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Potential of constructed wetland systems for treating tannery industrial wastewater

Mengiseny E. Kaseva and Stephen E. Mbuligwe

ABSTRACT

This paper reports on findings of a study on the performance of two units of a Horizontal Sub-Surface Flow Constructed Wetland (HSSFCW) units in treating wastewater effluent from a tannery industry. One of the HSSFCW units was planted with macrophytes, while the other was used as a control (without plants). Wastewater was fed into the wetland units at the mean flow rate of $0.045 \pm 0.005\,m^3$/day. The studied parameters were chromium, turbidity, salinity, Total Dissolved Solids (TDS), Electric Conductivity (EC), pH and temperature. The mean Hydraulic Retention Time (HRT) was 1.60 days (in the control) and 1.80 days (in the vegetated) units, obtained as a ratio of the volume of the wastewater and the volumetric flow rate of wastewater through the units while taking into consideration the porosity of the media. The vegetated HSSFCW exhibited higher chromium removal efficiency (99.83%), than the control unit with the removal efficiency of 92.53%. High chromium removal was associated with both high temperature as well as high pH values in the HSSFCW units. The reduction in turbidity was found to be 71% in the vegetated wetland unit while the corresponding value for the control unit was 66%. Results obtained indicated low reduction efficiencies of both EC (0.3% in the vegetated unit and 1.6% in the control unit) and salinity (11% in the vegetated unit and 22% in the control unit) in the two mesocosms. Generally, however, the study demonstrated that constructed wetlands can be used as an option for improving the quality of tannery effluents especially in the removal of chromium. Chromium removal might have been effected by, among others, gravitational settling of solids and formation of co-precipitation with insoluble compounds as well as adsorption on the substrates and plant surfaces.

Key words | chromium removal, constructed wetland, tannery industry, wastewater treatment

Mengiseny E. Kaseva (corresponding author)
Stephen E. Mbuligwe
Department of Environmental Engineering,
Ardhi University (ARU),
P.O. Box 35176,
Dar es salaam,
Tanzania
E-mail: *kaseva@uccmail.co.tz*;
kaseva@aru.ac.tz

INTRODUCTION

In Tanzania and many other developing countries, pollution of water sources by inorganic and organic chemicals from industrial activities has increasingly become an issue of concern in recent years. Industries like many other sources of wastewater are associated with water and environmental pollution problems. According to Mbuligwe & Kaseva (2006), even before they begin their production operations, industries and their infrastructure can cause extensive environmental degradation mainly due to their spatial extensiveness and enormous needs. Thus, in the growing economies of developing countries, the number of industries that discharge untreated effluents into sewerage systems or directly into water bodies (including rivers and lakes) has increased significantly during the past 30 years which intensively influence on the water quality for these water bodies. In many developing countries, therefore, economic growth and privatization have changed the profile of the industrial sector as a whole. As such, the ownership of the industries and product lines have ushered in new industrial environmental management challenges

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(Mbuligwe & Kaseva 2006). Chemicals from industries enter the water bodies by a wide variety of mechanisms including accidental spills as well as land disposal of domestic and industrial effluents. Once introduced in water sources, these chemicals are transported by flowing ground water and may degrade water quality at nearby wells and streams. The level and extent of environmental pollution from the industries very much depend on the nature or type and amount of materials produced.

Tannery industries, which normally use a variety of chemicals in the production processes, are among the important foreign exchange earners for many countries in the developing world. However, due to the variety of chemicals used, which include lime, sodium chloride, sodium carbonate, ammonium chloride, sulphuric acid, tannings, and dyes, tannery effluents have been reported to have damaged the environment and affected peoples' livelihood opportunities (Anbalagan *et al.* 1997). According to Di laconi *et al.* (2004) tannery industries are among the "dirtiest" industries in the world from the environmental point of view. This is because the characteristics of tannery wastewater vary widely depending on the nature of the tanning process adopted, the amount of water used, the process of hide preservation, the hide processing capacity, the in plant measures followed and the level of water minimization in the industry aimed at reducing the pollution levels (Kurt *et al.* 2007). The problems with the leather industries are also associated with the significant amount of water consumed in the production process which subsequently causes heavy pollution of water bodies by its strong industrial effluent (Song *et al.* 2000).

