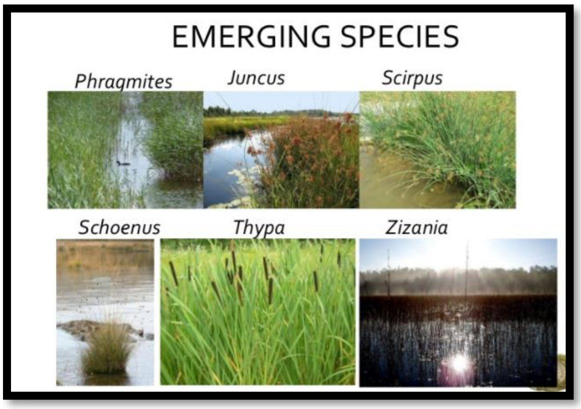
Types of Aquatic Plants-



(Fig.4: Diagram showing emerging, floating and submerged Aquatic plants)

1. Emerging plants:

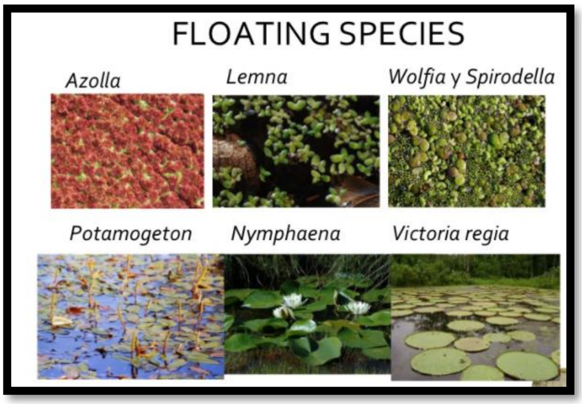
Those whose roots grow in wetland soil, but their stem and leaves emerge over water surface making photosynthesis , flowering, fructification and seed spreading in open air.



(Fig.5: Emerging Species)

2. Floating plants:

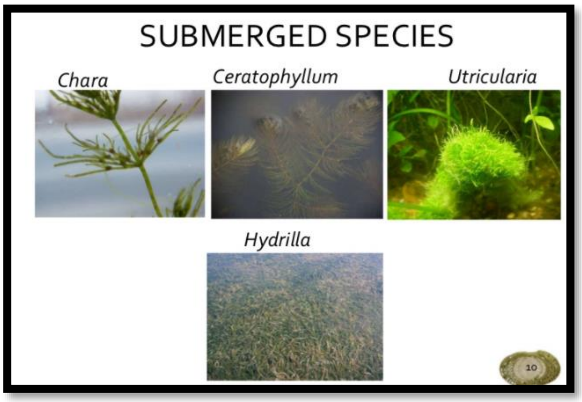
Those floating over water surface whose roots don't reach wetland bottom e.g duckweeds (Lemna, Wolffia, Spitodella, etc.), fern (Azolla sp.) ,water Hyacinth (Eirchornia crassipes) ,water Lilly (Victoria regia) etc.



(Fig.6: Floating Species)

3. Submerged plants:

Plants whose stems and leaves grow submerged in water and their roots are anchored in soil beneath water. This type of plants are commonly used in fishbowls.



(Fig.7: Submerged Species)

V. PROBLEMS OF AQUATIC WEEDS IN INDIA

Out of about 160 aquatic weeds, the following are of primary concern to India: (1) Eichhornia crassipes (2) Salvinia molesta (3) Nymphaea stellata (4) Nelumbo nucifera (5) Hydrilla verticillata (6) Vallisneria spiralis (7) Typha angustata (8) Chara spp. (9) Nitella spp. (10) Ipomoea spp. Among these, Eichhornia crassipes, Salvinia molesta, Hydrilla verticillata, Alternanthera philoxeroides and Pistia stratiotes are five primary aquatic weeds of the world and qualify the status of worst weeds in India too. It is, however, estimated that 20-25% of the total utilisable water in India is currently infested with water hyacinth (Eichhornia crassipes), while in the state of Assam, West Bengal, Orissa and Bihar, it was 40% (Gopal th and Sharma 1981). By the end of 20 centaury, A. philoxeroides had become a growing menace in water bodies in India, Sushilkumar et al. 2009).

