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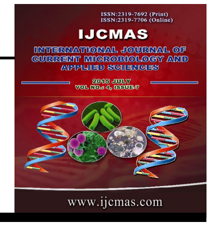

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Review Article

Root Zone Technology: Reviewing its Past and Present

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A B S T R A C T

Increasing urbanization and human activities exploits and affect the quality and quantity of the water resources. This has resulted in pollution of fresh water bodies due to increased generation of domestic waste, sewage, industrial waste etc. This paper reviews the Root Zone Treatment System (RZTS) which are planted filter-beds consisting of soil. This Technology uses a natural way to effectively treat domestic and industrial effluents. RZTS are well known in temperate climates and are easy to operate having less installation, low maintenance and operational costs and incorporates the self-regulating dynamics of an artificial soil eco-system. This technology has been successfully running in several countries like Europe and America. Use of constructed wetlands can now be recognized as an accepted low cost eco-technology, especially beneficial as compared to costly conventional treatment systems. There is a need to exploit this technology in a developing country like India to its maximum to gain its benefits and for sustainable development.

Keywords

Urbanization, Root zone treatment system, Constructed wetlands, Ecosystem

Introduction

Root Zone technology is a solution to the modern industrialised world's water pollution problems. Growth of wetland plants called reeds in specially designed beds provides eco-friendly mode to use nature to "Protect Nature".The root zone i.e. a filter plant is a biological filter, where biological treatment of wastewater takes place in a soil volume, which is penetrated by the roots of *Phragmites australis*. This technology is also called as Root-zone system or Bio-Filter or Reed Bed System or Constructed wetland (CW) system [constructed includes "man-made", "engineered" or "artificial" (Vymazal, 2005, 2007)] or Treatment wetland system.

Natural Wetlands are defined as areas which are in undated or saturated with surface or groundwater, saline or fresh, which supports vegetation adapted for living in saturated soil conditions. Wetlands exist in a broad variety of environmental conditions and have plant communities, soil and hydrology that differ from most upland plant communities. Wetland plants are adapted to growing in soils which, during the growing season, are too wet for plants that normally grow under upland conditions (Arceivala and Asolekar, 2007).

Constructed wetlands (CWs) are examples of non-mechanised treatment systems which are easy to build and operate and are sustainable. Aquatic plant systems consist of free floating growths and emergent vegetations. Emergent vegetations may be of natural wetlands like mangroves or Macrophytes such as water hyacinths, alligator weeds, duckweeds, hydrilla, mart, solms, etc., rooted in constructed wetlands which are mainly applied in reed bed and root zone systems. Aquatic plant ponds consisting of aquatic plants, free floating macrophytes, have been cultured in ponds either for their ability to remove hazardous chemicals.

Root zone technology process

Root Zone technology originated from research conducted in Europe by Seidel and Kickuth at the Max Planck Institute in Plan, Germany starting in 1952 (Bastion and Hammer, 1992). By 1995, over 200 units had been built in Europe (Denmark, Germany and UK) and another 200 in USA and in smaller numbers elsewhere. Only about 50–60 units were reported to be exist in India in 2005.

The Root Zone process functions according to the laws of Nature, to effectively purify domestic and Industrial effluent. Root Zone encompasses the life interactions of various species of bacteria, the roots of the reed plants, Soil, Air, Sun and of course water. Reed Plants have capacity to absorb oxygen from ambient air and creating numerous bacteria. Same bacteria oxidize and purify the waste water. Since the process occur underground inducing different types of chemical reactions, the process functions as a mirror of self regulating, purifying process found in nature. Three integrated components are essential in this system.

1) The reeds
2) The reed beds
3) Microbial organisms.

The process involves the raw effluent (after removing grit or floating material) which is passed horizontally or vertically through a bed of soil having impervious bottom. The effluent percolates through the bed that has all the roots of the wetland plants spread very thickly. Nearly 2,500 types of bacteria and 10,000 types of fungi, which harbour around roots get oxygen from the weak membranes of the roots and aerobically oxidize the organic matter of the effluent. The characteristics of plants of absorbing oxygen through their leaves and passing it down to roots through their stems which are hollow, is utilized as a bio-pump. Anaerobic digestion also takes place away from the roots. The filtering action of the soil bed, the action with fungi etc. and chemical action with certain existing or added inorganic chemicals help in finally obtaining very clear and clean water. The system of plants regenerates itself as the old plants die and form useful humus. Hence the system becomes maintenance free and can run efficiently for several years.

