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Performance Evaluation of Pilot-Scale Constructed Wetlands Planted with Canna Glauca for Domestic Wastewater Treatment

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Abstract*: Water is one of the most important natural resources required for the survival of all living organisms and the sustainable development of society. The present study aimed to evaluate the performance of a domestic wastewater treatment system using sewage collected near Leela mahal Circle in Tirupati District. The plant species Canna Glauca was used in the constructed wetland systems. Two types of constructed wetlands, namely vertical subsurface flow and recirculating systems, were investigated for wastewater treatment. The treated wastewater was analysed for important water quality parameters, including Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Solids (TS), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS), at different Hydraulic Retention Times (HRTs). The recirculating constructed wetland showed the highest removal efficiency for the tested wastewater parameters. At the optimum HRT, BOD decreased from 350 mg/L to 90 mg/L, COD from 480 mg/L to 140 mg/L, TS from 2700 mg/L to 550 mg/L, TSS from 400 mg/L to 50 mg/L, and TDS from 2300 mg/L to 500 mg/L. The treated wastewater met the specified irrigation limits for BOD (≤100 mg/L) and TSS (≤200 mg/L). The results indicate that constructed wetlands, particularly the recirculating system, can effectively reduce organic and solid pollutants in domestic wastewater and produce treated water suitable for irrigation purposes.*

Keywords*: Domestic Wastewater, Constructed Wetlands, Treatment of sewage, Canna Glauca. Recirculation.*

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I. Introduction

Water is an essential resource for human life, ecosystems, and sustainable development. However, rapid urbanization, population growth, and increasing domestic and industrial activities have resulted in the generation of large quantities of wastewater. The latest global assessment from UN-Water reported that, in 2022, 42% of household wastewater was not safely treated before discharge, demonstrating the continuing need for effective and sustainable wastewater-treatment approaches.

In recent years, constructed wetlands (CWs) have received increasing attention as a nature-based technology for wastewater treatment. Constructed wetlands are engineered systems that imitate the physical, chemical, and biological processes occurring in natural wetlands. They utilize a combination of wetland plants, substrate or filter media, microorganisms, and hydraulic processes to remove pollutants from wastewater**.**

Constructed wetlands can be designed in different configurations, including free-water-surface, horizontal subsurface-flow, vertical-flow, and hybrid or recirculating systems. Vertical-flow systems can provide favourable oxygen-transfer conditions and effective contact between wastewater, substrate, plant roots, and microorganisms. Recirculation and hybrid configurations have also been investigated to improve treatment performance. A large-scale review of constructed wetlands reported that hybrid systems can provide substantial removal of organic matter, nitrogen, and phosphorus, although performance varies according to temperature, hydraulic retention time, pollutant loading, plant selection, and substrate characteristics.

The treatment performance of constructed wetlands results from several mechanisms, including sedimentation, filtration, adsorption, plant uptake, microbial degradation, and chemical transformation. The interaction between plant roots and microorganisms is particularly important because the rhizosphere provides a suitable environment for microbial communities involved in the degradation and transformation of organic pollutants and nutrients. Recent research has also highlighted the potential of constructed wetlands for removing organic micropollutants through the combined effects of phytoremediation, adsorption, and microbial degradation.

An important advantage of constructed wetlands is their potential for low-energy and relatively simple

wastewater treatment, making them attractive for decentralized and small-community applications**.**

II. Materials and Methodology

The study investigated the use of plastic-fibre prototype-scale constructed wetlands to improve the visibility of the filter media and wastewater flow. Two types of constructed wetlands were used: vertical subsurface flow constructed wetlands (VSSFCW) and recirculating vertical subsurface flow constructed wetlands (RVSSFCW). Each tank had dimensions of 0.75 m in length, 0.40 m in width, and 0.30 m in depth.