In order to protect water bodies and the environment in general, treatment of tannery wastewater is of paramount importance. Treatment of tannery wastewater is a very important issue for pollution control in leather producing countries because its uncontrolled release in natural water bodies increases the environmental pollution and health risks (Kurt *et al.* 2007). Some of the problems related to tannery wastewater treatment include high chemical oxygen demand (COD), elevated chrome concentrations and deep colour contents.

Tannery effluents are generally treated by biological methods to remove biodegradable organic materials prior to the discharge into receiving water bodies. However, according to Song *et al.* (2000) pre-treatment of tannery effluents is essential, and based on this, options for cost effective methods for its final polishing before disposal can be determined. In another study (Di laconi *et al.* 2004), have reported conventional technologies as the only option for tannery wastewater treatment to achieve maximum allowable concentration prior to its discharge into receiving water bodies. However, these methods have some drawbacks such as production of large quantities of sludge, consumption of significant amounts of chemicals, an increase in salinity, and high operational costs.

In order to counter these drawbacks, various studies to establish optimal treatment methods have been reported in the literature. These include carboxylate-funtionalised cation exchanger prepared from lignocellulosis residue (Anirudhan & Radhakrishnan 2007), integration of chemical and biological oxidation in a sequential batch reactor (SBR) (Di laconi *et al.* 2004), Electro-Fenton process (Kurt *et al.* 2007), sedimentation (Song *et al.* 2000) and constructed wetland systems (Calheiros *et al.* 2007). In spite of all theses studies, tannery wastewater still awaits effective and feasible technological solutions as also reported by Di laconi *et al.* (2004).

The objective of this study was to assess the performance of a constructed wetland system (CW) in treating tannery industrial effluents, focusing on chromium removal. Constructed wetland systems were used in this study because they are reported to have been widely used over the past ten years in treating industrial waste effluents particularly for enhancing the overall biological performance (Calheiros *et al.* 2007). Haberl *et al.* (1998) have also reported that CWs have favourable attributes such as the utilization of natural processes, and simple construction, operation and maintenance. According to Kadlec *et al.* (2000) CWs can be used for treatment of agricultural and industrial wastewaters as well as effluent from petrochemicals when combined with a pre-treatment system.

MATERIALS AND METHODS

Description of the wetland system feed water source-industry

The case study for this study was Kibaha Tannery Industry (KTI). KTI, which is among the oldest tannery industries in Tanzania, is located in Kibaha (Coast region). KTI produces leather of different kinds especially ‘wet blue’, which is mostly exported. KTI uses hides and skins from within the country as well as imports from the neighboring countries. With a production capacity of 11.3 tons/day of wet blues, KTI consumes 50–65 m^3 of water per day in its different production processes, including those undertaken in the beam house where hides or skins are soaked, in the liming and deliming processes and in the tanning process. Water is also used in the general cleaning of the industry’s premises and facilities. Major types of chemicals used in various production processes include sodium sulphide, ammonium sulphite, and sodium metabisulphate.

Wastewater at KTI (both from the tanning process as well as from the beam house) is currently treated essentially by screening and settling (in sedimentation tanks) prior to discharge into an evaporation/detention basin located within the industry. The detention basin allows for evaporation and seepage of the wastewater into the ground. The existing treatment method is considered grossly inadequate and may lead to contamination of soil as well as surface and ground water sources. Recognizing the deficiencies of the existing wastewater treatment system at KTI, this study was carried out in order to, among other purposes, explore options for cost effective and more efficient wastewater treatment methods for KTI.

Collection of wastewater from the industry

Raw (untreated) wastewater from KTI was collected and transported in batches of about 150 L twice weekly to a pilot CWs located at the University of Dar es Salaam in Dar es Salaam city, about 20 km away from the industry.

Composition and characteristics of tannery wastewater treated in the HSSFCW

Characteristics of tannery wastewater, wastewater from the WSP system as well as those of the mixture of the two types of wastewater are presented in Table 1. Tannery wastewater was generally acidic (pH = 3.7) while that from the WSP system had a fairly neutral pH (pH = 6.7). Low pH enhances the tendency of metals to remain in solution rather than sorb. While tannery industry wastewater had a high concentration of chromium, wastewater from the WSP system had no significant chromium concentration.