(a) Aquatic weed problems in lakes and reservoirs

Aquatic weeds may cause following problems: impair commercial navigation; degrade and deteriorate water quality; disrupt hydropower generation; increase flood frequency, duration and intensity; reduce species diversity; increase extinction rate of rare, threatened and endangered

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species; habitat for insect-borne disease vectors; alter animal community interactions; recreational navigation impairment; interfere with safe swimming; change sediment chemistry; interfere with fishing; reduce water storage capacity in reservoirs, tanks, ponds; impede flow and amount of water in canals and drainage systems; reduce fish production, interfere with navigation and aesthetic value; promote habitat for mosquitoes. Malhotra and Ahmed (1996) has categorized aquatic weeds as a growing ecological menace. Thirunaqvukkarsu and Kayarkanni (1996) discussed the environmental impacts of aquatic weeds in India. The famous Kolleru lake in the West Godavari has succumbed to invasion of E. crassipes, Ipomoea aquatic, Typha Vallisneria, Nymphaea and Ulothrix spp.

In Punjab, floating, emerged and submerged aquatic weeds are major problem in many, reservoirs and wet lands. In Punjab, three wetlands namely Harike, Kanjili Kehhopur-Miani lake and Mand Bharthala in Roper have been threatened by aquatic weeds like water hyacinth, Potamogeton pectinatus, Hydrilla verticillata etc. (Ladhar 1996). Typha spp. (Kumar and Singh 1996d) and water hyacinth have been a big problem in reservoirs and ponds of Punjab (Sharma and Chandi 1996).

In Gorakhpur (Uttar Pradesh), about 22 sq km Ramgarh lake was filled with dense growth of Hydrilla, Najas, Potamogeton, Ceratophyllum and Chara spp. Of these, Hydrilla and Najas spp. infest the lake round the year while others invade it seasonally. The Gujar lake (110 ha) in Varanasi (Uttar Pradesh) has been invaded by aquatic weeds.

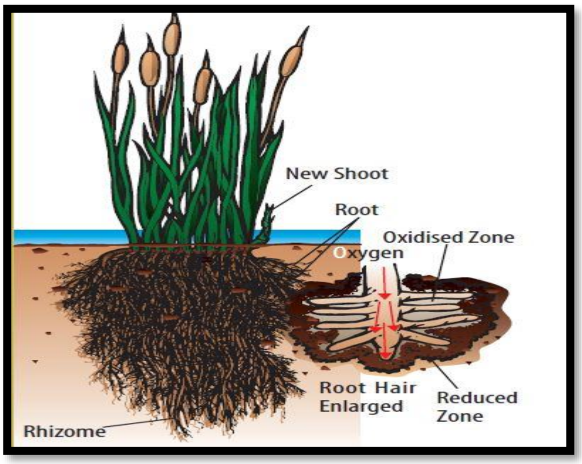
In West Bengal, E. crassipes is the foremost aquatic weed. In the southern part of West Bengal, Typha is a noxious weed. Aquatic weeds have played havoc in West Bengal in fishery waters, potable waters and in lowland paddy fields. In Palta and Baranagar water bodies, Eichhornia and Lemna spp., along with some molluscs, blocked the water pipes.

(b) Aquatic weeds problems in fish ponds and lakes of India Most of the freshwater fishes rely on aquatic plants at some point during their lives and prefer specific habitats based on their growth stage. Young fish use aquatic vegetation as a food source, both by directly consuming plants and by foraging for the microfauna associated with the plants, and as cover to hide from predators. Mature fish moves to more open waters to increase foraging success and consume other fish to supplement their diets. Nesting, growth and foraging success of plant-loving fish are influenced by plant composition and density. Of the 8 lakh ha of freshwater available in India for pisciculture, about 40% is rendered unsuitable for fish production because of invasion by aquatic weeds. Most of the fishery tanks and ponds in and around Bangalore and other cities have been badly invaded by water hyacinth. Some of the weeds like Eichhornia, Azolla, Nymphaea, Nelumbo, Nymphoides, Hydrilla, Vallisneria, Potamogeton, Najas, Ceratophyllum, Typha and Utricularia spp. are problematic weeds in fishery lakes and tanks of Andhra Pradesh, Assam, Haryana, Himachal Pradesh, Jammu & Kashmir, Maharashtra, Tamil Nadu and Uttar Pradesh in India. Some of the well-known fishery lakes like Barwar, Ramgarh and Guiar lake in Uttar Pradesh, Ansupa lake in Orissa, Ootucmund lake in Tamil Nadu, Kollern lake in Andhra Pradesh, Loktak lake in Manipur and the world famous Dal, Nigeen and Walur lakes in Jammu & Kashmir have been largely invaded by the aquatic weeds. Large number of water bodies, both natural and man made in Assam are infested with aquatic macrophytes, making them unfit for fish culture and other economic uses.

