EVALUATION OF THE PERFORMANCE OF DIFFERENT SOIL-BASE HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

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Abstract

At the National Institute of Technology Raipur, Chhattisgarh, India, fourteen horizontal subsurface flow constructed wetlands (HSSF-CWs) were built as part of this research work. The research was done between 2021 and 2022. As a substrate, various soils and gravels were used in this investigation for a constructed wetland system (CWs). The viability of treating wastewater was intentionally created and altered to simulate domestic wastewater. It was investigated using soil beds (entisols, inceptisols, alfisols, and vertisols) with and without plants and gravel beds. The selected macrophytes were *Canna indica* and *Typha latifolia*, and the hydraulic retention time (HRT) was 2 days. Every 2 days, the total suspended solids (TSS), biological oxygen demand (BOD5), chemical oxygen demand (COD), total phosphorus (TP), and total kjeldahl nitrogen (TKN) concentrations in the influent and effluent were measured and evaluated to determine how well the wetland units performed in terms of removal efficiency (RE) based on statistical studies. The CWs achieve the maximum TSS removal of 98% for all CWs. As for the BOD5 removal, an RE of 81.7% for planted and 58.9% for unplanted was achieved. As for the COD removal, an RE of 73.6% for planted and 50.4% for unplanted was achieved. As for the TKN, an RE of 62.3% for planted and 43.6% for unplanted was achieved. As for the TP, an RE of 76.2% for planted and 68.3% for unplanted was achieved. RE of TSS 99.6%, BOD5 81.0%, COD 72.4%, TKN 51.8%, and TP 75.3% were achieved for the aggregate base CWs.

Key words: Soil, Constructed wetland, wastewater, treatment, removal efficiency

Introduction

The CWs are an alternative way to treat wastewater that is cheap, uses less energy, has fewer moving parts, and works well. The natural method of wastewater treatment is a wetland land system. Traditional methods of treatment include CWs. CWs are viewed as secondary or tertiary forms of treatment. For the community, CWs offer a beautiful environment and higher-quality habitat (Swarnakar et al., 2021). 80% of wastewater, according to the World Health Organisation (WHO), is dumped into the environment without receiving adequate treatment. One of the natural wastewater (WW) treatment options is CWs (Swarnakar et al., 2022). CWs are a combination of plants and filter media. Various types of filter media are used as a substrate, like gravel, soil, charcoal, zeolite, lime stone, building waste, and stones. Various types of plants are used as per the types of CWs, like *Canna indica*, *Typha latifolia*, water lily, and duckweed (Jethwa and Bajpai, 2016). CWs are either planted or unplanted. According to Sehar and Naz (2016), wastewater treatment in CWs combines physical, chemical, and biological processes. In India, several research has been conducted on the use of CWs for the treatment of municipal wastewater and subsequent reuse of treated effluents. It has been observed that organic matter and nutrients are removed from wastewater by planted artificial wetlands in amounts ranging from 70% to 95% (Albalawneh et al., 2016; Haritash et al., 2015; Ramprasad and Philip, 2018). It's been noticed that organic matter and nutrients are removed from wastewater by planted artificial wetlands in amounts ranging from 70 to 95 % (Albalawneh et al., 2016; Haritash et al., 2015; Ramprasad and Philip, 2018).