According to Anirudhan & Radhakrishnan (2007), chromium is a well known toxic metal considered as a priority pollutant from tannery wastewater effluents. The source of chromium in tannery wastewater was chromium sulfate which is used for the tanning of hides. Based on a survey of 151 tannery industries in India, Wiegant *et al.* (1999) have reported that 70% of the chrome in tannery industries is normally absorbed by hides, while the rest (30%) is discharged in the wastewater effluent.

In this study, mixing of the two types of wastewater resulted in a slight elevation (compared to the raw tannery wastewater) for temperature (+3.3°C), pH (+1.4) and turbidity (+0.8 NTU), while a decrease occurred for EC (−14,234.1 μS/cm), TDS (−9,028.3 mg/l), salinity (−12.8‰) and chromium concentration (−10.7 mg/l).

In this study, mixing of tannery and WSP wastewater resulted in dilution of tannery wastewater (in terms of EC, TDS, salinity and chromium concentration). Wiegant *et al.* (1999) have reported that dilution of tannery wastewater reduces sulphate concentration and thus allows

Table 1 | Characteristics wastewater for selected parameters ($n = 30$)

	Source of wastewater		
Parameter	**Tannery industry**	**WSP**	**Mixture of the two**
Temp (°C)	27.6 ± 9.2	27.4 ± 9.3	30.9 ± 1.0
pH	3.7 ± 1.3	6.7 ± 2.4	5.13 ± 0.85
EC (μS/cm)	35,303.2 ± 2,101.2	320.7 ± 27.5	20,079.1 ± 2,698.3
TDS (mg/L)	19,946.1 ± 6,147.9	167.9 ± 52.5	10,917.8 ± 632.8
Salinity (‰)	21.7 ± 1.3	0.19 ± 0.04	8.9 ± 5.3
Turbidity (NTU)	187.4 ± 66.01	133.6 ± 45.1	188.2 ± 38.7
Cr-Conc. (mg/l)	382.4 ± 13.3	<0.01	371.7 ± 44.5

for anaerobic treatment which uses much less equipment and energy as is the case with the constructed wetland units, which according to Calheiros *et al.* (2007) can be used as an alternative to the conventional biological treatment.

Location and design of the CW pilot plant

Two horizontal subsurface flow (HSSF) CW units constructed at the University of Dar es Salaam, adjacent to an existing waste stabilization pond (WSP) system were used in this study. Each CW unit was 1.5 m long, 0.3 m wide and 0.75 m deep. Of the total bed depth of 0.75 m, only 0.60 m was saturated with wastewater; the remaining 0.15 m was left as freeboard. Based on the above given data, the effective surface area was 0.45 m^2 while the total bed volume was 0.27 m^3. The bed materials for each CW unit were crushed pumice and limestone with particle sizes ranging from 4 to 30 mm. Pumice and limestone were adopted as substrate materials primarily because of their generally good sorption properties. According to Davies *et al.* (2005), pumice and limestone also perform other functions such as effecting filtration and providing support for Biofilm and filtration. The porosity (n) of the substrate material was determined as described in Kaseva (2004).

Experimental set up

Figure 1 presents a schematic diagram of the HSSF-CW system. Unit A was planted with reeds (*Phragmites mauritianus*), while Unit B was used as a control. Wastewater from one of the primary facultative pond of the WSP system was mixed with tannery wastewater collected from KTI and stored in an elevated storage tank. The mixing ratio of wastewater effluent from the WSP and tannery industry effluent was 1:2 (v/v). Mixing of the two types of wastewater was done in order to supplement

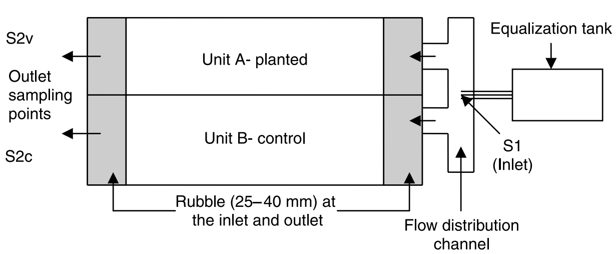

Figure 1 | Schematic diagram of the HSSFCW pilot plant.

nutrients deficiency in wastewater from the tannery industry so as to allow for growth of macrophytes. The mixture of facultative WSP unit and tannery industry effluents stored in the elevated tank was fed into the equalization tank. The equalization tank divided its effluent into two equal flows, directing one to CW unit A and the other to CW unit B. Wastewater samples for analysis were collected at the common influent point (S1) and the out flow points of the vegetated CW unit (S2v) and the control CW unit (S2c).

