Treatment of Municipal Wastewater by prototype-scale Constructed Wetlands

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Abstract: Water is essential for all living beings, yet despite its abundance, much of its unusable due to contamination from human activities, limiting the availability of fresh, clean water in This present research work aimed to evaluate the performance of municipal wastewater treatment system comprises sewage collection near Renigunta in Tirupati District. In this work, plant species such as umbrella plant (Cyperus alternifolius), were utilized in constructed wetlands. Two types of wetlands— vertical flow and recirculation systems—were tested. Key water quality indicators like Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Solids (TS), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS) were measured in the effluent at different Hydraulic Retention Times (HRT).The recirculation-type wetland demonstrated the highest removal efficiency across all wastewater characteristics. At the optimal HRT, BOD was reduced from 250 mg/L to 62 mg/L, COD from 460 mg/L to 100 mg/L, TS from 2600 mg/L to 820 mg/L, TSS from 400 mg/L to 25 mg/L, and TDS from 2200 mg/L to 800 mg/L, all falling within permissible irrigation standards (BOD ≤ 100 mg/L, TSS ≤ 200 mg/L). The results suggest that biodegrading microorganisms played a key role in COD reduction, while the root zone likely acted as a natural filter. These findings support the use of constructed wetlands as a cost-effective solution for treating municipal wastewater.

Keywords: Municipal Wastewater, Constructed Wetlands, Treatment of sewage, Cyperus alternifolius, Recirculation.

1. Introduction

Water is crucial for all living human beings The world's population growth, expected to reach 9.7 billion by 2050, is causing a significant increase in water demand. This growth is not only affecting water but also other natural resources like food and energy sources, as the world's population is expected to rise by 2 billion in the next three decades. Surface water bodies like rivers, lakes, and ponds are crucial for irrigation, drinking water, recreation, and aquatic biodiversity preservation. However, rapid urbanization, industrialization, and human activities have led to widespread pollution, primarily through inadequately treated domestic sewage. This pollution carries contaminants like nutrients, organic matter, heavy metals, and pathogens, causing water pollution, groundwater degradation, and environmental degradation, posing a severe threat to human health and sustainability. Sewage, or domestic effluents comes from bathrooms, laundries, and kitchens, is composed of human waste, feces, urine, and water from daily activities like body grooming, food preparation, washing clothes, and household utensils.

A constructed wetland is a wetland designed for pollution control and waste management, located outside natural wetlands. It can treat domestic, storm, combined sewer overflows, overland runoff, and industrial wastewater .Constructed wetlands, utilizing plant species like common reed, cattail, and bulrush, mimic natural

processes to remove and degrade contaminants from municipal, industrial, agriculture, storm water, textile, landfill leachates, and mining drainage, among other contaminated wastewater products. The main processes that occur in wetlands include physical processes such as filtration and sedimentation, chemical processes such as adsorption and precipitation, and biological processes such as biodegradation and plant assimilation .

CW designs range from passive to highly engineered systems, with horizontal flow constructed wetlands having a saturated hydraulic regime, while vertical flow constructed wetlands are generally unsaturated due to pulse loading or batch feeding. Aerated CWs, on the other hand, inject air at the base of a basin to boost oxygen levels, enhancing oxygen supply to plant roots for treatment reactions. Aerated CWs have reported to higher removal efficiency compared to non-aerated wetlands. Therefore, it is necessary to research to evaluate all or some of the wastewater treatment technologies, to choose the best process among all the different options in both developed and developing countries. These include activated sludge (AS), trickling filtration, membrane filtration, nano-filtration (NF), membrane bioreactor (MBR), waste stabilization ponds (WSPs), and constructed wetlands (CWs).

Constructed wetlands (CWs) are promising wastewater treatment alternatives due to the numerous ecological benefits, low operational and maintenance costs as well as low energy requirements. Constructed wetlands (CWs) can be designed as nature-based solutions that offer engineered systems for various wastewater treatment purposes while simultaneously providing additional benefits such as carbon sequestration and biodiversity enhancement. Phytoremediation is a plant-based process that uses enzymes, microorganisms, and water consumption to remove, retain, transform, degrade, or immobilize contaminants from soil, sediment, aquatic media, or atmosphere, and is also known for green remediation, agricultural remediation, and vegetative remediation.

This work aims to assess wastewater treatment effectiveness at different Hydraulic Retention Times (HRT) by analysing various wastewater parameters, including Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Solids (TS), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS).