The choice of different plant species depends on factors such as the rooting depth, plant productivity and tolerance to high loads of wastewater (Brix, 1994). The main emergent macrophyte species used in CWs inthe Mediterranean countries are *Canna* spp., *Iris* spp., *Cyperus* spp., *Typha* spp., *Phragmites* spp., *Juncus* spp., *Poaceae* spp. and *Paspalum* spp (Vymazal, 2005, 2011).

Advantages of using this technology:-

1) It achieves standards for tertiary treatment with low cost, such as no electricity, no chemicals for pH adjustment.
2) Low maintenance cost, since it involves no machinery and its maintenance.
3) It requires negligible attendance for operation and monitoring.
4) It has no sludge handling problem.
5) It enhances the landscape and gives the site a green appeal.
6) It provides natural habitat for birds and after few years gives an appearance of bird sanctuary and also provides recreational and educational areas.
7) Though it is a sewage treatment plant it doesn't have odour problems.
8) It becomes a green Zone and it does not have mosquito problem.
9) Above all it provides eco friendly solution to waste water treatment "Naturally".
10) The reeds are not grazed by ruminants.
11) Salinity may not be a problem for a survival or operations of reed beds.
12) It is recommended to combine vertical flow and then horizontal flow of sewage with a soil having impervious bottom.

Disadvantages

1. Relatively area requirements for advanced treatments.
2. Current imprecise design and operating criteria
3. Biological and hydrological complexity and our lack of important process dynamics.
4. Possible problems with pests.
5. Steep topography, shallow soils and high water tables, susceptibility to severe flooding may limit the use of constructed wetlands.

Constructed Wetlands have been used for (i) treating septic tank and Imhoff tank effluents from housing complexes, and (ii) providing tertiary treatment to effluents from aerated lagoons and conventional sewage treatment plants. In both cases, constructed wetlands are provided to meet more stringent BOD and suspended solids (SS) standards before discharge of effluent to surface waters or for reuse.

Constructed wetlands (Reed beds root zone treatment) are of two types as far as their water surface is concerned. (i) Free water surface type (ii) submerged flow (SF). And the direction of flow is either horizontal or vertical (rootzone.com.au). Figure 1 shows a typical reed bed filled with gravel, sand or selected soil with horizontal flow of wastewater.

Reed bed is one of the natural and attractive methods of treating domestic, industrial and agricultural wastes. A reed bed is an engineered method of purifying polluted water as it passes through artificially constructed wetland area, usually containing common reeds. Reed bed is considered as an effective and reliable secondary and tertiary treatment method where land area is not a major constraint. Generally reed bed is made in shallow pits, installed with a drain pipe in a bed of pieces of lime stones and filled up with pebbles, iron filings and graded sand. The figure 2 shows the sandy body, reed plants (with hollow root which bring oxygen into the filter bed) planted.

Several other plant species that are preferably cultivated for reed bed system are *Canna indica*, *Stenotaphrum secundatum, Scirpuslacustris,* and *Schoenopletus lacustris* (bulrush) (Trivedy, 2007) Arceivala and Asolekar (2007) have discussed several parameters which are reported in table 2 related to treatment of raw domestic waste waters.

The current design criteria for wetland design are based on either empirical or first order reaction rates.

Polprasert *et al.* (1998) have studied to incorporate bio-film kinetics and dispersion data to predict COD in free water surface wetland design and determine performance from lab experiments.

Shulin *et al.* (1999) have used the concept of solute transport to develop a mathematical model to predict BOD removal in submerged flow constructed wetlands. The advantage is that it considers the impact of dispersion and is therefore more accurate in predicting BOD removal from submerged flow wetlands. Only a few well documented cases have been quoted in literature in India (Rengasamy and Subramaniyan, 2002; Joshi and Islam, 2004).