VI. 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 fi ltration. Pollutants are removed within the wetlands by several complex physical(sedimentation,filtration,adsorption and volatisation) 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 eff ectively 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)

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VII. CASE STUDY

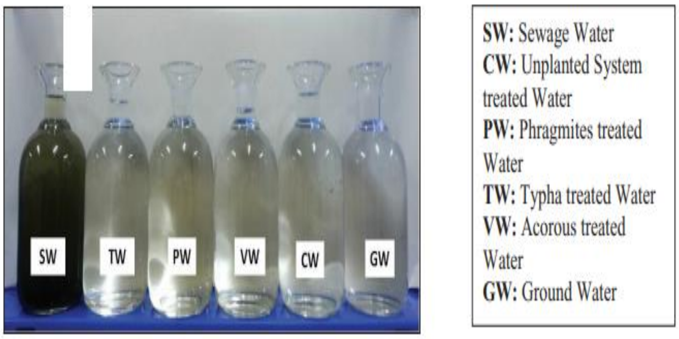
1. PILOT RURAL HOUSEHOLD SEWAGE WATER TREATMENT SYSTEM AT PANDIT DEEN DAYAL UPADHYAY VILLAGE- FARAH, MATHURA (BY IARI)-

Design configuration:-

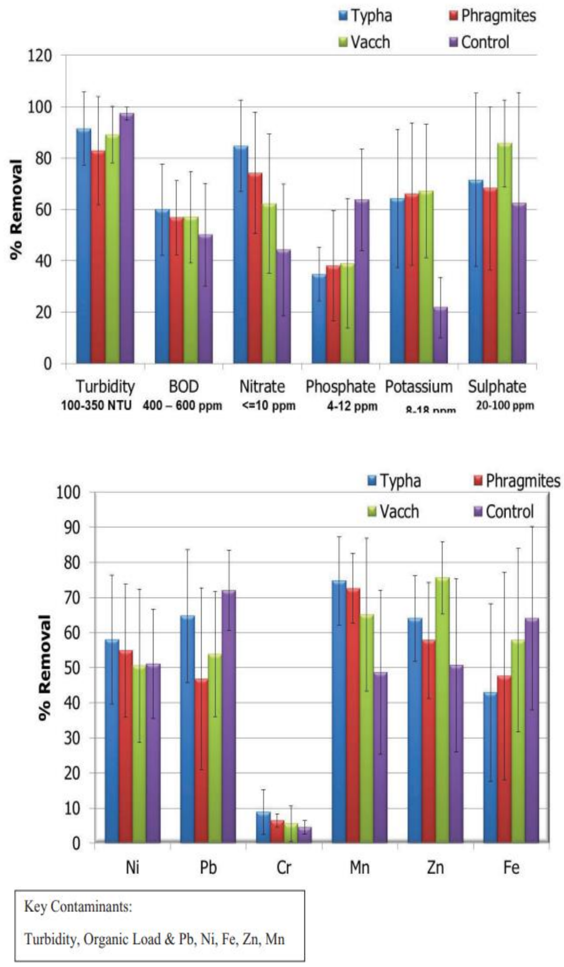
Capacity: 1500 LPD (4 Households with 4 members)
Design: Batch fed Vertical Sub-surface
Flow HRT: 14.41 hrs (< 1 day)
Land area: 2 sq. meter/ KL

(Figure9:Layout of Pilot Rural Household Sewage Water Treatment System)

(Figure 10: Showing grown vegetation (Arundo donax and Typha latifolia) and inlet outlet points across the system)



(Figure 11: Quality of treated waste water)



(Figure 12: Long Term (2009-2019) Pollutant Reduction Range of (a) Different wastewater parameters (b) Heavy metals for Various Rural Household Models)

2 . MLD CONSTRUCTED WETLAND FOR SEWAGE TREATMENT AT INDIAN AGRICULTURAL RESEARCH INSTITUTE (DELHI CAMPUS)-

The Indian Agricultural Research Institute (IARI) is constructing a wetland in its Delhi campus. Covering over an area of 1.42 hectares, it is capable of holding and treating two million litres of sewage in a day. The source of raw sewage is from the Krishi Kunj Colony adjoining

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IARI's campus. The treated wastewater is used for the agricultural purpose. The one time construction cost incurred was Rs 1.4 crore, the wetland consists of three treatment tanks/ cells and one treated-water holding tank.