According to Liang et al. (2017), the commonly grown wetland plant species *Canna indica* is highly effective at extracting nutrients from wastewater. The rapid growth rate and high biomass output of *Canna indica* create surfaces for the development of biofilms, and the plant's fibrous root system and oxygen release from the roots promote microbial activity (Lekshmi et al., 2020; Li et al., 2013). According to Suganya and Sebastian (2017), *Canna indica* is a good phyto-accumulator for lowering pollutant loads (Pinninti et al., 2022). *Typha latifolia* is the very common plant for CWs. *Canna indica* and *Typha latifolia* are perfect candidates for phytoremediation because of these traits, as their rapid growth implies increased nutrient levels, consumption, and tolerance for nutritional concentration variations. The performance of the CWs will be affected by a number of variables, including HLR, HRT, temperature, pH, dissolved oxygen, etc. In comparison to tropical and subtropical areas, artificial wetlands typically have lower RE (Varma et al., 2020). Soil orgenic matter is essential for plant growth for initial stablization (Swarnakar and Bajpai, 2021). Structure, texture, and the amount of organic matter in the soil are some of the characteristics that identify its kind. Plant development and survival are significantly influenced by the composition of the soil. The bioavailability of pollutants is also impacted by soil texture. For instance, compared to silt or sand, clay is better in binding molecules (Brady and Weil, 1996). The choice of an appropriate soil type becomes crucial for the effectiveness of a specific phytoremediation mechanism since soil structure and texture have a role in regulating the bioavailability of pollutants. According to research, soil with a high organic carbon concentration (>5%) typically has considerable adsorption that lowers availability, and soil with a moderate organic carbon level (between 1 and 5%) may also limit availability (Otten et al. 1997). Wetland soils contain phosphorus in a variety of forms, including soluble or insoluble, organic or inorganic compounds. Furthermore, TP can adsorb onto clay particles. Various researchers are used top or full layer of soil as substrates in CWs (Bisone et al., 2017; Bhagwat et al., 2018; Thalla et al., 2019; Jethwa et al. 2020)

In this research, we assessed the RE of soil-based CWs planted with *Canna indica* and *Typha latifolia* and unplanted CWs. Second, we assessed the RE of aggregate-base CWs.

Materials and methods

Study area

The wastewater was collected from the National Institute of Technology Raipur, Chhattisgarh, India, residential (Lat. 21° 15′ 00″ N and Long. 81° 36′ 15″ E; elevation at 294 m above mean sea level).

Experimental set up

Using mild steel sheets measuring 2 mm thick, fourteen laboratory-scale CWs with dimensions (Lx Wx H) of 1.0 m x 0.35 m x 0.35 m and an outward slope of 0.01 (1.0%) were created. According to CPCB 2001 and EPA 1988 recommendations, each unit was created. Four of the 14 CWs were used as blank, with four distinct types of soil substrate but no plant species. For comparison, two sets of CWs with only aggregates as substrate (40 mm, 20 mm, 10 mm, and sand) were also employed. Eight rest CWs were employed with pairings of four different soil substrates, each of which was planted with *Canna indica* and *Typha latifolia*. The local natural wetlands provided the plants used on site. All experiments have been performed as per APHA. Fig. 1 shows the lab-scale CWs used for experiments.