2. Materials and Experimental Methodology

The study explored the use of plastic-fibre models in prototype scale constructed wetlands to enhance the visibility of filter media and wastewater flow. Two types of wetlands were used: vertical subsurface flow constructed wetland (VSSFCW),and Recirculation vertical subsurface flow constructed wetland (RVSSFCW). Tank dimensions were 0.75 meters long, 0.4 meters wide, and 0.3 meters deep.

In the VSSFCW system, wastewater flows vertically from the planted layer down through the substrate as shown in Fig.1. Recirculation constructed wetlands were designed to allow the wastewater to flow through vertical-to-vertical systems.

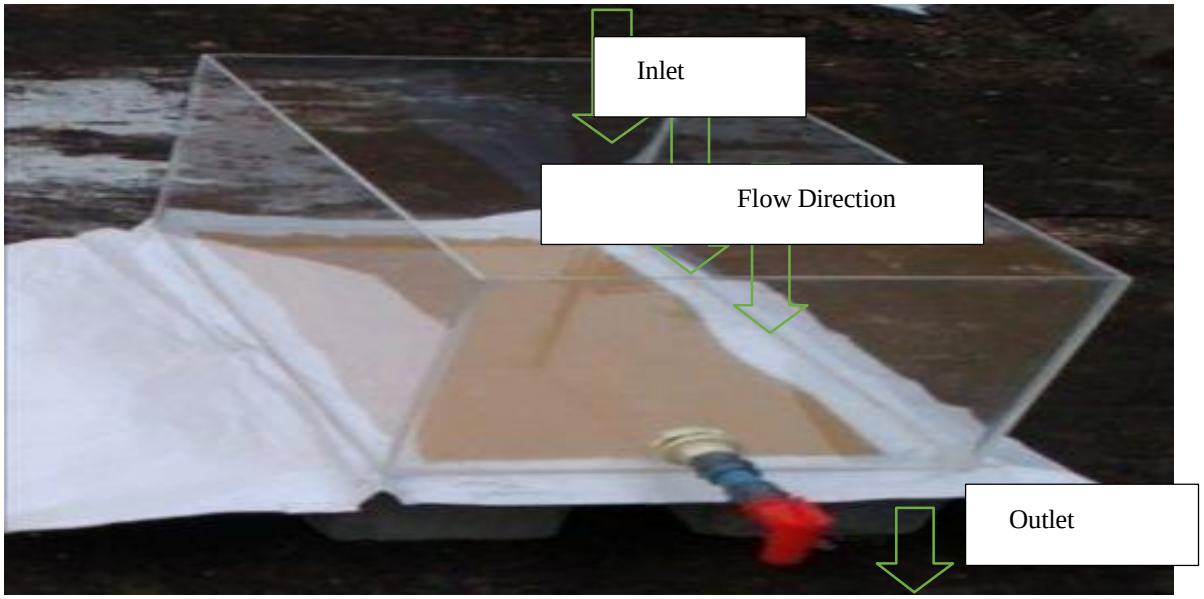


Figure 1: VSSFCW Model without Filling

2.1 Collection of Municipal Wastewater Sample:

- For the performance analysis of BOD, COD, TS, TDS, and TSS using prototype constructed wetland models, grab sampling was collected at the Municipal Sewage Treatment Plant in Tirupati District.



Figure 2:Municipal Sewage Treatment Plant

2.2 Filter Media:

A soil medium plays a crucial role in both VSSFCW and RVSSFCW systems by providing support for emergent vegetation. The system was constructed using plastic-Fiber and filled in a structured way as follows:

- In the VSSFCW, the reactor was organized into three layers. The top and bottom layers each had 0.05 meters of coarse aggregate (12 mm), with a middle layer containing 0.1 meters of soil (0.3-0.5 mm) for filtration and support.



Figure 3: Layers of media in VSSFCW

2.3 Vegetation Establishment:

Plant species, Cyperus alternifolius, were used in the VSSFCW and RVSSFCW systems, respectively, as shown in Figures 4. Each unit contained six plants arranged in a 2-row by 3-column layout. The width of each root was approximately 0.12 meters, with a plant spacing of 0.12 meters along the length and 0.10 meters along the width. The root depth was at 0.15 meters.



