

Reed Bed System: An Option for Reclamation of Polluted Water Resources: A Review

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ABSTRACT

At present, India is facing the worst water shortage in its history. According to a report by Niti Aayog, about 600 peoples are suffering with high to extreme water shortage and also states that around 200,000 lives of Indians are losing every year owing to the contamination of water or inadequate water supply. Here comes, the need for the safeguard of water resources in our country. But the fact is that Indian rivers are polluting at an alarming rate of 80% due to untreated wastewater flowing into water bodies have almost doubled in recent years. To reduce the contamination level of water resources, wastewater treatment will play a predominant role. Conventional wastewater treatment technique, i.e., activated sludge, were used to reduce the concentration of the pollutants in sewage water. However, there are still some confines especially that they operate at a higher cost. The objective of this review paper is to elaborate on how the reed bed system can act as a better alternative technology to conventional system for wastewater treatment.

Keywords: Conventional techniques, Reed bed system, Wastewater treatment, Water contamination and shortage.

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INTRODUCTION

Water is the basic source of life. About 1,460 tera tonnes (Tt) of water covers 71% of the Earth's surface, mostly in oceans and other large water bodies, with 1.6% of water below ground in aquifers and 0.001% in the air as vapors, clouds (formed of solid and liquid water particles suspended in air), and precipitation (Subalakshmi *et al.*, 2015). Out of 100% of water quantity 97% occupied by vast oceans, 2% of fresh water got stuck with ice caps and glaciers and only 1% is available as fresh water in rivers, lakes, ponds, etc., (Bralower and Bice, 2011). The era of industrial development had gained the attention for environmental protection due to urbanization and rapid growth of industries. As a result, the major water bodies are polluted by the hazardous discharge of domestic sewage and industrial wastewater in the world (Arvind Chavhan, 2012). So, the conservation and treatment of the water become more important in order to preserve this fast depleting resource.

Due to increasing population and all-round development in the country, the per capita average annual freshwater availability has been reducing. Wastewater treatment is not given the necessary priority it deserves and therefore, a significant volume of wastewater is not subjected to any treatment and is ultimately discharged into surface water bodies leading to the deterioration of water quality. This leads to an accelerated increase in the pollution of surface water bodies. Major rivers were contaminated through industrialization, urbanization and land use pattern (Jindal and Sharma, 2011).

Currently, providing housing, health care, social services, and access to basic human needs infrastructures, such as clean water and the disposal of effluent, presents major challenges to engineers, planners, and politicians (Giles and Brown, 1997). Nearly, only 60% of industrial wastewater,

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mostly large scale industries is treated. Performance of state-owned sewage treatment plants for treating municipal wastewater and common effluent treatment plants for treating effluent from small scale industries were also not complying with prescribed standards. Thus, effluent from the treatment plant not suitable for household purpose and reuse of the wastewater is mostly restricted to agricultural and industrial purposes.

Wastewater-irrigated fields generate great employment opportunity for female and male agricultural laborers to cultivate crops, vegetables, flowers, fodders that can be sold in nearby markets or for use by their livestock (Asano and Levine, 1996). However, there are higher risk associated to human health and the environment on use of wastewater especially in developing countries, where rarely the wastewater is treated and large volumes of untreated wastewater are being used in agriculture. In the metro politics, city facilities are provided wastewater treatment plant, but in a rural area, sewage drains are directly connected to water bodies (Mankoskar *et al.*, 2016). Hence, there is an urgent need for efficient water resource management

through enhanced water use efficiency and wastewater recycling.

WATER AVAILABILITY AND ITS USE IN INDIA

Although India occupies a geographical area about 3.287 million km² (2.45% of world's land area) and 4% of world water resources, it supports for 17.74% of world's population (Department of Economic and Social Affairs, Population Division, World Population Prospects: 2017). Total utilizable water resource in the country has been estimated to be about 1123 BCM. In India per capita surface water availability in the years 1991 and 2001 were 2300 m³ and 1980 m³, respectively and these are projected to reduce to 1401 and 1191 m³ by the years 2025 and 2050, respectively (Kumar *et al.*, 2005). By 2025, demand for domestic and industrial water usage may increase to 29.2 BCM. Water availability for irrigation is expected to reduce to 162.3 BCM. With the present population growth rate (1.9 % per year), the population is expected to cross the 1.5 billion mark by 2050 (CGWB, 2011) (Graph 1).

WASTEWATER REGENERATION

Industrialization is the means for the economic development of a nation. During the production, industries generate useless by-products and waste materials with 1 to 10% of the number of parent chemicals (CPCB, 2004). The effluent discharged from industries contaminates our soil and water resources. River pollution is an environmental problem in third world countries. While developed nations adopt stringent water quality requirements to control river pollution from point and non-point sources, the situation is different in most developing countries.

Wastewater treatment is not given the necessary priority it deserves and therefore, a significant volume of wastewater is not subjected to any treatment and is ultimately discharged

into surface water bodies leading to the deterioration of water quality. This leads to an accelerated increase in the pollution of surface water bodies nowadays (Manju *et al.*, 2015).

