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Vertical Constructed Wetlands to Treat Institutional Wastewater

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***Abstract*:** Country like Bharat where the population is getting increased and urbanized due to the fresh water is getting polluted. The major problem in such big countries with high populations is not reusing natural resources. Here, we came up with an idea of vertical constructed wetlands which can treat domestic wastewater. Pilot scale setup of vertical constructed wetlands using materials like coarse aggregates, fine aggregates, red soil, and medicinal plants. We have chosen plants like elephant ear plants, insulin plants and bryophllum. The plants that we have chosen are very helpful for human health. We collected the STP plant wastewater from BVRIT educational institute for its treatment. We placed vertical constructed flow of water to control the flow of the wastewater so that the soil doesn't get disturbed. Main reason for using red soil is to improve the growth of plants. We determined the Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), pH, TSS parameters for the wastewater before treatment and after treatment by considering 1-Day,3-Day, and 5-Day retention periods. The removal efficiency for BOD is 60%-90% and for COD 66.89%-91.29%, TSS are 59.48%-87.4%. The treated water can be used for gardening purposes, flush tanks in washrooms and many more.

Key Words: Vertical Constructed Wetlands, Vertical Flow Constructed Wetlands, Constructed Wetlands, and Wastewater Treatment.

1. Introduction

Water scarcity and environmental degradation have emerged as pressing global challenges, necessitating sustainable, low-cost, and decentralized wastewater treatment solutions. Conventional wastewater treatment plants, though effective, are resource-intensive, requiring high energy inputs, skilled manpower, and significant operational expenditure, rendering them less feasible for semi-urban and rural institutions. In this context, Constructed Wetlands (CWs) have gained prominence as nature-based, eco-efficient systems capable of addressing wastewater challenges with minimal energy demand and operational requirements. CWs are engineered analogues of natural wetlands that integrate the synergistic functions of plants, substrates, and rhizosphere microorganisms to achieve pollutant removal through microbial degradation, plant uptake, sorption, sedimentation, and filtration. Utilizing locally available materials such as gravel, sand, charcoal, or slag, CWs are not only cost-effective but also adaptable to local ecological and social contexts. Their design flexibility allows for implementation across scales—ranging from single households to community-based treatment systems—making them highly relevant for developing nations like Bharat, where inadequate access to safe drinking water and sanitation persists.

Among the various typologies, Vertical Flow Constructed Wetlands (VFCWs) have emerged as particularly efficient due to their enhanced oxygen transfer, higher hydraulic loading capacity, and superior nutrient removal compared to horizontal systems. In VFCWs, wastewater infiltrates vertically through inert substrates such as gravel, enabling efficient microbial activity and pollutant breakdown before being collected in a drainage network at the base. This design not only reduces energy and chemical inputs but also aligns with ecological sanitation principles, delivering treatment in an environmentally friendly manner. In contrast, Free Water Surface (FWS) CWs circulate water above the soil and through plant stems, while Horizontal Subsurface Flow (HSSFCWs) move wastewater laterally across porous media. For institutional campuses such as universities, hospitals, and hostels—where wastewater generation is continuous and characterized by variable organic loads—VFCWs offer a strategic intervention. Beyond meeting discharge standards, they facilitate resource recovery by enabling treated water reuse for landscaping, flushing, and groundwater recharge. Their low energy footprint, aesthetic integration, and adaptability to local conditions position them as a sustainable technology aligned with both national wastewater management missions and global sustainability goals.

2. Classification of Wetlands

Constructed wetlands employed for wastewater treatment are broadly classified based on the direction of water flow. The two primary categories are Free Water Surface (FWS) constructed wetlands and Subsurface Flow (SSF) constructed wetlands as shown in fig 1. In FWS systems, wastewater circulates above the soil surface, passing through the stems of emergent plants while remaining directly exposed to the atmosphere and sunlight. These wetlands generally operate with a shallow water column—typically only a few centimetres deep—and do not require structural support media.

In contrast, SSF systems channel water through a porous substrate, thereby enhancing filtration, adsorption, and microbial activity. SSF wetlands are further divided into Vertical Subsurface Flow Constructed Wetlands (VSSFCWs) and Horizontal Subsurface Flow Constructed Wetlands (HSSFCWs). In VSSFCWs, wastewater infiltrates vertically through inert substrates such as gravel before being collected in a drainage network at the base, enabling higher oxygen transfer and effective pollutant removal. Conversely, HSSFCWs promote continuous horizontal circulation of wastewater through the substrate, moving from the inlet to the outlet in a parallel flow pattern, thereby facilitating sustained contact between the wastewater, media, and microbial community.

