Pilot-Scale Horizontal Subsurface Flow Constructed Wetland for Removal of Chromium from Tannery Waste Water with Suitable Local Substrate Material

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Abstract. The aim of this study was to investigate the performance of pilot scale horizontal subsurface flow constructed wetlands (HSSFCW) for removal chromium containing industrial wastewater with locally available two plant species (Cyprus Papyrus) and Para grass (Brachiara mutica). Twenty-one constructed wetland systems half-filled with coarse aggregate were built. Eighteen of them were used to study the efficiency of chromium (VI) removal with both plants in three replicates and the other three units were used as a control. The experiments were performed at different bed depth of 0.20 m, 0.40 m, and 0.60 m. It was found that HSSFCW with papyrus at constructed wetland bed depth of 0.20 m was the best performed for chromium removal with an efficiency of 98.41%. Comparing efficiency for chromium (VI) removal at the same bed depth, papyrus plant was better than Para grass. On one hand, the growth rate of the plant species was unaffected by the depth of the constructed wetland wastewater system.

Keywords: Constructed wetlands · Tannery wastewater · Para grass · Papyrus grass · Horizontal subsurface flow

1 Introduction

Water scarcity is becoming a global issue since industrial evolution which is manifest by global warming [1]. The world population growth and the trend in industrial revolution have led to environmental degradation especially by the release of partially treated or untreated wastewater into the water body. Due to such activities, the global freshwater resource is at risk and the majority of the problems that humanity face in recent years is related to access to clean water [1]. Thus, the treatment of wastewater is a basic component to protect the health and the environment of the communities [2]. However, many developing countries lack adequate and low-cost wastewater treatment facilities.

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One such promising technology for wastewater treatment is the constructed wetland system [3].

Constructed wetland system for the removal of heavy metal from wastewater effluent is becoming a focus of many investigations in recent years. Constructed wetlands are considered as a technical, economical, and environmentally sustainable solution for wastewater treatment in small communities since they are efficient with diverse pollutants removal [4–11].

Subsurface flow wetlands are engineered systems, which mostly employ gravel as a substrate to support the growth of plants, and wastewater flows vertically or horizontally through the substrate where it comes into contact with microorganisms, living on the surfaces of plant roots and substrate.

Subsurface flow constructed wetlands are further divided into two groups, according to the flow direction inside the packed media: (1) vertical flow, and (2) horizontal flow systems [12–14].

Horizontal Wetland system is a cost-effective, environmentally friendly, aesthetically pleasing approach and most suitable for developing countries. It is a multi-beneficial system for environmental protection. Subsurface flow constructed wetlands, which are commonly seen as low cost, green treatment technologies [11, 15].

The removal mechanism of chromium in constructed wetlands is a complex combination of physicochemical and biological processes including sedimentation, binding to porous media, plant uptake, and precipitation as insoluble forms. The efficient reaction zone in constructed wetlands is the root zone area (rhizosphere) where physicochemical and biological processes take place by the interaction of plants, microorganisms, and pollutants [16, 17].

Currently, Ethiopia is focusing on industries majorly textile and tannery sector. These factories release toxic chemicals to the environment. In practical, leather industries release toxic heavy metal that cannot be treated by conventional treatment methods. Currently, about 54% of leather industries reported that they have treatment facilities (12% secondary and 42% primary), which can treat their wastewater to a certain degree [18]. The rest are discharge the wastewater directly into the nearby water bodies without any form of treatment.

The objective of the present study is therefore to evaluate the performance of pilot-scale constructed wetland system with two plant species at three different bed depth for the removal of chromium from leather wastewater effluent, since the influence of water depth has received a relatively less attention and the information available is presently limited to a few reports [19–21]. Since the depth of the wetland will affect the performance of the plant by stressing its root. The significance of this study is to help the industries to use green wastewater treatment technologies of constructed wetland with suitable plants (C. papyrus and Para grass) to remediate wastewater.