Wastewater Treatment Process:-

Raw sewage collected from the Krishi Kunj Colony enters into one sump where all the coarse particles are settle down. The wastewater is then pumped into the second sump for additional sedimentation process. For overcome the clogging problems all the sumps were cleaned periodically. After that all the wastewater enters towards grit chamber which have broken pieces of bricks to eliminate any floating matter, finally it goes to the wetland beds. The wastewaters in the CW beds are retained for 2.2 days. Each bed is covered with 60 cm thick layer of stones, on which plant species such as Phragmites, Typha and Acorus are planted. The final treated water is collected in the holding tank, and distributed through a riser pipe to IARI's fields.

CW system Performance-

The analysis results showed that the plants works efficiently and gives high quality treated water which is reused for the agricultural purpose within the premises. It is noted that CW system is highly effective in reducing TSS and BOD . BOD 460 -100 mg L-1 ; TSS 220 -2.2 mg L-1 ; NO3-N 86-50 mg L-1 ; PO4-P 69-26 mg L-1 at the inlet and outlet zones respectively. The unplanted tanks work as a control system. The plants not only remove pollutants but also aid in oxygenation through their roots.

3. PHYTORID TECHNOLOGY FOR SEWAGE WASTEWATER TREATMENT IN INDIA-

Phytorid Technology was developed by NEERI, India. It has been extensively used in treating wastewater at different locations in India. PHYTORID system works on the principle of subsurface flow constructed wetland technology in which wetland beds filled with filter media are connected in series /parallel manner. Crushed bricks, gravel and stones are used as a porous filter material to enhance the purification processes naturally. This technology was patented by Kumar et al., 2004. The design parameter includes: minimum requirement of about 35.0 m2 of land area for treating a wastewater load of 20 m3 /day .

Components of the treatment system :

- Sewage Collection Tank
- Settler/Screening Chamber
- Phytorid Bed
- Treated water Storage Tank

Phytorid technology has been used in treating variety of wastewaters such as:

- Domestic wastewater
- Open Drainage
- Cleaning of nallah water
- Agriculture wastewater
- Dairy wastewater
- Municipal landfill leachate
- Pre treated industrial wastewater

Commonly used plants species in Phytorid systems:

- Reeds (Phragmites Spp)
- Elephant grass (Pennisetum purpurem)
- Cattails (Typha Spp.)
- Cana Spp
- Golden dhuranda
- Bamboo
- Nerium
- Colosia

Major benefits of adopting Phytorid technology for Sewage treatment-

- Cost effective
- Operation of Phytorid is based on gravity rule, so less electricity required.
- Operation and maintainance expenses are low/negligible.
- The treated water is reused in various operation facilitating Zero liquid dischage.
- Able to endure the situation of variation in temperature, pH and flow rate of the sewage treated.

Pollutant Removal processes occur during treatment process: -

- Sedimentation
- Filtration
- Adsorption
- Precipitation
- Decomposition
- Microbial degradation
- Nutrient uptake

Table 2: Removal efficiency of Phytorid System:

Water Parameters	Removal rate (%)
Biochemical oxygen demand (BOD)	85-95
Chemical oxygen demand (COD)	85-95
Total nitrogen	60-70
Phosphate	30-40
Total suspended solids	75-95
Faecal Coliform	90-95

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(Figure 13: Photographs of Phytorid systems developed by NEERI, India)

CONCLUSION

- 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.

In-situ remediation processes, such as constructed wetlands, have produced "satisfactory" results (Cao et al., 2012). This manual provides holistic review of few case studies i.e.: Vertical flow subsurface systems (Egypt), Phytorid technology in india developed by NEERI (India), Vertical sub-surface constructed wetland units for treatment of dairy waste water (Dehradun , Uttrakhand), Neela-hauz biodiversity park (New Delhi), 2 MLD Constructed Wetland for sewage Treatment at Indian Agricultural Research Institute (Delhi campus), Constructed wetland system to treat wastewater at Indian Institute of Technology (Powai, Mumbai) and Pilot rural household sewage water treatment system at Mathura by IARI.

Constructed wetlands serve from single-family dwellings to large-scale municipal systems. Also they are essential for humans to live and prosper. More than one billion people depend on wetlands for their living. The use of CWs for wastewater treatment provides many environmental, social and economic benefits.

In India, Central Pollution Control Board (CPCB) and MoEF, New Delhi has set standards for discharge of wastewater to the surrounding area including land and water bodies. Thus a constructed wetland system should be designed with proper care so that it could produce the effluent that meets all the discharge standards.

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