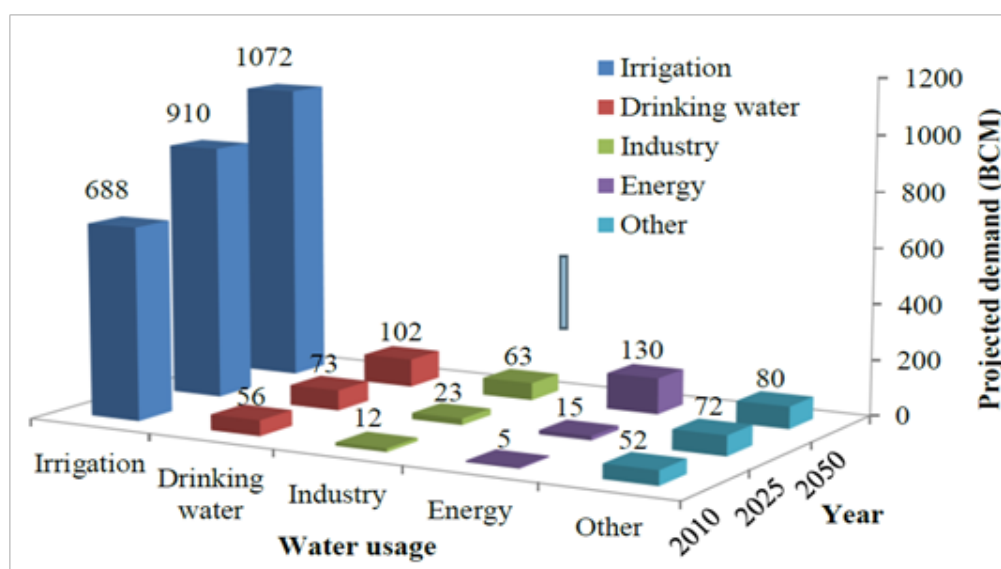
Central Pollution Control Board carried out a study on the status of Municipal wastewater generation in India and published a document (CUPS/61/2005-06). The sewage generation from Municipal cities (35), class I cities (498) and class II town's (225) accounts about 15644 MLD (million liters per day), 11553 MLD and 2696 MLD, respectively. Maharashtra generates a higher volume of sewage of about 10200 MLD which followed by UP, Delhi and West Bengal. The country's total sewage generation reaches 38254.82 MLD.

TREATMENT CAPACITY

The treatment capacity of Municipal cities, class I cities and class II town's are 51%, 32%, and 8% respectively. Thus, there occurs a great gap between sewage generation and its treatment in India. Operation and maintenance of existing treatment plants and sewage pumping stations are not satisfactory, and nearly 39% treatment plants are not meeting the requirements to the general standards prescribed under the environmental (protection) rules for discharge into streams as per the CPCB's survey report. In a number of cities, the existing treatment capacity remains underutilized while a lot of sewage is discharged without treatment in the water bodies (CPCB, 2010) (Fig. 1).

WATER QUALITY SCENARIO

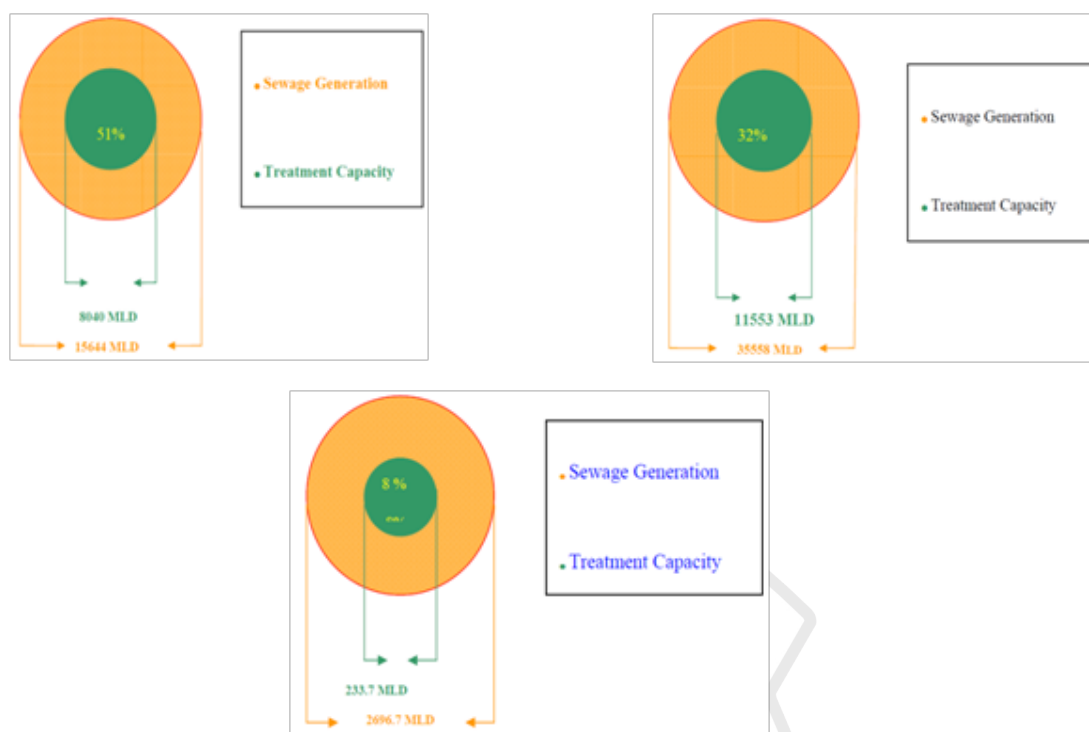
The dissolved oxygen levels in rivers like Cauvery, Godavari and Pennar are relatively deoxygenated that can affect the flora, fauna and also natural purification capacity of the river. In the rivers like Cauvery, Godavari, Mahanadi, Pennar, Krishna, Narmada, and Mahi recorded the TDS value of about >200 mg/L which is significantly higher than the average value among worldwide (JM *et al.*, 2015). The salinity of the



Source: CWC, 2010

Graph 1: Projected water demand by different sectors in India





Source: CPCB, 2005-06

Fig. 1: Sewage generation and treatment capacity in India

Pennar, Mahanadi, and Narmada rivers was categorized under C3 ($EC > 750 \mu S/cm$) in which the river water can be used for agricultural purposes with special management of salinity hazard. To remove the contaminants, it is necessary to treat the wastewater effectively (Suthar *et al.*, 2009).