2 Materials and Methods

2.1 Experimental Setup and Operating Conditions of Wetlands

The experimental study was conducted in HSSFCW system at Bahir Dar University, Bahir Dar Institute of Technology Campus Bahir Dar, Ethiopia. The system consists of twenty-one analogous treatment beds aligned in parallel and is designed with a range of wastewater flow-rate from 14 L/d to 42 L/d measured using a bucket and stopwatch method and theoretical hydraulic residence time (HRT) of 3 days. The substrate or plant growth media used for the 21 HSSFCW systems was 20 to 30 mm diameter sized gravel [22]. The substrate was filled to a height of 0.45 m. Fragments of rhizomes about 10 cm long carrying young shoots of C. papyrus and Para grass plants selected according to Dr. Heike [23] were taken from the natural wetlands of Lake Tana and transplanted into their respective treatment beds with a surface area of 4.2 m^2 at a density of four rhizomes/m. For each depth (0.2 m, 0.4 m, and 0.6 m) there were seven constructed wetlands which were planted with C. papyrus and Para grass with three replicates and a control. Each treatment bed was fed with the influent water which was taken from Lake Tana with their respective average flow rate from the equalization tank through pipes after 3 months acclimation period. During the acclimation period, the nutrient was prepared and feed into the system once per week [24]. The Wastewater used in the study was prepared via Chromium six with a concentration of 1 mg/L and added to the storage tank. After the plants were well grown the prepared wastewater was pumped to the wetland at a rate of 20 L/d.

2.2 Wetland Design

Constructed wetlands are classified according to whether the water level is above or below the substrate surface [23, 25] (Fig. 1).

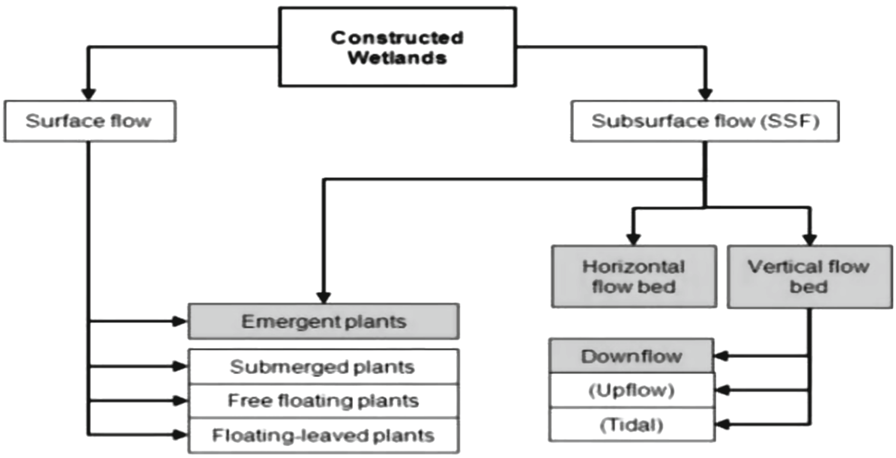


Fig. 1. Classification of constructed wetlands for wastewater treatment [23].

Because of its low cost and widely used, we selected horizontal flow and the hydraulic retention time is calculated according to Eq. (1) [25].