Figure 4.VSSFCW with Cyperus alternifolius

2.4 Methodology:

Wastewater inflow rate was regulated at the bay stopcock. Since the volume for all reactors was known, the needed time was calculated using a specific formula (Eq.1). The time intervals used are outlined in Table 1. Wastewater was introduced at the bay at these calculated time intervals.

$$T=V/Q \quad (1)$$

Table. 1 Details of HRTs for varying Flow Rates (Q)

Types>>>	VSSF CWs	RVSSF CWs
Volume (V)	V=L×B×H =0.75x0.4x0.2 =0.06m^3	V=LxBxH =0.75x0.4x0.22 =0.066m^3
Discharge (Q)	Q=100ml/25sec=345 L/day	
	Q=100ml/30sec=288 L/day	
	Q=100ml/36sec=240 L/day	
	Q=100ml/40sec=216 L/day	
HRTs (hours), T=V/Q	4.17 Hours(250min)	4.59 Hours(275min)
	5 Hours(300min)	5.5Hours(330min)
	6 Hours(360min)	6.6 Hours(396min)
	6.6 Hours(396min)	7.33Hours(439min)

3. Results and Discussion

3.1 Performance of Constructed Wetlands without Vegetation

The wetland models were first evaluated without plants to assess the reactor's potential as a natural filter. This helps determine the specific role plants play in the purification process. The wastewater characteristics treated without vegetation in VSSFCW systems at a 9-hour HRT are shown in Figure 5.TSS removal was significant, while TS removal was relatively low suggesting that the reactor functioned as a filtration medium in the absence of plant.

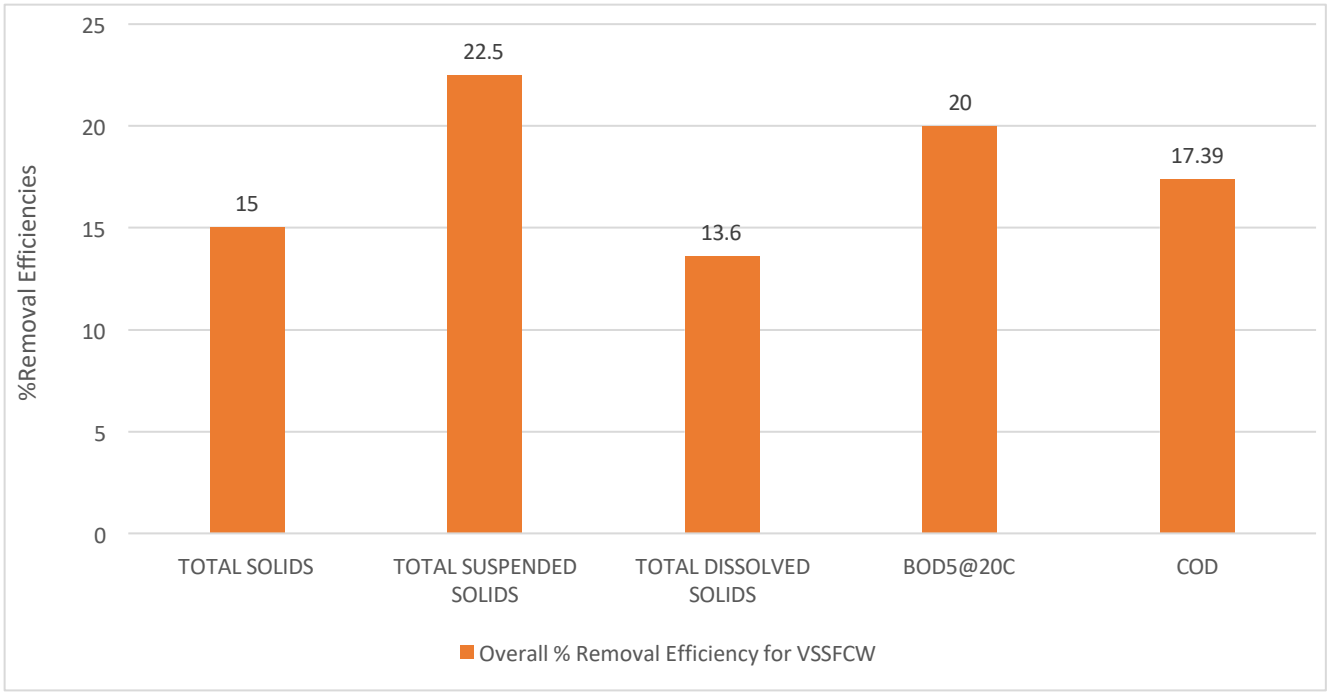


Figure 5. Removal Efficiency for Unplanted VSSFCW without vegetation

3.2 Performance of Vertical Subsurface Flow Constructed Wetland (VSSFCW) with Cyperus alternifolius

The VSSFCW system, planted with Cyperus alternifolius, was tested for wastewater characteristics at four different Hydraulic Retention Times (HRTs) and analysed for Total Solids, Total Dissolved Solids, Total Suspended Solids, BOD, and COD, revealing percentage removal efficiencies.