NEED OF SEWAGE TREATMENT

Wastewater treatment involves the breakdown of complex organic compounds in the wastewater into simpler compounds that are stable and nuisance-free, either physicochemical and/or by using microorganisms (biological treatment). The adverse environmental impact of allowing untreated wastewater to be discharged in groundwater or surface water bodies and or lands are as follows:

- The decomposition of the organic materials contained in wastewater can lead to the production of large quantities of malodorous gases.
- Untreated wastewater (sewage) containing a large amount of organic matter, if discharged into a river/stream, will consume the dissolved oxygen for satisfying the biochemical oxygen demand (BOD) of wastewater and thus deplete the dissolved oxygen of the stream, thereby causing fish kills and other undesirable effects.
- Wastewater may also contain nutrients, which can stimulate the growth of aquatic plants and algal blooms, thus leading to eutrophication of the lakes and streams.
- Untreated wastewater usually contains numerous pathogenic, or disease-causing microorganisms and toxic compounds, that dwell in the human intestinal tract or may

be present in certain industrial waste. These may contaminate the land or the water body, where such sewage is disposed of.

For the above-mentioned reasons the treatment and disposal of wastewater, is not only desirable but also necessary (Jayashree *et al.*, 2012).

TERMINOLOGIES INVOLVED IN WASTEWATER TREATMENT

Wastewater

Wastewater is "used" water, the water leftover after its use in numerous applications such as industrial, agricultural, municipal and domestic.

Sewage

The used water and added waste of a community which is carried away by drains and sewers. Sewage includes both liquid and solid waste.

Sludge

A system of sewers; the removal of waste materials by means of a sewer system.

Influent

The untreated wastewater or raw sewage coming into a wastewater treatment plant.

Effluent

The final output flow of a wastewater treatment plant (Glossary of wastewater terms).

WASTEWATER TREATMENT

Wastewater defined as the liquid discharge carried wastes from industries, residences, institutions, etc. The main objective of wastewater treatment is to remove the contaminants so that the treated water can be let safely into the environment. Natural treatment technologies are considered viable because of their low capital costs, their ease of maintenance, their potentially longer life-cycles and their ability to recover a variety of resources including treated effluent for irrigation, organic hummus for soil amendment and energy in the form of biogas (Dhote *et al.*, 2012). Wastewater treatment comprises three stages—primary, secondary and sludge disposal. Primary treatment involved in removing the suspended solids, odor, color and pH neutralization. Secondary treatment aids in reducing the BOD of wastewater biologically and sludge disposal to remove the solid waste and stabilize the solids into stable products (Subalakshmi *et al.*, 2015).

Primary Treatment

The objective of primary treatment is the removal of settleable organic and inorganic solids by sedimentation and the removal of materials that will float (scum) by skimming. Approximately 2–50% of the incoming biochemical oxygen demand (BOD₅), 50–70% of the total suspended solids (SS) and 65% of the oil and grease are removed during primary treatment. Some organic nitrogen, organic phosphorus and heavy metals associated with solids are also removed during primary sedimentation but colloidal and dissolved constituents are not affected. The effluent from primary sedimentation units is referred to as primary effluent.

Secondary Treatment

The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids. In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolize the organic matter in the wastewater, thereby producing more microorganisms and inorganic end-products (principally CO₂, NH₃, and H₂O). Several aerobic biological processes are used for secondary treatment differing primarily in the manner in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolize the organic matter.

The biological solids removed during secondary sedimentation called secondary or biological sludge are normally combined with primary sludge for sludge processing. Common high-rate processes include:

- Activated sludge processes
- Trickling filters or bio-filters
- Oxidation ditches

- Rotating biological contactors (RBC)
- Constructed wetland
- Coagulation
- Membrane bioreactors
- Adsorption, precipitation, and reduction (Ahalya *et al.*, 2005)

A combination of two of these processes in series (e.g., biofilter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources (Kulkarni *et al.*, 2000).

Tertiary Treatment

Tertiary wastewater treatment is employed when specific wastewater constituents which cannot be removed by secondary treatment must be removed. Tertiary treatment usually follows a high-rate secondary treatment process; it is sometimes referred to as advanced treatment. However, tertiary treatment processes are sometimes combined with primary or secondary treatment (e.g., chemical addition to primary clarifiers or aeration basins to remove phosphorus) or used in place of secondary treatment (e.g., overland flow treatment of primary effluent) (Subalakshmi *et al.*, 2015).