$$t = \frac{\eta h l w}{Q} \tag{1}$$

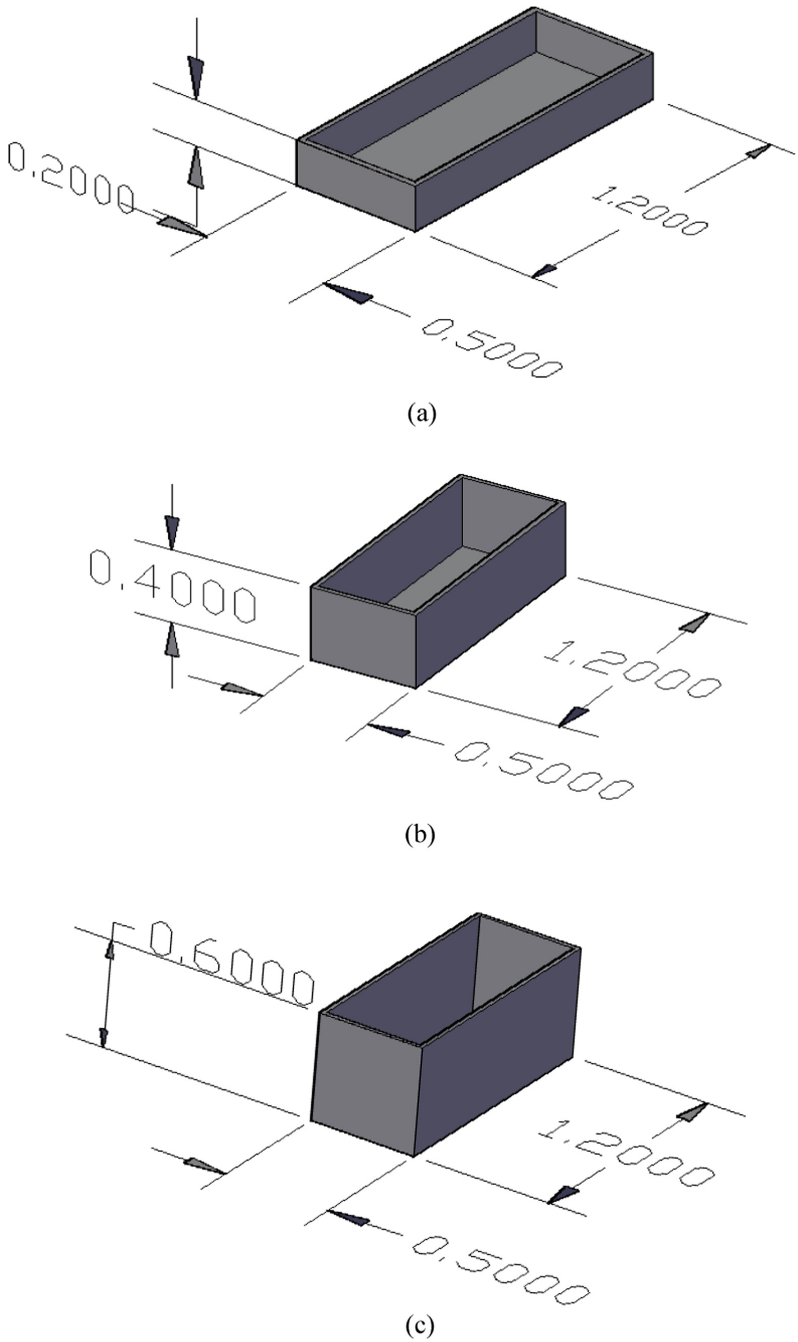


Fig. 2. A schematic diagram of the wetland system (a) with a depth of 0.2 m, (b) with depth 0.4 m and (c) with a depth of 0.6 m and the other entire dimension were the same.

Where t is hydraulic detention time, is the porosity of the substrate material, l is the length, Q is the average flow rate and w is the width of the treatment cell.

It is widely reported, those small aspect ratios are preferable because they offer reduced construction costs and improved hydraulic control [25]. So we select the aspect ratio between 0.2–3 which was (l: w) 2.4. Figures 2, 3, 4 shows the scheme of the wetlands.

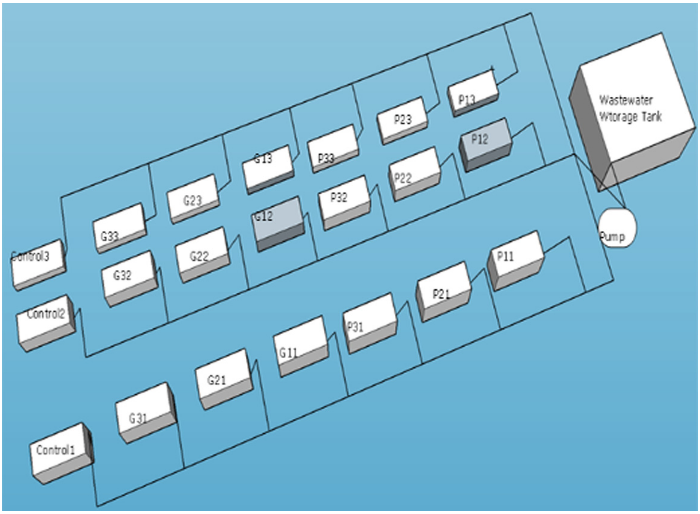


Fig. 3. Setup of the constructed wetlands showing the twenty-one sampling sites

Fig. 4. Photo of Pilot scale constructed wetlands at BiT, Bahir Dar

2.3 Construction of the Wetlands

The wetlands were constructed with concrete at the bottom and hollow concrete block for the walls and an approximate 1% slope at the bottom. All sides of the bed and the bottom were covered by geo-membrane to prevent leakage. Leakage was tested by keeping water within the system one weeks and monitoring the water level change. The outlet and the level of the effluent were controlled with pipes typically used for drip irrigation. Each wetland tank had a surface area of 1.2 m $\times$ 0.5 m and a depth of 0.20 m, 0.40 m, and 0.60 m from shallow to deep beds. The wetted depths of the shallow and deep beds were 0.18 m, 0.35 m and 0.55 m, respectively.