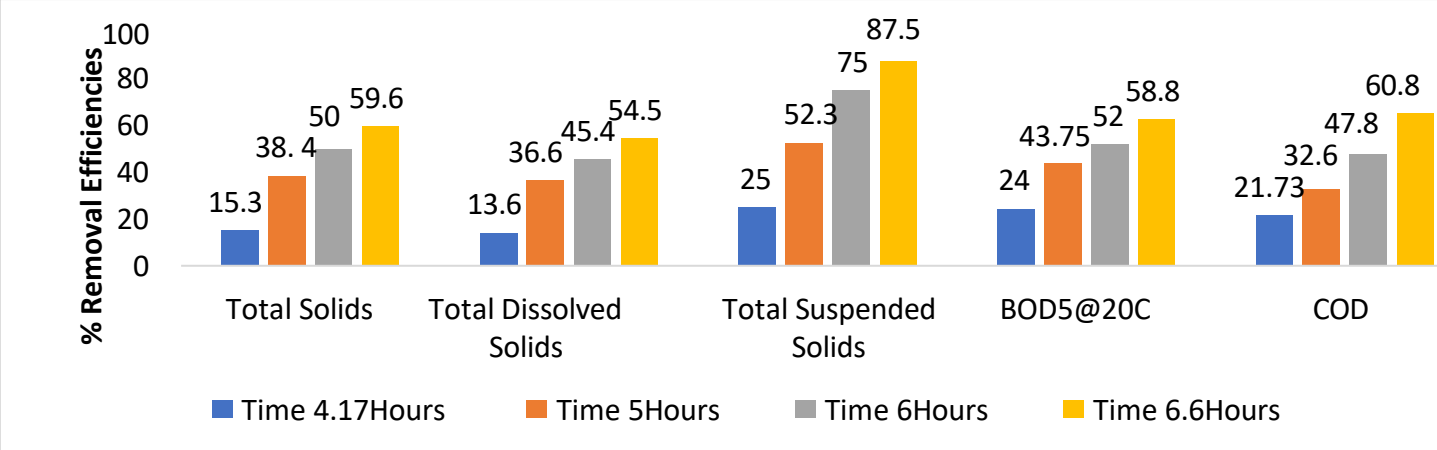


Figure 6. Removal Efficiencies of VSSFCW with Cyperus alternifolius

The highest removal rates for all parameters were observed at an HRT of 6.6 hours. Notably, the VSSFCW system demonstrated a greater percentage removal of TSS compared to the HSSFCW. This difference may be attributed to the more pronounced activity of the root zones in the vertical flow reactor, which functions as a more effective filter bed than the horizontal flow reactor.

The VSSFCW showed higher TSS removal due to active nutrient uptake by plant roots, with longer retention times promoting biological activity. The removal rates for COD and TSS were also higher in the VSSFCW compared to the HSSFCW, possibly due to the total root zone's involvement from top to bottom, resulting in a larger contact area between wastewater and roots.

The study indicates a direct correlation between HRT and the removal efficiencies of TSS, BOD, and COD, with an increasing trend in the percentage removal of all parameters.

3.3 Performance of Recirculation Vertical Subsurface Flow Constructed Wetland (RVSSFCW) with Cyperus alternifolius

A recirculation constructed wetland (CW) operates by supplying wastewater in a vertical-to-vertical flow system. This system was tested with four different Hydraulic Retention Times (HRTs) and percentage removal efficiencies for different wastewater parameters in the recirculation CW are presented in Figure 7.