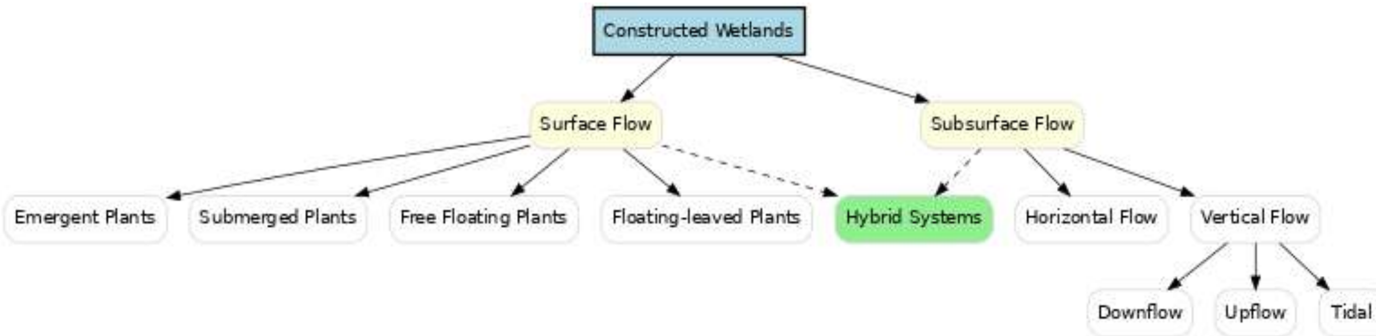


Fig 1 classification of wetlands

3. Materials and Methods

A. Prototype Design

The vertical constructed wetland (VCW) prototype was developed using a rectangular plastic crate with a total capacity of 58 liters and dimensions of 512 × 363 × 328 mm. The system comprised two auxiliary tanks serving as the inlet and outlet units, with capacities of 20 liters and 10 liters, respectively. Wastewater was introduced into the system through a drip irrigation mechanism, ensuring uniform distribution and controlled flow at a specific velocity.

B. Preparation of Vertical Constructed Wetlands

The wetland bed was prepared using a stratified arrangement of locally available materials—coarse aggregate, fine aggregate, and red soil. The base layer consisted of 10 cm of well-washed coarse aggregate, placed at the bottom of the crate to facilitate drainage. This was overlain by a 15 cm layer of fine aggregate, followed by a 7.8 cm layer of red soil to support plant growth and microbial activity. The system was vegetated with selected medicinal plant species such as Elephantopus scaber (elephant tree), Costus igneus (insulin plant), and Bryophyllum pinnatum, chosen for their adaptability and potential phytoremediation properties.

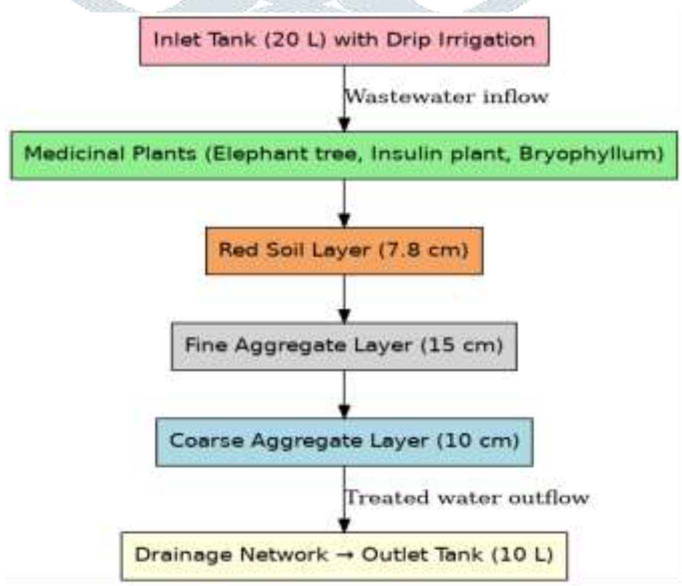


Fig 2 Typical arrangement of vertical flow-down constructed wetlands.