2.4 Sample Collection and Laboratory Analysis

Water samples were collected manually in 500 ml clean bottles every three days since April 23- to May 5, 2018. In each CW, two points were monitored (inlet, outlet) once a day since, the pump was working only for 12 h a day. The water quality parameters analyzed were chromium six, TDS, pH and temperature. To confirm steady state flow water was collected in a measuring cylinder for a certain time using a stopwatch and calculate the flow rate.

2.5 Sample Preparation and Analyses

Samples of wastewater (influent) and treated water (effluent) were collected by 500 mL plastic bottles on the third day three times starting from April 23- to May 5, 2018, each day at 12:00 PM. The sample was filtered through 0.45 µm Watt man paper and 100 ml of the filtered sample was rinsed with sulphuric acid. The analyses were done immediately after sample collection [26]. PerkinElmer UV-Vis XLS single beam UV-visible spectrophotometer with 10 mm quartz cell was used for Cr6+ measurements at $\lambda = 540$ nm. The pH meter (HANNA Instruments) was calibrated at pH of 4, 7, and 10 with appropriate buffer solutions and use for the adjustment of sample pH.

Reagents and Standard Preparations. Astandard stock solution was prepared according to [27]. By dissolving 141.4 mg dried K2Cr2O7 to 1 L distilled water. 10.00 mL of potassium dichromate stock solution was added to 100 mL of distilled water. Phosphoric acid and sulfuric acid was used to adjust the pH below 2 and 250 mg 1, 5-diphenylcarbazidein dissolved in 50 mL acetone and added to the sample to form the complex reaction which shows violet color.

UV Vis Spectrometric Analysis of samples. Acalibration equation ($y = 0.688x + 0.035$, $R2 = 0.990$, where y is absorbance and x is concentration in ppm) derived from a calibration curve was plotted from standards (0.2 ppm, 0.4 ppm, 0.5 ppm, 0.8 ppm and 1 ppm) for the determination of Cr(VI) in wastewater samples. However, due to the low sensitivity to low Cr (VI) concentrations and low detection limits of Cr (VI) in wastewater samples, no pink color developed on complexation with 1, 5-diphenylcarbazide. According to Harris [28].wastewater samples were spiked with 2 mL, 7 mL, and 9 mL of a 0.5 ppm Cr (VI) standard to determine the Cr (VI) in the wastewater samples.

Statistical Analyses. Comparison of the efficiency and growth of the two plants in each unit for chromium (VI) removal was by using one-way ANOVA at 95% confidence. All statistical analyses were performed with Microsoft Office EXCEL 2007 and SPSS program (version 20).

3 Results and Discussion

3.1 The Chromium Removal Efficiency of the Horizontal Subsurface Flow Constructed a Wetland

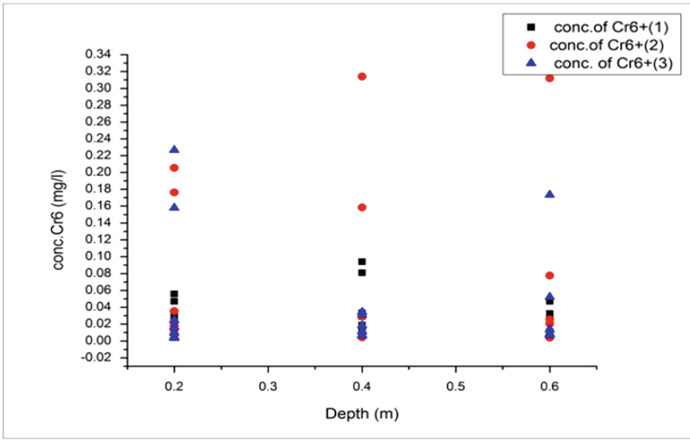
The effect of bed depth on the removal efficiency of chromium by the two plants was investigated. The efficiency of the pilot units subject to the different depth with two plants was monitored through their operation, and the characteristics of the wastewater collected from the inflow and outflow of each pilot unit are determined. The results are presented in Fig. 6, Tables 1 and 2. As it can be seen in Fig. 6 higher removal efficiency of chromium was achieved in a bed with a depth of 0.2 m by C. papyrus (98.41%). While lower removal efficiency was in the planted wetland was by Para grass (94.21%) in the 0.2 m depth. From Fig. 5 we can see that the concentration of chromium (VI) for all depths at the outlet of the treatment bed were below 0.1 ppm which is the permissible standard limit [29].