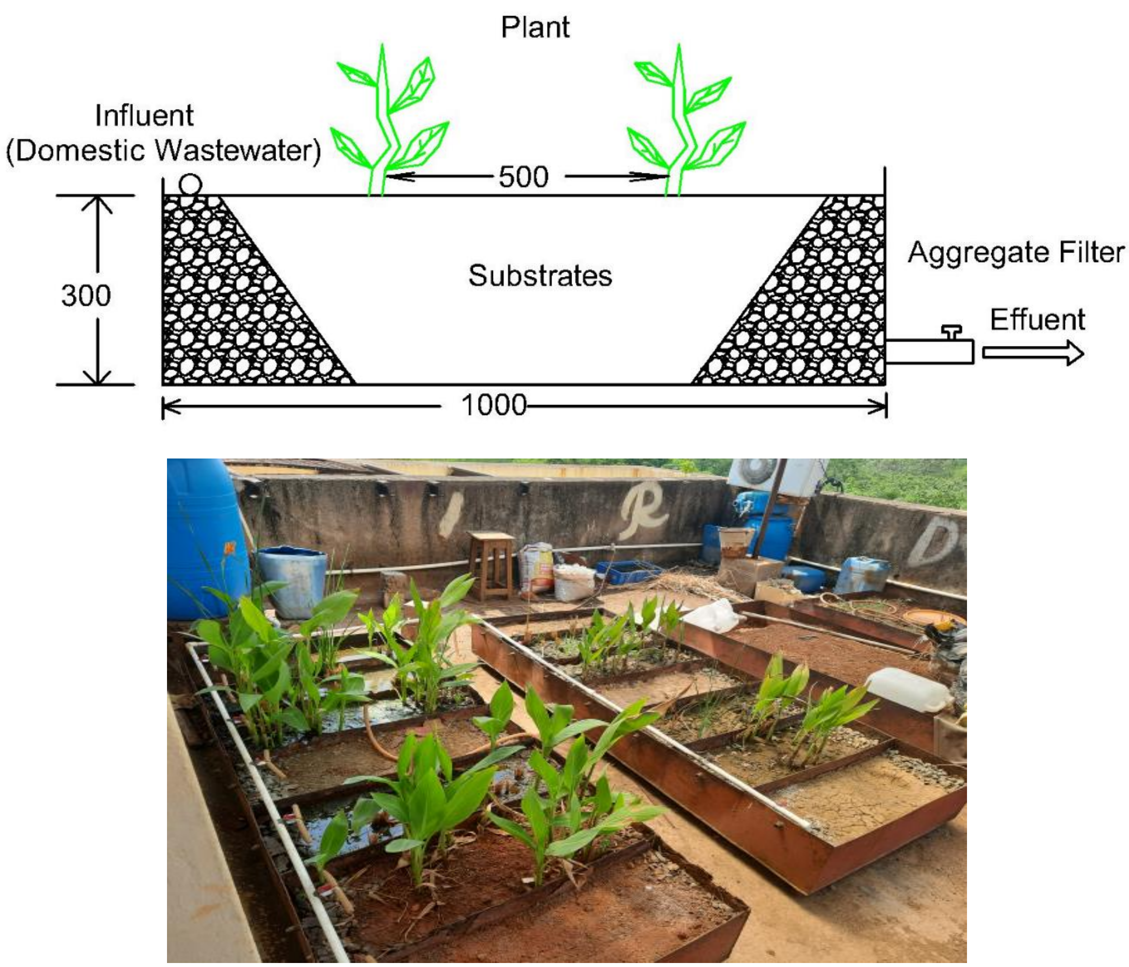

Figure 1: View of Horizontal subsurface flow Constructed wetland (pilot scale), A. Cross section B. Site View

Soil media description and characterization

Four types of locally available soils were used as substrates in CW. Table 1 shows the relevant properties of the soil medium.

All soil samples were collected and brought to the laboratory in polyethylene bags. To remove coarse debris, all soil samples were sieved using a 2mm sieve after being air-dried at room temperature for three weeks. To determine soil pH and electrical conductivity (EC), the apportionment of dried soils was ground and sieved through a 1 mm sieve; the remaining portion was ground and sieved through a 0.075 mm sieve to determine total nitrogen (TN), organic carbon (SOC), and the cations and anions (Na^+, K^+, Ca^{2+}, $CaCO_3$, SO_4^{-2}). Soil pH and electrical conductivity (EC) were measured in the supernatant of a 1:2.5 (w/v) soil–distilled water mixture using a pH meter and a conductivity meter (Eutech Instruments, India), respectively. The practical size distribution was analyzed using a hydrometer. Heavy metals were analyzed using an atomic absorption spectrophotometer (AAS, model AA8000 FG, Lab India). The AAS was powered by acetylene and compressed air. The porosity of each type of soil ranges from a minimum of 43.9% to a maximum of 53.9%. Porosity was calculated by the void ratio, which is defined as the ratio between the specific gravity and the density of water and materials. All soil parameters were tested in loose conditions as placed in each reactor. Total soluble sulfate was analyzed by IS: 2720 (Part XXVII)–1977 (reaffirmed 1995). Total organic carbon was analyzed by IS: 2720 (Part XXII)–1972 (reaffirmed 2010). Calcium carbonate ware analyzed by IS: 2720 (Part XXIII) – 1976. The effective size (D_{10}), uniformity coefficient (Cu), and coefficient of curvature (Cc) were analysed by sieve analysis. As per the EPA, the D_{10} should be between 0.15 and 0.35. The values of Cu greater than 4 to 6 and Cc should be between 1.0 and 3.0 classify the soil as well graded (the contractor.org). The value of Cc in matasi (Vertisols) is low, at 0.35.