4. Literature Review

The initial concept of a vertical flow constructed wetland was introduced by Seidel in 1965. This design was first implemented in conjunction with horizontal flow for wastewater treatment at the Max Planck Institute in Germany, as documented by Vymazal in 2009. Gargi Sharma in July 2016 studied and aimed to enhance the quality of secondary treated wastewater by targeting both indicator microbial species (Total coliforms and fecal streptococci) and a pathogenic species (Salmonella typhi). To achieve this objective, three vertical subsurface up-flow constructed wetlands were established, each featuring different-sized gravel layers. Two of these wetlands were planted with Phragmites Australis (UN-ph.) and Canna indicia (UN-cn), while the third served as an unplanted control unit (UN-ct). The research assessed the performance efficiencies of all three wetland units in terms of removing microbial contaminants. Additionally, a thorough analysis of physico- chemical parameters, including pH, dissolved oxygen (DO), chemical oxygen demand (COD), Total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH3-N), and nitrate nitrogen (NO3-N), was conducted. While background analysis encompassed the physico-chemical parameters, the primary focus of the study remained on the removal of microbial contaminants. Borkar and Mahatme in 2011 investigated, the performance of a constructed model designed for treating local Amba Nala effluent was evaluated, focusing on parameters such as pH, dissolved oxygen (DO), total solids (TS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). The study involved varying substrate conditions, utilizing black cotton soil and sandy soil, and examining different detention times—specifically, 3 days, 5 days, 7 days, and 9 days. The research revealed that beds featuring Typha Orientalis (macrophyte plants) yielded effluents of superior quality compared to those without Typha Orientalis. The results indicated a significant reduction, with Typha Orientalis contributing to a 75% decrease in total solids, an 86% reduction in BOD, and a 63% decrease in COD. In contrast, the absence of Typha Orientalis still resulted in notable reductions, showing a 70% decrease in total solids, a 62% reduction in BOD, and a 53% decrease in COD. The comparison between the planted wetland system and the unplanted system demonstrated the superior performance of the planted system. Furthermore, the study highlighted that an extended detention period for wastewater positively correlated with increased removal rates. There is potential for further exploration of this research by implementing a pilot plant on-site.

5. Result and Discussion

In the laboratory analysis as shown in fig 3, raw wastewater samples were collected from BVRIT STP tank. A comprehensive set of tests, including pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total solids (T.S), chlorides, Turbidity, Conductivity, was conducted following established procedures outlined in standard methods.

Table1 Characteristics of STP wastewater

Parameters	Result	Standard Parameters
pH	7.89	6-9
TSS	980 mg/l	30 – 300 mg/l
BOD	1289 mg/l	20 – 500 mg/l
COD	1791.4 mg/l	50 – 1000 mg/l

Fig 3 Arrangement of vertical wetlands

All the characteristics of STP water shown in table 1. In these except pH all parameters are ranged above standard ones. So, by this we can say that STP effluent wastewater should be treated.

Flow Rate = Volume of The Tank / Retention Time --- equ- 1 Volume of Tank = 0.27×0.2×0.44 cubic cm

A. 1 -day retention time

- Retention time is the term used to describe how long wastewater is left in a treatment unit or process. When wastewater is retained or treated for one day. It is referred to as 1-day retention time.
- Since it influences how well treatment procedure work, retention time is a crucial component of wastewater parameters determine the proper retention period. Depending on the circumstances, a shorter retention period can be adequate in some situations or a longer one might be required to provide more comprehensive.
- So, in our study we treated the wastewater through the retention time period.
- We initially set up the arrangement for 1 day, 3 day and 5-day retention periods.
- By using the drip irrigation system, we control the flow of water from the influent tank by valves.
- By using the equation 1 we substituted the values, and we got the velocity for 1 day retention time for 20 liters capacity is $0.99 m^3/hr$.

Table 2 Results of 1 day, 3day and 5day retention time

parameters	Result
pH	7.74
TSS	397mg/l
BOD	473mg/l
COD	593mg/l

Parameters	Result
pH	7.7
TSS	212mg/l
BOD	196mg//l
COD	357mg/l

parameters	result
pH	7.2
TSS	123mg/l
BOD	127mg//l
COD	156mg/l

B. *3-day retention time*

1. When discussing wastewater treatment, a 3-day retention time is the period of time that wastewater stays in a unit or system before being released or receiving additional treatment.
2. Various factors, including wastewater's characteristics, the treatment techniques used, and regulatory requirements may affect the precise length of retention time needed for efficient treatment.
3. By using the equation 1 we substituted the values, and we got the velocity of 3-day retention period for 20 litres capacity is 0.33m³/h