The performance of Constructed Wetlands Treating Domestic Waste water can be judged on the basis of various parameters such as biochemicals/ chemical oxygen demand (BOD / COD), TSS, nitrogen, phosphorus and coliform removal. The BOD removal efficiency in India when reed beds used in horizontal flow mode varies from 80–96%. Several examples of organic material removal are sited here. In case of Phragmites in North Europe studied for phenol removal 72% was metabolised by soil organisms, 16.7% by plant tissue and 9% was volatilised (Rust and Barlow, 1995). Nitrogen from the waste water was partially removed by the mechanism of nitrification-de nitrification and partially by physically harvesting the crop and removal from site. In case of raw sewage from residential complexes, pretreatment has to be provided in the form of a septic tank in order to remove settable solids before the flow goes to any macrophyte bed. Use of constructed wetlands in Germany (Bielefeld) for treating organic chemicals was successful.

Burkitt Tom *et al.* (2000) also reported that in UK, where reed beds with *Phragmites australis* are being used by ICI to treat industrial chemical waste from the manufacture of alcohols, phenols, acetones and amine with various derivatives.

Studies related to nitrogen and phosphorus removal show that phosphorus removal depends on the type of soil used in reed bed area. The removal efficiencies for nitrogen and phosphorus reported from cold climates are generally poor (20–30%). Reports from India indicate that phosphorus removal is highly variable. Nitrogen removal is also dependent on the carbon-nitrogen balance in the system (Rust and Barlow, 1995). Studies also show that pathogen and coliform removal is observed to be high.

Perfler and Haberl (1995) described the comparative studies carried out in Europe, Germany, Denmark, The Netherlands and Vienna, Austria, using both horizontal and vertical flow reed beds. They also concluded that by optimization of operating conditions it should be possible to establish the wetland system as a useful technology for waste water technology in rural areas (Perfler *et al.,* 1995)

From 1960 to 1980 many such natural and constructed wetlands were installed for treating Municipal waste waters in China. The waste from LIAOHE oil field treated mechanically and partly by natural techniques in which the final effluent showed a decrease in oil and COD.

Examples from India using constructed wetlands for industrial waste include: Tannery waste water has been treated successfully in selected tanneries of Tamil Nadu giving 50–60% organic removal along with better colour and turbidity removal. In some pilot studies constructed wetlands have been used to treat an automobile factory waste water giving 90% removal of COD and Reed bed systems have also been installed in India for treating industrial waste admixed with domestic sewage. Several data have revealed that the Bangalore Lake, Hussain Sagar Lake, Hyderabad, Andhra Pradesh in India which were badly polluted were also cleaned up using the Root Zone technology (Arceivala and Asolekar, 2007).

A review conducted by Sonavane *et al.* in 2008 on technology assessment programs conducted in collaboration with other countries to engineer this technology but here the nutrient removal aspects were not essentially focused. They also showed that there is a need for direct lab scale research to identify potential wetland plants, bed media and comparative study of their combination specific performance under similar conditions. The field application of the data will help to understand variability in performance and disparities in the mechanism. The systems would be amended based on these studies to establish combination specific performance standards for typical Indian conditions. Maintenance strategy and optimization of design will help to foster the technology. The development strategy should give due consideration to the contributions of other countries so as to avoid repetition of work which will save time, money and efforts, and help for the real acceptance of RZTS in Indian conditions.

Sohsalam *et al.* (2008) conducted a study to remove pollutants from seafood processing waste water using constructed wetlands planted with six emergent species.

Studies by Babatunde *et al.* in 2008 aimed at environmental pollution control through the use of constructed wetlands systems (CWs) in Ireland, a detailed review of CWs was undertaken. They laid emphasis on CWs technology, placing them in the overall context of the need for low-cost and sustainable wastewater treatment systems. Its use in protecting estuarine quality was also considered and the emerging concept of integrated constructed wetlands (ICWs) was also cited. In addition, CWs in operation in Ireland towards abating environmental pollution was done, and compared with CWs operating in other European countries. They also gave data that assisted in development of CWs and modelling studies.

A report by Vymazal and Kropfelova (2009) revealed that the highest removal efficiencies for BOD_5 and COD were achieved in systems treating municipal wastewater while lowest efficiency was recorded for landfill leachate. The survey also revealed that Horizontal sub-surface flow HF CWs are successfully used for both secondary and tertiary treatment of wastewater. They also showed the positive effects of macrophyte vegetation on removal of organism.

A report by Baskar *et al.* (2009) showed that the pilot unit setup reduced the concentrations of TSS, TDS, TN, TP, BOD, COD by 90%, 77%, 85%, 95%, 95%, 69%, respectively on an average. Root zone system also achieved standards for tertiary treatment with no operating costs, low maintenance costs, enhanced the landscape, provided a natural habitat for birds, and does not have any odour problem.