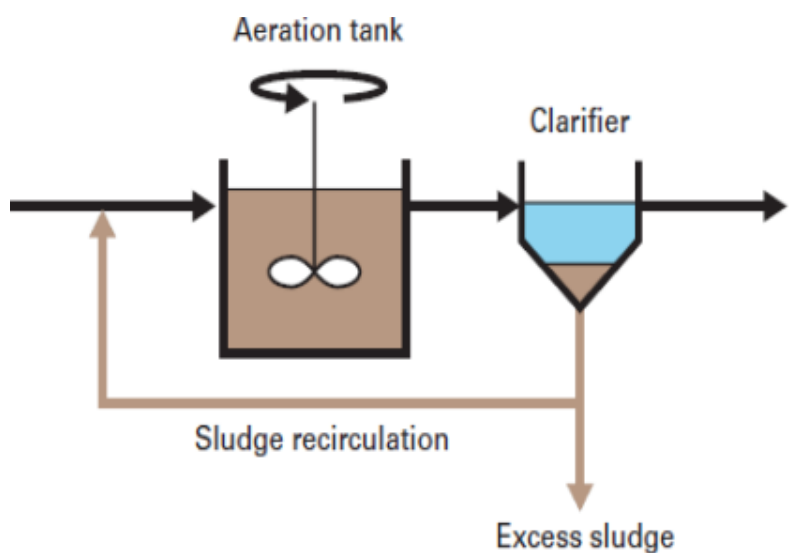
CONVENTIONAL SYSTEM: ACTIVATED SLUDGE

Activated sludge is the conventionally used system for wastewater treatment. In the activated sludge process, the dispersed-growth reactor is an aeration tank or basin containing a suspension of the wastewater and microorganisms, the mixed liquor. The contents of the aeration tank are mixed vigorously by aeration devices which also supply oxygen to the biological suspension. Aeration devices commonly used include submerged diffusers that release compressed air and mechanical surface aerators that introduce air by agitating the liquid surface. Hydraulic retention time in the aeration tanks usually ranges from 3–8 hours but can be higher with high BOD wastewaters (Akshey Bhargava, 2016).

Following the aeration step, the microorganisms are separated from the liquid by sedimentation and the clarified liquid is secondary effluent. A portion of the biological sludge is recycled to the aeration basin to maintain a high mixed-liquor suspended solids (MLSS) level. The sedimentation process separates micro-organisms from the liquid suspension and the clarified liquid is treated effluent. The process of removing organic matter in wastewater with the help of high concentration of micro-organisms, principally bacteria, protozoa and fungi which present as a loose clumped mass of fine particles that kept in suspension by constant stirring with a mechanical stirrer (Rajasulochana and Preethy, 2016).

The remainder is removed from the process and sent to sludge processing to maintain a relatively constant concentration of microorganisms in the system. Several variations of the basic activated sludge process, such as





Source: SUEZ water treatment handbook

Fig. 2: Activated sludge treatment process

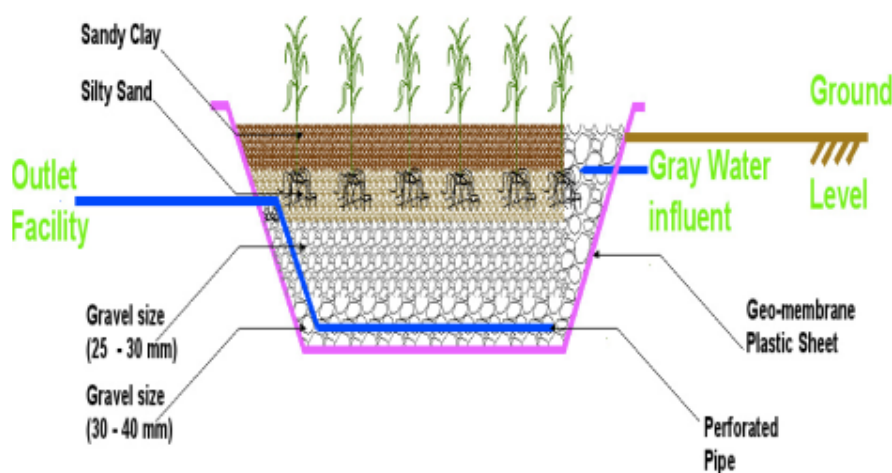
extended aeration and oxidation ditches, are in common use, but the principles are similar. Aerobic activated sludge reactors have been used on a limited scale as it requires bio-scrubbers for the treatment of odorous air (Bowker, 2000) (Fig. 2).

REED BED SYSTEM

Reed bed system is a secondary or tertiary treatment method for wastewater treatment. Reed bed is one of the natural and cheap methods of treating domestic, industrial, and agricultural wastewater. The basin lined with the sand, gravel and then planted with macrophyte which is called as reed bed. Treatment involves various processes which include physical, chemical and biological interactions between

wastewater, plants, gravel, atmosphere, and microorganisms. This is also known as constructed wetland or root zone technology (Tiwari, 2017). It is an environmentally sustainable, highly effective and alternative method for high energy mechanical treatment systems and also it requires a lower cost than a conventional system. Reed bed system has sure to be an alternative and favorable technology for wastewater treatment (Amol and Sagar, 2016) (Fig. 3).