In the VSSFCW system, wastewater flowed vertically downward from the planted layer through the filter media, as shown in Figure 1. In the recirculating constructed wetland system, the wastewater was allowed to flow through vertical stages, with recirculation between the stages to improve the treatment process.

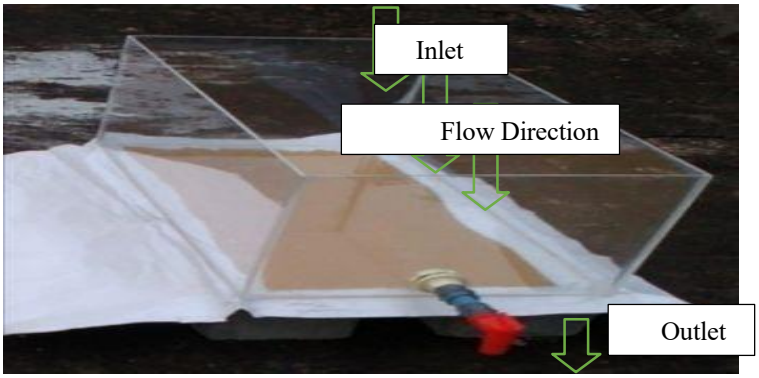


Figure 1: VSSFCW Model without Filling

a. Collection of Municipal Wastewater Sample:

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



Figure 2: Municipal Sewage Treatment Plant

b. **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:

i.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

c. Vegetation Management:

The plant species *Canna glauca* was used in both the VSSFCW and RVSSFCW systems, as shown in Figure 4. Each reactor contained six plants arranged in two rows and three columns. The average root spread was approximately 0.12 m. The spacing between plants was maintained at 0.12 m along the length and 0.10 m along the width of the reactor. The root depth was maintained at approximately 0.15 m.



Figure 4: VSSFCW with Canna Glauca

d. Methodology:

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

$$T=V/Q$$

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=345L/day	
	Q=100ml/30sec=288L/day	
	Q=100ml/36sec=240L/day	
	Q=100ml/40sec=216L/day	

HRTs (hours), T=V/Q	4.17 Hours	4.59 Hours
	5 Hours	5.5Hours
	6 Hours	6.6 Hours
	6.66 Hours	7.33 Hours

III.RESULTS AND DISCUSSION

a. PERFORMANCE OF CONSTRUCTED WETLANDS WITHOUT VEGETATION

Wetland models have been tested without plants to determine the potential of the reactor as a natural filter in the absence of vegetation

The characteristics of wastewater parameters, including Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD), were evaluated using constructed wetland models without vegetation at a Hydraulic Retention Time (HRT) of 8 hours.

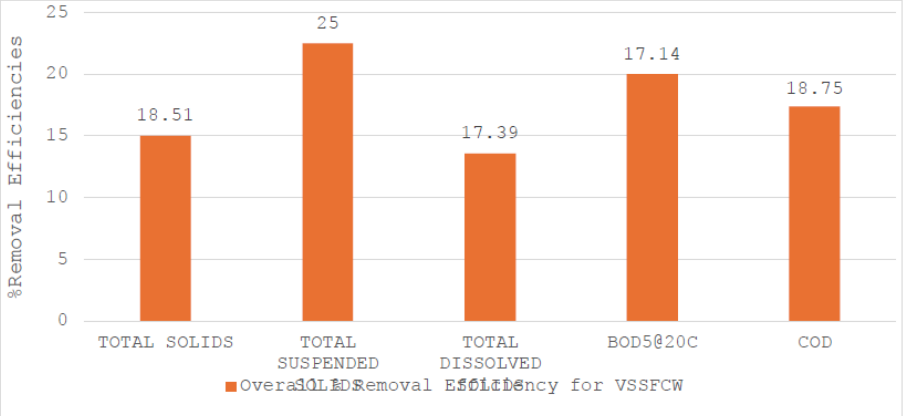


Figure 5: Removal efficiency for unplanted VSSFCW without vegetation

b. PERFORMANCE OF VERTICAL SUBSURFACE FLOW CONSTRUCTED WETLAND (VSSFCW) WITH CANNA GLAUCA

The VSSFCW system was planted with Canna Glauca, and operated at four different hydraulic retention times (HRTs) to evaluate its efficiency in removing wastewater pollutants, including TSS, TS, TDS, BOD, and COD.