Their experimental results demonstrated the feasibility of applying sub-surface horizontal flow constructed wetland unit to treat campus waste waters. They suggested that the root zone treatment can be utilized independently or as an addition to conventional treatment for complete treatment of waste water (Baskar *et al.*, 2009).

Studies by Idris *et al.* 2012 in Australia evaluated the efficiencies of two emergent macrophytes, *Arundodonax* and *Phragmites australis* in experimental horizontal subsurface flow (HSSF), gravel-based constructed wetlands (CWs). The major water quality parameters monitored (biological oxygen demand (BOD), suspended solids (SS) and total nitrogen (TN) but not total phosphorus) were generally improved after the effluent had passed through the CWs. BOD, SS and TN removal in the *A. donax* and *P. australis* CWs was 69, 95 and 26 % and 62, 97 and 26 %, respectively.

Bacterial removal was observed but only to levels that would allow reuse of the effluent for use on non-food crops under Victorian state regulations. The planting of *A. donax* provides additional opportunities for secondary income streams through utilisation of the biomass produced.

In Ireland a study was conducted using the RZT for treating primary secondary and dairy soiled water by Healy and Flynn (2011). The performance of thirty-four FWSF (free water surface flow), comprising fourteen CWs treating primary-treated municipal wastewater, thirteen CWs treating secondary-treated municipal wastewater, and seven CWs treating DSW Dairy soiled water, were examined.

In most CWs, good organic, suspended solids (SS) and nutrient removal was measured. CWs treating primary and secondary wastewater removed 11295% and 84% of influent BOD. But again BOD removal depended on the SS loading rates. Their study also indicated that, all CWs examined had variable performance in ammonium-N (NH (4)(+)-N) removal, with average removals varying between 37% (for CWs treating secondary wastewater) and 88% (for CWs treating DSW). Variable ortho-phosphorus (PO(4)(3-)-P) removal was attributable to different durations of operation, media types and loading rates.

The use of constructed wetlands (CWs) for the treatment of the runoff waters from field cultivation and peat production in boreal climate was reviewed by Koskiaho and Puustinen (2005). The effectiveness of different types of CWs as well as the design and dimensioning parameters at the bottom of the effectiveness are also discussed. They also showed that CW area in relation to its catchment and hydraulically efficient CW shape are the main issues that a CW designer should focus on. Although both these factors stand up to as general guidelines, drawing conclusions from direct comparison of CWs in different locations is often misleading because of the differences in climate, catchment properties etc that highly effect the retention performance. Landscape improvement and increased birdlife are raised as examples of the ancillary benefits of CWs.

Several studies by Cristina and Calheiros (2014) demonstrated that phosphorus uptake capacity of macrophytes was reported to belower than the nitrogen uptake capacity (Brix, 1994) and removal of chromium was also negligible but different plants have different capacities of metal removal.

Table.1 shows the aquatic plant species that are preferably cultivated

Name of plant species	Country where cultivated	References
Typhalatifolia(cattail)	North America, Czech Republic	Vymazal, 2005
Typhaan gustifolia (cattail)	England	Sinicrope et al., 1990
Phragmitesaustralis(reed*)*	Switzerland	Stuffer, 2010; www.sswm.info
*Phragmiteskarka(*reed)	Czech Republic	Vymazal, 2011
Iris pseudacorusYellow flag	Czech Republic	Vymazal, 2005

Table.2 Process design norms for subsurface flow wetlands for treating raw domestic waste waters in India (Adapted from Arceivala and Asolekar, 2007)

Parameters	Typical Values	
	European Literature	Recommended for India
Area requirement, m^2 / person[1]	2-5	1-2
BOD_5 loading rate, g / m^2 - day [2]	7.5-12	17.5-35
Detention time, days	2-7	2-3
Hydraulic loading rate, mm / day	(Must not exceed hydraulic conductivity of bed)	
Depth of bed, meters		0.6-0.9
Porosity of bed, %		30-40
1st Order reaction Constant, K_T /day		0.17-0.18
Evapotranspiration losses, mm /day[3]	10-15	>15

1. Constructed wetlands may be suitably downsized when wastewater is pre-treated.
2. Based on raw sewage BOD= 50g/person-day and 30% reduction in presetting.
3. 1.0mm/day=10m^3/ha-day.