Application of root zone technology (RZT) is finding wider acceptability in developing and developed countries, as it appears to offer a more economical and ecologically acceptable solution to water pollution management problems and it is reliable and flexible (Nielsen, 2012). Root zone systems, whether natural or constructed, constitute an



Source: Afifi et al., (2015)

Fig. 3: Reed bed system

interface between the aquifer system and terrestrial system that is the source of the pollutants. These are reported to be most suitable for schools, hospitals, hotels and for smaller communities. The country's reportedly first RZT system was designed by NEERI at Sainik School, Bhubaneswar, Orissa. It has reportedly been giving a very good performance of removing 90% BOD and 63% nitrogen (CPCB 2000).

Types of Reed Bed (Bouali *et al.*, 2006)

- Based on construction type
- Based on type of macrophytic growth

Based on Construction Type

Surface Horizontal Flow (SHF)

This design allows water to flow over the surface of the bed between the stems of the reed plants which are planted in the earth. The water is visible, usually to a depth of around 150mm. The design is effective for settling out solids prior to further treatment (Bansari M Ribadiya, 2014).

Subsurface Flow (SSF)

This design allows water to flow below the surface of the reed bed through gravel media. The reed plants are planted in the gravel. There is no visible water in the bed and as such presents no public safety of odor problems. The reed plants are allowed to dieback in winter and form a warm composted layer which protects the bio-film below. This design is effective in reducing SS, BOD, COD and partial ammonia removal. It is also effective in the removal of hydrocarbons, some heavy metals, and nitrates. There are classified into three types.

1. Horizontal flow
2. Vertical flow
3. Hybrid flow

Horizontal Flow

Sewage effluent fills the space between the gravel and circulates horizontally, naturally, each time water comes into

the system. There is no external energy dependency (and therefore no contribution to pollution output). Most of the HLRs are in the range of 10–100 mm/d (Tanner, 2001). In an evaluation of different HFRBs, it was found that the system with the lowest water depth (0.3 m) showed the second highest ammonia removal efficiency (EPA, 1993) (Fig. 4).

Down Flow or Vertical Flow (VF)

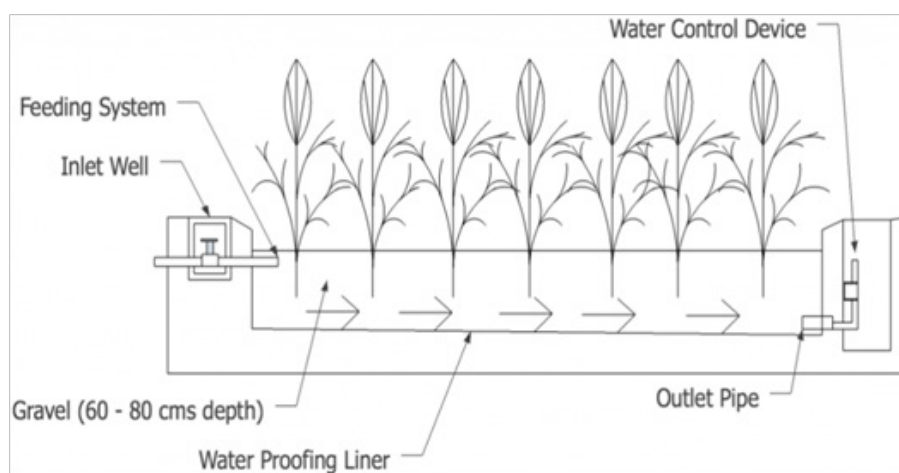
Sewage water is pumped at regular intervals (every 2–6 hours, depending on design and treatment levels sought) through a network of pipes laid on top of a bed filled with gravel-type media of generally three different granulometries through which the water percolates. Vertical flow CWs generally require 2/3 of the space of a horizontal flow CW and can raise treatment quality in certain parameters yet they are less passive systems as they rely on a controlled source of energy.

This design requires dosing of the bed's surface using a network of pipes using either pumping or a siphon system. The idea is to flood the surface of the reed bed a number of times per day. As the water flows down through the bed, it draws air in creating the right bacterial environment. VF reed beds are very effective in the removal of BOD, ammonia and some heavy metals and take up less area for similar treatment compared to SSHF. The correlations of urease activity with pollutant removal efficiencies for different parameters in vertical subsurface flow reed bed system and observed a strong correlation for total nitrogen (Liang *et al.*, 2003).

The efficiency of SSHF and VF reed beds may be improved by adding certain chemicals to the water during the treatment. This dosing technique can be used for COD or phosphorous removal in industrial process water, for example. Water can be treated progressively through multiple reed bed stages and some or all of the above systems can be incorporated into a complete treatment system (Fig. 5).