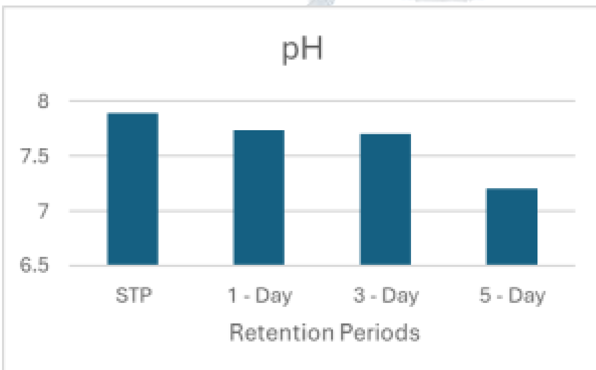
C. *5-day retention time*

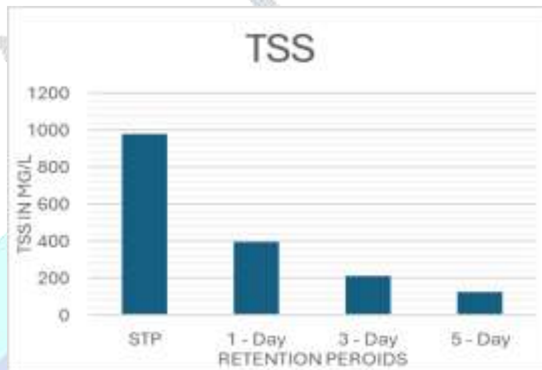
- Regarding wastewater treatment, a 5-day retention period usually means how long the wastewater stays in a tank or treatment system before being released or treated further.
- Various biological chemical and physical activities are carried out during this time to clean the wastewater and get rid of pollutants.
- By using the equation 1 we substituted the values, and we got the velocity of 5-day retention period for 20 litres Capacity is 0.198m³/h.

GROWTH OF PLANTS

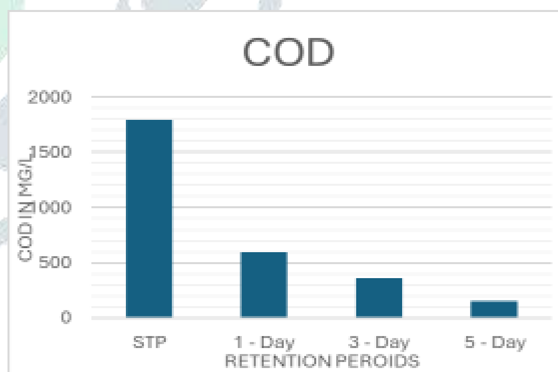
The experimental setup is conducted in civil Engineering department at BVRIT Narsapur, Telangana, India. Narsapur is located at latitude 17.7386°N,78.2830°E and is situated on Deccan plateau of south. All the plants were planted in the month of December. After planting the plantlets, growth pattern was observed for each plant species in terms of propagation. Once they started to propagate the plant species were allowed to acclimatize for period of 2-3 months till month of March. Initially when medicinal plants are planted their height are measured. So for the span of 15 days, we are measured the length of plants the plants we used in our study are insulin, elephant plant, bryophllum as shown in fig 5.

Fig 4 Medicinal plants **Fig 5** Graph showing growth of plants.





a) **b)**



c) **d)**

Fig 6: Graph showing the variation of a) pH b) TSS c) BOD d) COD

Table 5 Results of All Retention Periods

Parameters	STP	1 - Day	3 – Day	5 – Day
pH	7.89	7.74	7.7	7.2
TSS (mg/l)	980	397	212	123
BOD (mg/l)	1289	473	196	127

COD (mg/l)	1791.4	593	357	156

Table 6 Removal Efficiencies of All Retention periods

parameters	1 - Day	3 – Day	5 – Day
BOD	63.3%	84.7%	90.1%
COD	66.89%	80.07%	91.29%
TSS	59.48%	78.36%	87.4%

From Figure 6 and Tables 5 and 6, the following observations were made:

1. pH: A comparison between STP effluent and the 5-day retention period indicates only a slight variation in pH values. Overall, the treated water maintains a neutral range of 7–8, which is considered safe for general usage.
2. TSS (Total Suspended Solids): The treatment process resulted in a notable reduction in TSS, reflecting the effective removal of suspended dust and particulate matter. The values achieved are within standard permissible limits.
3. BOD (Biochemical Oxygen Demand): BOD represents the amount of dissolved oxygen required by aerobic microorganisms to degrade organic matter in water. A progressive decline in BOD values was observed from STP effluent through to the 5-day retention period, with the 5-day retention showing significantly improved purification compared to 1-day and 3-day periods.
4. COD (Chemical Oxygen Demand): COD measures the oxygen consumed during the chemical oxidation of organic and oxidizable inorganic matter. The results demonstrate a marked reduction in COD across the treatment duration, indicating effective degradation of organic pollutants in the 5-day retention period.

6. Conclusions

The present investigation highlights the treatment potential of constructed wetlands for STP effluent wastewater. Based on the experimental findings, the following conclusions are drawn:

1. The characterization of raw wastewater confirmed a significant pollutant load, necessitating effective treatment interventions.

2. A retention period of five days demonstrated superior pollutant removal efficiency compared to shorter retention durations.

3. Utilizing red soil as a substrate in planted constructed wetlands achieved notable removal efficiencies, with BOD and COD reductions of 90.1% and 91.29%, respectively, under a five-day retention period. In contrast, the three-day retention period exhibited comparatively lower removal efficiencies of 84.7% for BOD and 80.07% for COD.

4. The planted wetland system consistently outperformed unplanted setups, confirming its effectiveness in enhancing organic pollutant removal.

5. Enhanced plant growth was observed during the treatment phase, indicating a synergistic relationship between vegetation development and pollutant removal.

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