The vertical subsurface flow constructed wetland (VSSFCW) demonstrated effective filtration and pollutant-removal performance. The higher removal efficiency of TSS observed in the VSSFCW may be attributed to the filtration action of the substrate, adsorption of suspended particles, and nutrient uptake by the plant roots. The increased HRT also provided greater contact time between the wastewater, substrate, microorganisms, and plant roots, thereby improving treatment efficiency.

The highest removal efficiencies for Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) were observed at higher HRTs. This indicates that longer retention periods enhance microbial degradation and other biological processes, allowing more time for the breakdown and removal of organic pollutants from the wastewater.

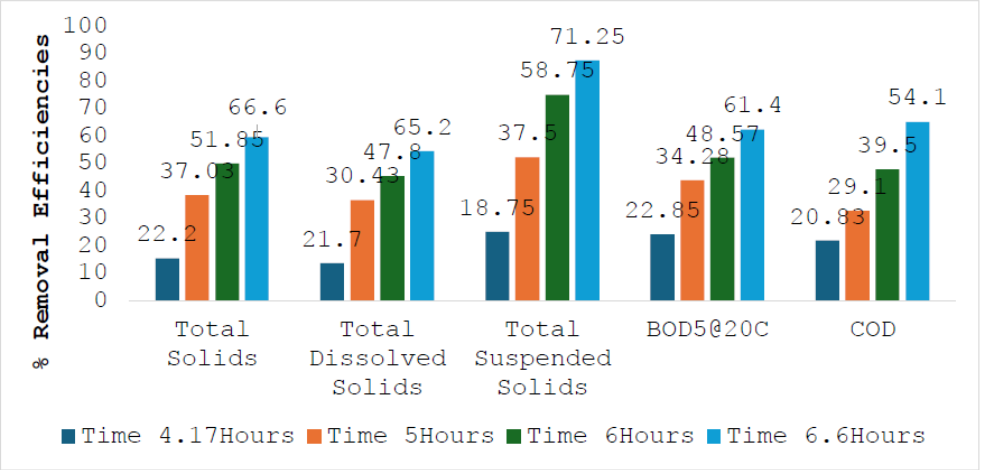


Figure 6: Removal efficiency for VSSFCW with Canna Glauca

c. PERFORMANCE OF RECIRCULATION VERTICAL SUBSURFACE FLOW CONSTRUCTED WETLAND (RVSSFCW) WITH CANNA GLAUCA

A recirculation constructed wetland (CW) system operates by circulating wastewater through a vertical subsurface flow configuration. The system was evaluated at four different Hydraulic Retention Times (HRTs) to assess its treatment performance based on wastewater characteristics such as Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Total Solids (TS), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD).