Hybrid Flow

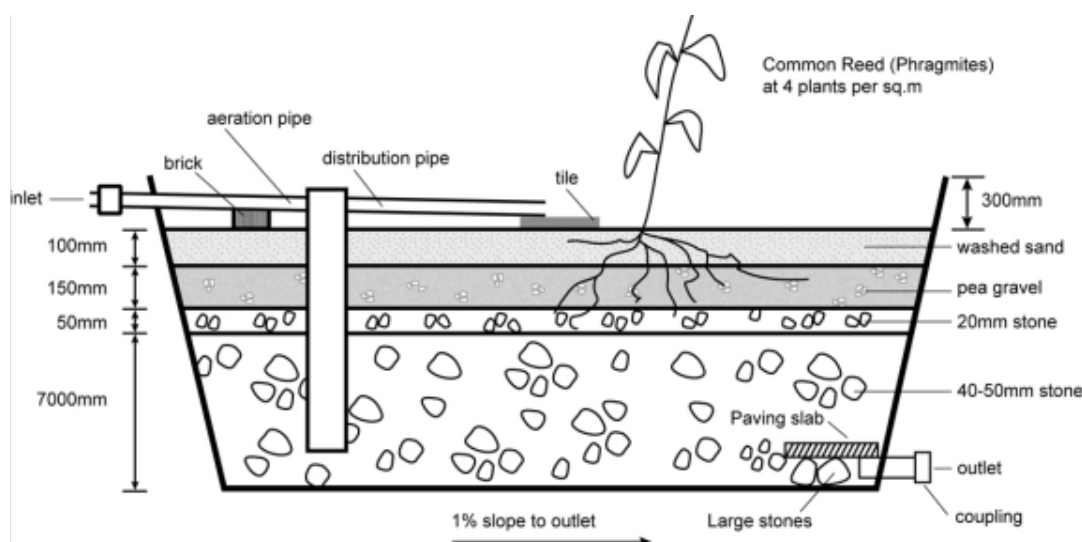
Hybrid flow involves both horizontal and vertical flow. It incorporates one or two stages of vertical flow followed by



Source: <https://sswm.info.com>

Fig. 4: Horizontal flow





Source: Zipperlen (2006)

Fig. 5: Vertical flow

one or more stages of horizontal flow in series. This type of hybrid flow was designed to achieve higher treatment efficiency of wastewater. Hybrid flow constructed wetland targets in total nitrogen removal, organic reduction and pathogen removal from wastewater (Table 1).

Based on Type of Macrophytic Growth

Based on the macrophytic growth, constructed wetland can be classified into four types:

1. Reed beds with free-floating macrophytes
2. Reed beds with floating-leaved macrophytes
3. Reed beds with submerged macrophytes
4. Reed beds with emergent macrophytes.

REED BEDS WITH FREE-FLOATING MACROPHYTES

Free-floating plants have most of their photosynthetic parts above the surface of the water and their root below it. Free-

floating plants can be used as raw sewage as well as for primary or secondary treated effluents.

Typical plant species that have been used in the large scale applications are water hyacinth and duckweed species (*Lemna*, *Spirodela*, and *Wolffia*). The use of temperate climates of reed beds with water hyacinth, one of the most productive plants in the world is limited because hyacinth needs high temperature for its growth. The major disadvantage of duckweed compared to water hyacinth is their shallow root system and sensitivity towards wind, however, the major advantage is their lower sensitivity towards colder climates.

REED BEDS WITH FLOATING-LEAVED MACROPHYTES

Floating-leaved macrophytes include plant species that are rooted in the substrate, and their leaf floated on the surface. Water lily, yellow pond lily, and lotus are the typical representative of this group. So far, only a few systems have been used this type of vegetation, and the use of reed beds with floating-leaved species for wastewater treatment are considered questionable.

REED BEDS WITH SUBMERGED MACROPHYTES

The photosynthetic tissue of submerged aquatic plant is entirely submerged. Sea moss (*Cladophora* sp), green weed (*Enteromorpha* sp), pondweed (*Potamogeton* sp), hornwort (*Ceratophyllum* sp), giant duckweed (*Myriophyllum* sp), *Elodea canadensis*, *Egeria muttalli*, sea lettuce (*Ulva lacytuca*) and *E. densa* have been studied for wastewater treatment, but the use of submerged macrophytes for wastewater treatment is still in the experimental stage. The development of epiphytic communities on the leaves of vascular plants may reduce photosynthesis in submerged macrophytes.

REED BEDS WITH EMERGENT MACROPHYTES

These plants are rooted in the bottom mud, with aerial stems and leaves at or above the water surface. The leaves are broad

Table 1: Percentageremoval of pollutants by reed beds

Bed type	Removal
Horizontal sub-surface flow	Results obtained from large number of beds indicate that BOD removal is 80–90% with a typical outlet concentration of 20 mg L ⁻¹ , total-N removal is 20–30% and total-phosphate removal is 30–40% (Cooper, 1990)
Vertical flow	A system with two stage of vertical flow to treat domestic sewage remove 93% BOD, 90% suspended solids, 75% NH-N and 37% orthophosphate (Burka and Lawrence, 1990)
Surface flow	The effluent from lead-zinc mine which passed through a bed of <i>Typha latifolia</i> had achieved level of reduction 99% of SS, Pb of 95% and Zn 80% respectively (Lan et al., 1990)

in many plants and sometimes like grasses. These leaves do not rise and fall with water level as in the case of floating weeds. Constructed wetland for wastewater treatment with emergent macrophytes can be constructed with a different design. Various emergent macrophytes species can be used in constructing wetlands, including cattails, bulrushes, reeds, rushes.

MECHANISM OF REED BED

The macrophytes play a major role in the reed bed system that greatly influenced the physical, chemical and biological processes (Tiwari, 2017). The wastewater is allowed to pass through the root zone of the reed where it undergoes different processes. The retention period for wastewater is about 5–7 days. Macrophytes provide oxygen for microbial proliferation which breakdown complex organic substance and also involved in absorbing some of the nutrients and heavy metals in the wastewater. The main pollutant removal mechanisms are biochemical transformation, adsorptions, precipitation, and plant uptake (Fig. 6).