3.2 The Growth Rate of Plants

The experiment took eight months starting from the planting of the C. papyrus and Para grass to the end of the analysis period. It was initially observed that, in all water depths, the growth rate of both plants was low. This is due to the accumulation period needed by the plant to adopt the new environment. In the first 10 days, leaves were narrow and the upper surface had a yellow pale color. The growth rate after 10 days was the same as the control unit. After the accumulation period, it was found that the growth rate of C. Papyrus was higher than Para grass in all of the water depths. On the other hand, statistical analysis by ANOVA demonstrated that water depth had no significant effect on the growth rate of the plant (Tables 2 and 3).

Table 1. Influent wastewater characteristics

Analysis items	Average (±SD)
Temperature	21.6 ± 4.9
pH	7.66 ± 0.36
BOD5	210 ± 25
TDS	100 ± 4.56
Cr6+	1 ± 0.008



Conc. of Cr^{6+} (1) for depth 0.2m
Conc. of Cr^{6+} (2) for depth 0.4m
Conc. of Cr^{6+} (3) for depth 0.6m

Fig. 5. Chromium concentration at the three wetland depths

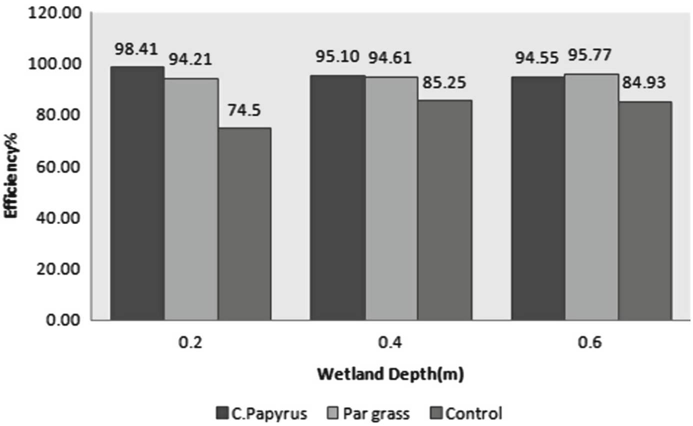


Fig. 6. Average removal efficiency of plants for chromium six at three wastewater depths

Table 2. Average height of experimental plants at three wastewater depths

Water depth (m)	C. Papyrus		Para grass	
	Experiment (cm)	Control (cm)	Experiment (cm)	Control (cm)
0.20	116.2	100.3	65.6	70.3
0.40	106.0	106.0	70.0	85.2
0.60	104.6	110.5	91.2	98.0
	ns	ns	ns	ns

ns no significant difference at 95%

Table 3. Overall influent and effluent concentrations and removal efficiencies in each unit

	Influent concentration (mg/L)	Effluent concentration (mg/L)			Effluent concentration (mg/L)			Removal efficiency (%)					
		C. Papyrus at different depth			Para grass at different depth			C. Papyrus at different depth			Para grass at different depth		
		0.2 m	0.4 m	0.6 m	0.2 m	0.4 m	0.6 m	0.2 m	0.4 m	0.6 m	0.2 m	0.4 m	0.6 m
Cr 6+	1	0.016	0.049	0.054	0.058	0.054	0.042	98.41	95.10	94.55	94.21	94.61	95.77
BOD	215	40.02	52.01	49.54	43.00	41.23	39.12	81.39	75.81	76.96	80.00	80.82	81.80

Total number of sample 63

4 Conclusions

In this study, the removal efficiency of 98.4% was achieved with C. papyrus at constructed wetland depth of 0.20 m. Comparison of the efficiency for chromium (VI) removal of wetland at 0.20 m, 0.40 m and 0.60 m depth was found that papyrus and Para grass have better efficiency for chromium (VI) removal at 0.20 m and 0.60 m pilot-scale constructed wetland depth respectively.

On the other hand, it was found that the growths of both plants were not affected by three wetland depths when compared with the control. It can be suggested in general that horizontal subsurface flow constructed wetland system with Papyrus plant species could be a potential candidate for removal of chromium at large discharge volume.

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