Table 1: Soil media reverent properties (n=3, Average value)

Parameter	**Entisols**	**Inseptisols**	**Alfisols**	**Vertisols**
Local Name	Bhata	Kanhar	Dorsa	Matasi
pH	6.2	7.0	7.3	7.5
Available water, %	2.1	8.9	17.3	16.5
Conductivity (μS/cm)	160	212	230	310
Specific gravity	2.72	2.65	2.62	2.60
Porosity (%)	53.9	51.9	50.8	43.9
Free Swell Index (%)	16.2	49.4	11.5	32.9
Particle size distribution				
Bulk density (gcm^{-3})	2.10	1.97	1.90	1.93

Effective Size (D_{10}), mm	0.22	0.26	0.29	0.15
Uniformity coefficient (Cu)	12.6	15.9	21.5	8.87
Coefficient of Curvature (Cc)	2.27	2.31	2.9	0.35
Sand (%)	66.8	22.8	24.8	32.6
Silt (%)	15.1	40.2	48.8	52.6
Clay (%)	5.9	24.6	9.9	8.9
Gravel (%)	12.2	12.4	16.5	5.8
Chemical properties				
Total Soluble Sulphate (SO_4, %)	0.2	0.14	0.09	0.11
Soil organic carbon (%)	1.4	1.8	2.1	3.4
Calcium Carbonate (%)	1.6	1.7	1.8	2.0
Sodium (Na^+), mg/kg	243	201	153	167
Potassium (K^+), mg/kg	239	360	263	145
Calcium (Ca^{2+}), mg/kg	365	449	413	395

Calcium carbonate is an important parameter for the materials used as substrates. The presence of calcium carbonate improves the efficiency of phosphorus removal in the soil (Yanamadala, 2005). Different soils can be expected to be differently adapted for wetland development due to the removal of nitrate (NO_3), denitrification, and the requirement of organic carbon (Davidsson and Stahl et al., 2000).

In the CW aggregate bases, the porous media used were course aggregate (40mm and 20 mm) and medium gravel (6 mm). The porous medium came from several sources. Carbonate rock makes up medium gravel, which was extracted from a quarry. The fine aggregate (sand of the upper layer) was collected from a nearby river bed. Al, Fe, and Ca, the three primary elements involved in the adsorption of phosphorus, are abundant in the river bed material (Zhu et al., 1997).

Wetland removal efficiency (RE)

The % difference between values at 48 hours, which is denoted, was used to calculate the removal efficiency of various CWs. Using the following equation, the removal percentage for all wetland situations was computed.

Removal efficiency (%)= $((C_{in}-C_{out})/C_{in})*100$

where,
C_{in} = Concentration of a parameter in influent
C_{out} = Concentration of parameter in effluent (at 48 h).

Results and discussion

pH in influent is 7.7, and for effluents, it was between 6.8 and 7.3. All TSS RE were found at 98.7% to 99.6% in planted, 98.7% in unplanted, and 99.6% in aggregate CWs. Sedimentation and interception are the main physical processes for removing TSS. Table 2 shows the maximum RE for the CW (planted, unplanted, and aggregate-based). At lower HRTs, BOD and COD removal using CW was ineffective (Shukla et al., 2021), so authors used two days of HRT. The HSSF CWs are very effective at removing organic loads from wastewater, including BOD, COD, nitrogen (nitrate, ammonia), phosphate, and pathogens (Vymazal et al.,1998).
BOD_5 is a crucial measure to define the size of a wetland and is highly helpful in determining the system's organic load. The maximum BOD_5 has been observed at 81.7% RE for kanhar type soil planted with *Typha latifolia* though unplanted CW have been observed at 58.9% RE. Aggregate-base CW planted with *Canna indica* has been RE 81.0%. According to table-1, soil porosity has increased the RE of CWs for nutrients.