AQUATIC PLANT SPECIES

The aquatic plant species cultivated should preferably be one of the native plant species which grows locally in that area. The selected species should have a relatively rapid growth rate, be tolerant rich feeds and be able to withstand wetlands conditions. Thus, one of the following species could be selected:

1. *Phragmites australis* (Common reed)
2. *Typha orientalis* (Bullrush)
3. *Schoenoplectus validus* (Great bulrush)
4. *Baumea articulata* (Jointed twigrush)
5. *Baumea rubiginosa* (Twigrush)
6. *Bolboschoenus fluviatilis* (Marsh clubrush)
7. *Eleocharis sphacelata* (Tall spikerush)
8. *Lepironia articulata* (Grey rush)

In India, the *Phragmites sp.* (locally called Nanal in Tamil Nadu). They have relatively deep roots and rhizomes

which create a large volume of active rhizosphere per unit surface area. They supply oxygen to the microorganisms in the substrate and help stabilize the organic matter applied. The plants create oxidized microorganisms perform, stabilizing organic matter and promoting nitrification and denitrification. Most degradation of nutrients is however undertaken by the microbes.

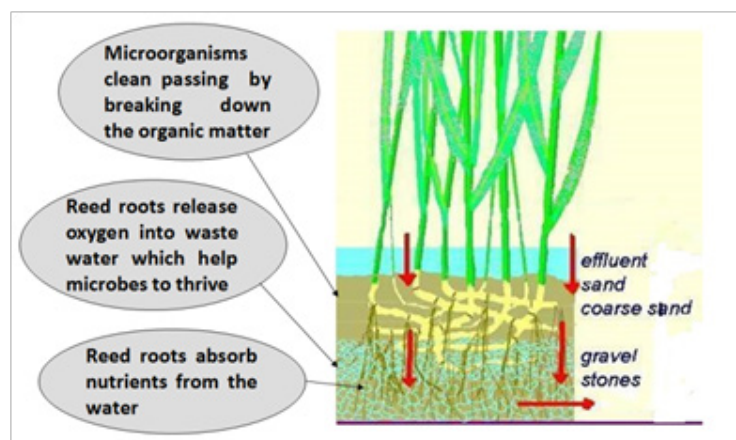
As the roots and rhizomes penetrate through the soil, they loosen the soil and improve percolation thus helping in stabilizing the hydraulic conductivity at a level reported to be resembling coarse sand, within 2-5 years regardless of the initial porosity of the soil. The reed beds also promote evapotranspiration in the growing season up to 10–15 mm/day or 100–150 m³/ha-d (Arceivala *et al.*, 2007).

Roots of reeds release O₂ into the bed matrix, promoting aerobic conditions for nitrification to occur (Browning *et al.*, 2002). The roots may also release exudates that support the growth of microorganisms, and antibiotics that kill pathogens (Brix, 1994 and Vymazal *et al.*, 1998).

The factors which influencing purification process includes hydraulic retention time and hydraulic loading rate (HLR), gravel size, reeds used and its growth stage, the design adopted and pollution concentration (Garcia *et al.*, 2004). Organic matter in polluted water is removed in HFRBs through a combination of five possible mechanisms: sulfate reduction, denitrification, diffusion of air at the air and water interface (aerobic respiration), oxygen transport through macrophytes (aerobic respiration) and methanogenesis (Burgoon *et al.*, 1991) (Table 2).

CONSTRUCTION OF CONSTRUCTED WETLAND

The unit was constructed by placing separate layers of bricks (bricks or brickbats) stone chips, sand, stone dust, after arranging the layers the plants were planted in the unit. Further, the growth of plants was monitored. During the growth period of one month, only plain water was sprinkled. Then sewage water was let into the root zone system and the



Source: Garcia *et al.*, (2004)

Fig. 6: Mechanism of reed bed system



Table 2: The average values of measured chemical and biological parameter

Parameters	Influent (gray/settled water)	Effluent (reclaimed water)	Removal %
BOD5 mg/L	397	122	69.3
COD5 mg/L	683	215	68.5
FC µ/100 mL	105	103	99.9 (2 logs)
Total solid (TS) mg/l	1500	1250	19.5
Total suspended solids (TSS) mg/L	300	177	41

Source: Afifi *et al.*, (2015)

samples were collected at the outlet. The bottom is covered with a gravel drainage layer of 0.25 m, which also contains the perforated drainage pipes to drain the excess sewage water (Artur Mennerich *et al.*, 2017).

GUIDELINES FOR CONSTRUCTION

Selection Site

- The selected site should not impair the drinking water sources
- The site must be safe from flooding
- The ground at the site should be flat and at a lower level than the wastewater source
- If properly design and built, CW does not create any order or nuisance in the vicinity
- It must be possible of the treated wastewater at the selected site as per the standards set by the concerned regulatory agency
- The site should be accessible for maintenance (Kumarrohill, 2013)
- Shape
- It is preferred to construct the CW planted filter bed rectangular in shape with more length than breadth. This allows an increase in the flow path that helps in higher treatment efficiency.
- In the case of space constraint, either an alternative shape can be given to the filter bed such as zigzag or vertical flow CW can be developed (Kumarrohill, 2013). Several studies with innocuous tracers for horizontal flow beds have repeatedly demonstrated that an increasing aspect ratio delays the breakthrough time but the spread of the response curve is similar for lower and higher aspect ratios (Fisher, 1990 and Netter, 1994).

Selection for Suitable Filter Media

- Rounded gravel should be chosen. Sharp-edged media can lead to the damage of liner. Size of the filter media should be 2–4 cm. Effective grain size should be >2 mm.
- Different size of filter media in a proportion of 1:3 should be used that will give an effective pore space of 30 percent (Suresh Kumarrohill, 2013).