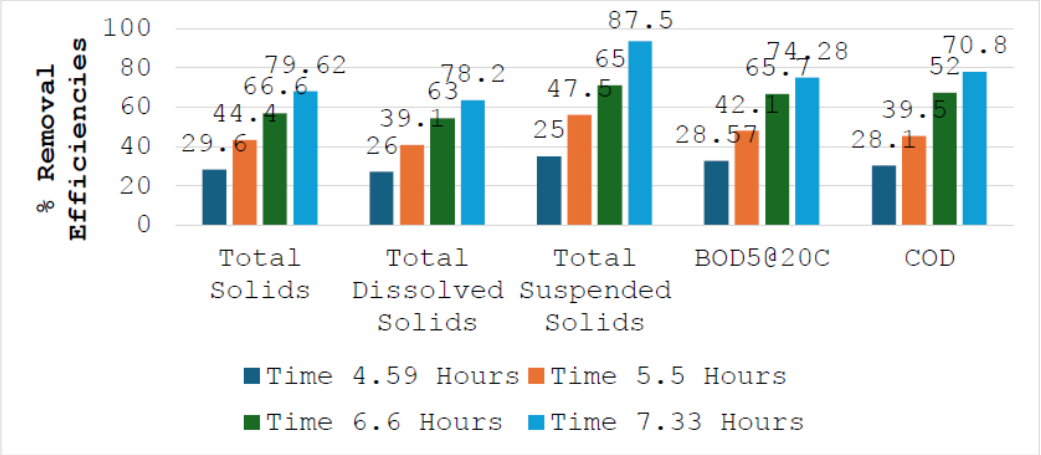


Figure 7: Removal efficiency for planted RVSSFCW with Canna Glauca

The highest TSS removal efficiency was observed at an HRT of 7.33 hours. The Recirculation Vertical Subsurface Flow Constructed Wetland (RVSSFCW) exhibited better TSS removal performance than the conventional Vertical Subsurface Flow Constructed Wetland (VSSFCW). The improved performance can be attributed to the repeated circulation of wastewater through the filter media, which enhances contact between the wastewater, substrate, microorganisms, and plant roots.

It was observed that the removal efficiency of all the investigated parameters increased with increasing HRT. Longer HRT provides greater contact time for the wastewater to interact with the wetland media and macrophytes. This facilitates the settling and filtration of suspended solids, while the organic matter present in the wastewater is utilized and degraded through microbial activity and plant uptake. Consequently, higher HRTs resulted in improved overall pollutant removal efficiency in the recirculation constructed wetland system.

At the optimum HRT, the treated water showed BOD at 90mg/L COD at 140mg/L, TS at 550mg/L, TSS at 50mg/L and TDS at 500mg/L. The parameters all within irrigation norms (BOD≤100mg/L, TSS≤200mg/L) The treated water from the recirculation CW can be used for different purposes. Including irrigation. gardening, road cleaning, restroom flushing. The all parameters were advanced in recirculation CWs compared to VSSFCW.

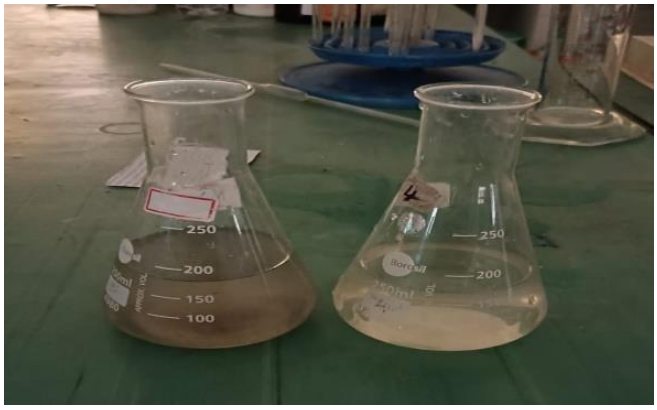


Figure 8: Before and After Treated by RVSSFCW

IV. CONCLUSIONS

- In this study, two types of constructed wetlands, namely VSSFCW and RVSSFCW, were evaluated for their effectiveness in wastewater treatment at different Hydraulic Retention Times (HRTs). Among the reactors tested, the recirculating vertical subsurface flow constructed wetland (RVSSFCW) planted with Canna glauca demonstrated the highest wastewater treatment performance. At an HRT of 7.33 hours, the recirculating bioreactor effectively treated the wastewater to a quality suitable for disposal onto land for irrigation purposes. The overall treatment efficiency was attributed to the combined effects of mechanical straining, biodegradation, and gravitational sedimentation, which contributed to the removal of pollutants from the wastewater.

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