Table 2: Maximum RE for planted, unplanted, and aggregate base CWs

S. No.	Specification	Maximum RE	Type of CWs	Condition
1.	TSS	99.6%	CW with kanhar soil	Planted with *Typha latifolia*
		98.7%	CW with kanhar soil	Unplanted
		99.6%	CW with aggregate	Planted with *Canna indica*
2.	BOD_5	81.7%	CW with kanhar soil	Planted with *Typha latifolia*
		58.9%	CW with kanhar soil	Unplanted
		81.0%	CW with aggregate	Planted with *Canna indica*
3.	COD	73.6%	CW with kanhar soil	Planted with *Canna indica*
		50.4%	CW with kanhar soil	Unplanted
		72.4%	CW with aggregate	Planted with *Canna indica*
4.	TKN	62.3%	CW with kanhar soil	Planted with *Canna indica*
		43.6%	CW with dorsa soil	Unplanted
		51.8%	CW with aggregate	Planted with *Canna indica*
5.	TP	76.2%	CW with kanhar soil	Planted with *Canna indica*
		68.3%	CW with dorsa soil	Unplanted
		75.3%	CW with aggregate	Planted with *Canna indica*

The length of HRT, the kind of filter medium, the plant species employed, and the characteristics of the microbial consortium all influence the level of treatment by CWs. A longer retention time expedites the removal of pollutants, although too-long retention times might be harmful. Sand silt clay and gravel are available in all types of soil used as filter media. A variety of physical methods, like as adsorption and filtration, as well as aerobic/anaerobic molecular processes can be used to remove COD in constructed wetlands (Prochaska et al., 2007). The maximum COD, RE (73.6%) has been observed in kanhar soil planted with *Canna india* and 50.4% in kanhar soil unplanted with CWs. 72% RE was observed in both aggregate-base CWs. The same findings have been reported by Nema et al. 2020.

TKN is a combination of organic nitrogen and ammonia (NH_3), that responds to the environment. For raw municipal WW, the value of TKN have been ranged from 15 – 50 mg/L (Benefield and Rendall, 1980). Nitrogen and phosphorus are the two plant nutrients in surface and groundwater that need the most attention (Sparks, 2003). Table 2 shows that the maximum RE (62.3%) for TKN has been observed in kanhar-base CWs planted with *Canna indiaca* although 43.6% in unplanned CWs with dorsa-type CWs. TDS and TKN RE, however, are said to be less effective than other metrics. They were largely unaffected by plantations, remaining similar under both circumstances. *Canna indica* planted CWs has more RE (51.8%) than *Typha latifolia* CWs in aggregate base CWs. The processes of volatilization, ammonification, nitrification/denitrification, and plant absorption control the process of removing nitrogen from CWs (Vymazal et al., 1998). The RE (76.2%) for TP has been observed in kanhar soil planted with *Typha latifolia* and 68.3% RE in unplanted CWs. Sand's presence boosts the ability to retain phosphate. The most popular techniques for phosphorus removal in CWs include adsorption, precipitation, and plant absorption. These processes are essential for plant growth.

The aggregate-base CWs planted with *Typha latifolia*, have more potential to remove the TP as compared to the *Canna indica*. The good amount of calcium (table 1) in the soil has helped remove the TP. All soils contained enough sodium, potassium, calcium, and orogenic carbon for plant growth. Enough porosity reduces the chance of chocking in soil-based CWs. Kanhar soil has good swelling properties compared to all others (Table 1). Good swelling properties promote root growth and avoid the chocking problem.

Conclusion

After a 48-hour HRT, the horizontal sub-surface flow soil-base CWs being investigated were treated with strong, primary treated sewage. With regard to the removal of various physicochemical and biological factors, all CWs have attained good removal efficiencies. When compared to an unplanted wetland, the planted CWs and aggregate-based CWs performed better, and different parameters were removed at the HRT (48 h). The HSSF-CWs may serve as a superior alternative to traditional wastewater treatment plants given how simple and affordable they are to operate. The performance of the various CWs for the treatment of primary treated sewage has steadily improved over the course of about a year of operation. The wetland treatment effluent's quality was within the parameters allowed by a regulatory body like the CPCB of India. This technology is an excellent choice for sewage treatment in such areas of

India due to a number of factors, including the simplicity of land availability, the local availability of wetland filter media (soil), and the availability of a significant number of native macrophytes in the study area. Over all, soil-based CWs are cheap and easily available compared to aggregate. *Canna indica* and *Typha letifolia* showed high pollution removal efficacy across all parameter assessments among the examined plants. The selection of plants has a considerable impact on how effectively CWs remove organic contaminants, minerals, and bacteria.

Conflict of interest: There is no any conflict of interest.

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