Depth and Dimension

Water depth probably influences treatment efficiency because this parameter is involved in the mass transfer coefficient of oxygen from the atmosphere to the water (Burgoon *et al.*, 1995). For the dimensioning of the planted filter bed, two factored have to be considered (Kumarrohill, 2013):

1. Volume of wastewater
2. Organic load

Lining the Reed Bed

It is critically important that the reed bed be contained in a durable water-tight membrane to avoid leakage of poorly treated effluent into the environment and intrusion of groundwater into the reed bed. The membrane must be durable enough to resist being punctured by the gravel during installation, macrophyte rhizomes, and external tree roots and rocks. It must also be able to withstand sustained exposure to sunlight and potentially corrosive wastewater. Care should be taken when placing the gravel into the reed bed so sharp points do not puncture the liner. Earthmoving machinery should not be permitted to travel on the reed bed.

Inlet and Outlet Structures

One of the primary aims of the inlet and outlet structures minimizes the risk of short-circuiting of flow through the reed bed by ensuring the even distribution of influent across the width of the bed and the even collection of effluent across the width of the bed at the outlet end. To achieve this in a round reed bed, baffles should be installed at the inlet and outlet ends of the bed (WWG information sheet).

FACTORS INFLUENCING THE PURIFICATION

The main factors that typify the treatment characteristics are:

- Hydraulic loading rate ($m^3/[ha \times d]$) and hydraulic detention time(d)
- Temperature
- Influent pollutant concentration
- Oxygen supply
- The development stage of the reed ecosystem

The typical HLR reported is 7.5–10 cm every 7 to 10 days (Nelson, 2003). Reed beds are not a long term solution. They are a relatively new idea and even when they are designed and maintained properly, they will only be viable for up to a maximum of 7 to 10 years for reed beds that follow a full treatment plant as a final polishing filter only. Each batch operation of the reed bed system lasted for 105 days when reeds were being cultivated and matured (Zhao *et al.*, 2003).

Oxygen

Oxygen in wetland systems is important for heterotrophic bacterial oxidation and growth. It is an essential component for many wetland pollutant removal processes, especially nitrification, decomposition of organic matter, and other biological mediated processes. It enters wetlands via water inflows or by diffusion on the water surface when the

surface is turbulent. Although wetlands are characterized by anaerobic and reducing properties that result from flooding of the soil, layers with oxidative properties due to the wetlands aeration by vegetation roots also are present in many flooded systems. This results in the development of microbes and results in decomposition (Sima *et al.*, 2015).

pH

Wetland waters usually have a pH of around 6–8. The biota of wetlands especially can be impaired by sudden changes in pH.

Temperature

Temperature is a widely-fluctuating abiotic factor that can vary both diurnally and seasonally. Temperature exerts a strong influence on the rate of chemical and biological processes in wetlands, including BOD decomposition, nitrification, and denitrification (WWG information sheet).

OPERATION AND MAINTENANCE

Reed beds system requirements relatively simple and even conducted by unskilled labor because it doesn't involve high-tech appliances or chemical additives, which may allow an organization or a private sector to manage the system. The maintenance includes a periodical sludge and scum control and emptying in primary treatment, plant harvesting, ensuring clogging does not occur in the bed with time the gravel will become clogged and may have to be replaced or regenerated every 10–20 or several years (Raval, 2015).

APPLICATION OF REED BED SYSTEM

The reed bed system is effective in treating effluent from rural areas, food processing industry, breweries, animal husbandry, sewage from the residential area, Institutional and industrial complex and chemical industry.

ADVANTAGES OF REED BED OVER CONVENTIONAL SYSTEM

Reed beds are low-cost technology; it is easy to construct, operate, maintain and also have ecological values (Tiwari, 2017). They need not require any machineries and electricity treatment under gravity. Constructed wetlands were found to have significantly lower total lifetime cost and often lower capital costs than conventional treatment systems. Plants used in this system enhance the efficiency of nutrient removal, raise microbial diversity, do not alter the esthetics of the landscape and can be used for composting. Reed bed has better adaptability and flexibility of treatment, tolerates fluctuations in flow and does not involve additional pollutants. This technology can be worth and less expensive to build other than treatment options (Nergis *et al.*, 2017).

DISADVANTAGES

The main drawback of this system is the requirement of a larger area than the conventional system. Construction

should have proper planning and implementation. The reeds are sensitive to nutrient concentration and toxic levels and require a constant water supply. Plants may have plant stress, mortality symptoms, susceptible to nitrogen burn, heat stress, ammonia toxicity and damage by aphids. The chances for developing negative micro-organisms and may lead to the accumulation of heavy metals in plants (Halverson, 2004).

CONCLUSION AND SUMMARY

Reed bed treatment is an efficient method for treating domestic wastewater and very suitable for arid climate areas. In India, it has achieved 80–96% in horizontal flow, about 75% of TSS removal in most cases. In cases of pathogens and coliform removes almost 100% removal can be expected. It can be used for saving fresh water, mitigating climate change effects and environmental issues, produce quality fertile water which can be used for irrigation purposes. In future, improved construction with different lining materials, an adaptation of different plants for purification and studies on the biological process required for maximum utilization so that quality of shallow water can be improved which leads to future sustainability.

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