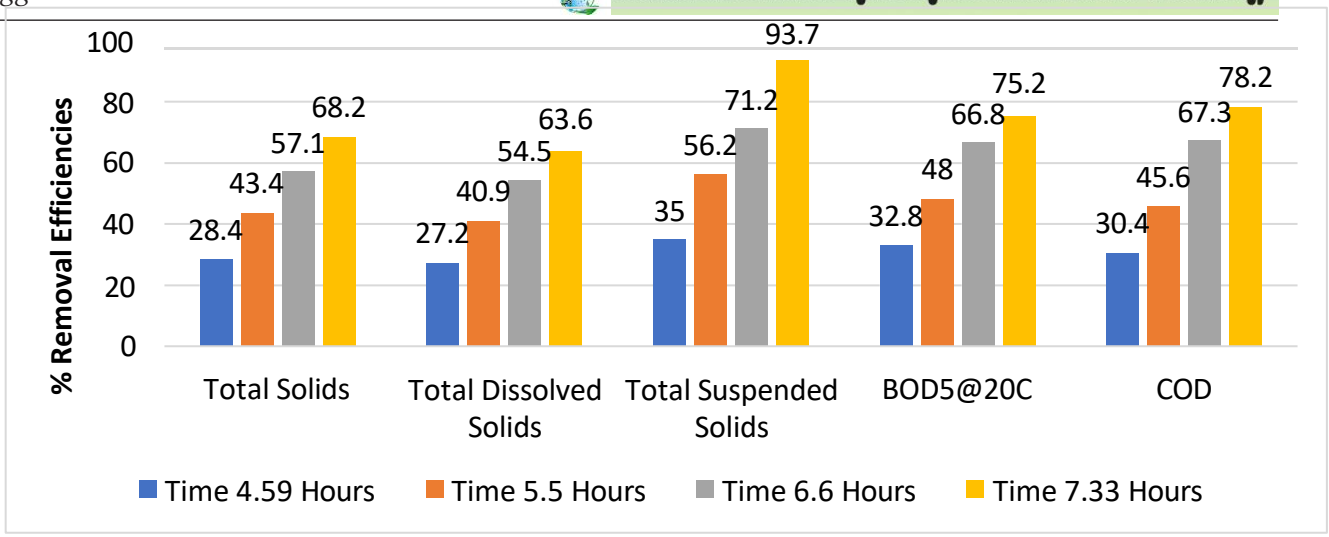


Figure 7. Removal Efficiencies of Recirculation CW with Cyperus alternifolius

The loftiest junking effectiveness for all parameters was observed at an HRT of 7.33 hours. Among the parameters tested, TSS junking was the most effective in the recirculation constructed wetland(CW). This junking primarily results from physical processes similar as sedimentation and filtration, with utmost suspended solids being retained within the bed due to the calm conditions and shallow liquid depth in the system. also, the CW outperformed both the VSSFCW and RVSSFCW in TSS junking. The maximum junking rates for both TSS and COD passed at advanced HRTs, with COD junking chance exceeding that of BOD, indicating a stronger dominance of natural exertion. Overall, the junking probabilities for all parameters showed an adding trend with longer HRTs. As HRT increases, junking edge also ameliorate because suspended solids settle, and organic matter is employed by the macrophytes. At the optimal HRT, the treated water showed BOD at 62 mg/ L, COD at 100 mg/ L, TS at 820 mg/ L, TSS at 25 mg/ L, and TDS at 800 mg/ L, all within admissible irrigation norms (BOD≤ 100 mg/ L, TSS ≤ 200 mg/ L). The treated water from the recirculation CW can be used for different purposes, including irrigation, gardening, restroom flushing, road cleaning, golf courses, and laundry. The junking edge of nearly all parameters were advanced in the recirculation CWs compared to the VSSFCW and RVSSFCW, suggesting that the combined goods of microbial exertion, root filtration, and sedimentation significantly contributed to its superior performance. A visual comparison of wastewater before and after treatment is illustrated in Figure 8.

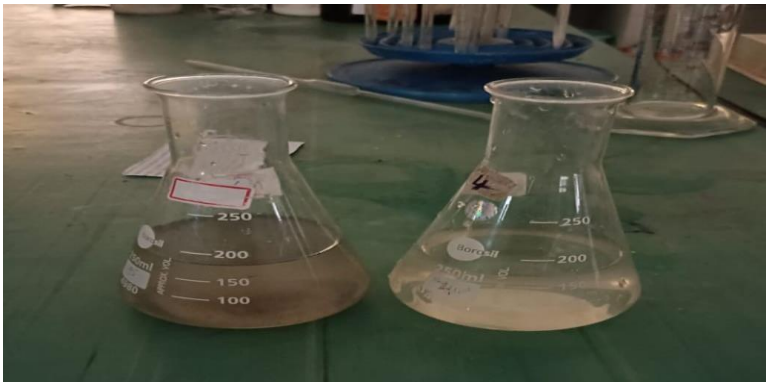


Figure 8. Before Treated and After Treated by Recirculation CWs

4 Conclusions

In this study, various types of constructed wetlands, VSSFCW, and recirculation CWs, were examined for their effectiveness in wastewater treatment at different Hydraulic Retention Times (HRTs). The recirculation constructed wetlands with Cyperus alternifolius demonstrated the highest performance in treating wastewater among both the reactors tested. At an HRT of 7.33 hours, the recirculation bio-reactor treated wastewater is suitable for disposal into land for irrigation. The treatment of wastewater resulted from a combination of mechanical straining, biodegradation, and gravity settlement.

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