Figure.1 Reed bed filled with gravel, sand or soil with horizontal flow of wastewater

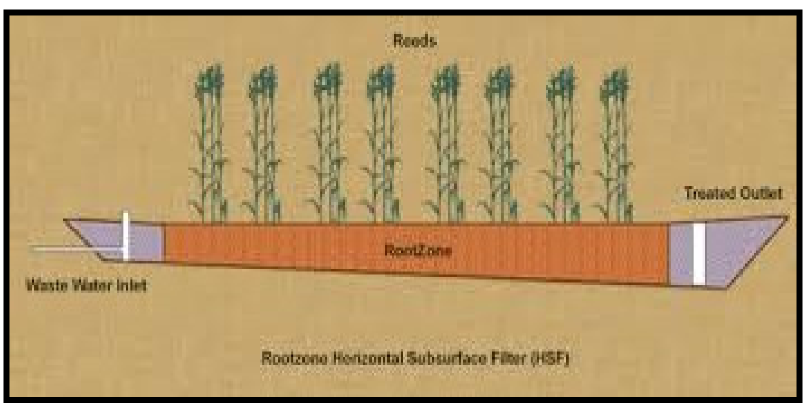
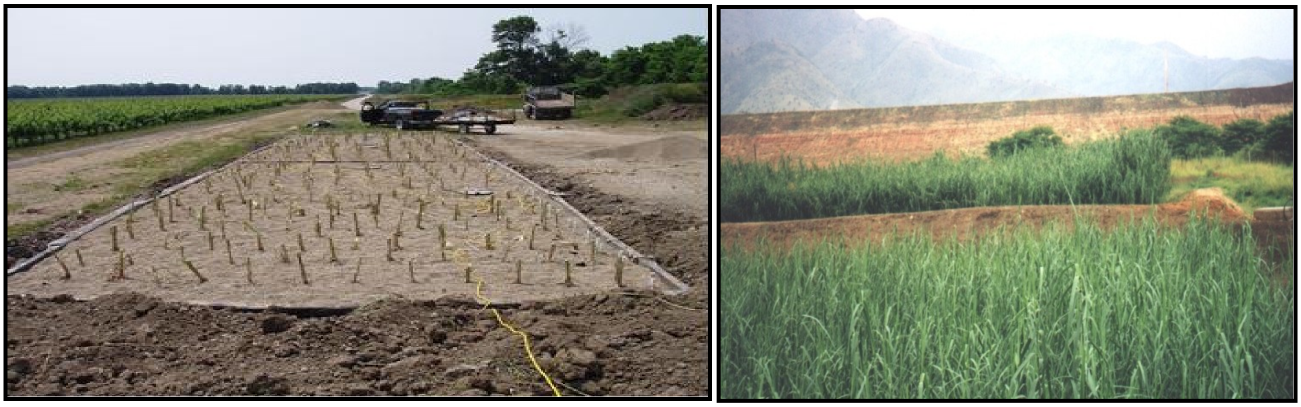


Figure.2 Sandy body with reed plants



Makvana and Sharma (2013) also proved that the method of root zone in a constructed wetland is capable to remove indicator bacteria, total coliforms, faecal coliforms and pathogenic microbes including *Salmonella*, *Shigella* and *Vibrio* significantly and thus improve water quality**.** The overall study strongly recommends the use of CWs for treatment of domestic waste water for pathogenic bacteria, besides pollutants.

A recent study conducted at Ekant Park, Bhopal, India clearly proved that the water quality during Root Zone treatment improved a lot which was indicated by reduction in BOD, COD, nitrate & phosphate value and increase in DO value. They also concluded that the root zone system was working effectively to treat the wastewater and the treated water could be reused for secondary purposes like fishing, swimming, irrigation etc. and safe disposal in nearby water bodies (Thakur *et al.*, 2014)

Considering the above facts we can say that the application of constructed wetlands in small towns, district and area can now be recognized as an accepted low cost eco-technology, especially beneficial as compared to costly conventional treatment systems. Hence "Root Zone Technology" scores over the conventional chemical treatment of waste water and sewage water on these counts. Today constructed wetlands are recognized as are liable wastewater treatment technologies and represent a suitable solution for the treatment of many types of wastewater including industrial effluents, to treat storm-waters, industrial, mining and agriculture wastes. In this way the population that can be served is dependent on the land area available, the media used, climate, and other factors.

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