Monitoring, sampling and analysis procedure

Planting of *Phragmites* sp. was done immediately after commencement of wastewater flow through the CW units. However, wastewater sampling for analysis commenced two months later. The delay in starting sampling was aimed at giving enough time for the establishment of vegetation and bio-film in the CW unit beds (Billore *et al.* 1999). Sampling and analysis were carried out for three months (between February and April, 2007). Grab samples were collected from the three sampling points after every two days between 10 and 12 am. Soon after sampling, the collected samples were taken to the environmental engineering laboratory at Ardhi University for immediate analysis. Analyses were done for total dissolved solids (TDS), salinity, electrical conductivity (EC) and turbidity in accordance with the *Standard Methods for the Examination of Water and Wastewater* (APHA *et al.* 1998). Chromium was analyzed using an Atomic Absorption Spectrometer (AAS) GBS906. Wastewater flow rates (l/d) as well as temperature and pH were measured in-situ.

The hydraulic retention time (HRT) of the CW units was obtained from Equation (1), while treatment efficiency was calculated as a percentage of removal by using Equation (2).

$$t = \frac{Vn}{Q} \quad (1)$$

$$\text{r.e.} = \frac{C_i Q_i - C_e Q_e}{C_i Q_i} \times 100 \quad (2)$$

where t is the HRT (days), V is the effective volume of the HSSF-CW (m^3), n is porosity and Q is wastewater flow rate

(m^3/day), r.e. removal efficiency (%), C_i and C_e are the influent and effluent concentrations (mg/l) while Q_i and Q_e are the wastewater influent and effluent flow rates, respectively (l/day).

Mathematical and statistical analysis

The experimental data obtained from this study were processed and summarized using standard statistical procedures. Their integrity and comparability were tested and tested using standard statistical tests such as the *t*-test and *F*-test.

RESULTS AND DISCUSSION

Wastewater flow rate and the HRT

On site flow measurements indicated that each of the two CW units were fed with wastewater from the equalization tank at the rate that varied from 0.036 m^3/day to 0.053 m^3/day with a mean value of 0.045 $\pm$ 0.005 m^3/day. At the out flow, the flow rate varied from 0.030 to 0.04 m^3/day with a mean value of 0.040 m^3/day, and from 0.033 to 0.045 m^3/day with a mean value of 0.043 m^3/day in the vegetated and control HSSFCW units, respectively. The HRT ranged from 1.40 to 2.30 days in the vegetated unit while in the control unit it ranged from 1.40 to 2.1. The HRT mean values were 1.80 $\pm$ 0.2 and 1.6 $\pm$ 0.2 days in the vegetated and control units, respectively. Figure 2 presents variations in the HRT in the CW units.

Variation of the HRT in the CW units might have been caused by variations in wastewater flow into the wetland units due to hydraulic pressure changes as result of water level changes in the equalization tank. The mean storage change ($Q_{influent} - Q_{effluent}$) was established to be 0.005 and 0.002 m^3/day in the vegetated and control HSSFCW units, respectively. The mean storage change represents equivalent of 11.1 and 4.4% of the mean wastewater influent into the vegetated and control mesocosms, respectively and is likely to have been due to precipitation as well as direct evaporation (in the control unit) and evapotranspiration through wetland plants in the vegetated HSSFCW unit.

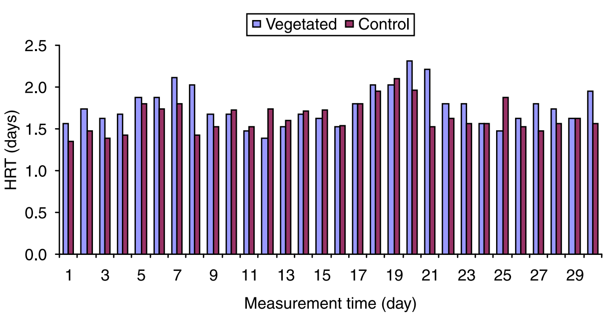

Figure 2 | Variation of HRT in the Macrocosms.

Plants' growth in the HSSFCW unit

The growth of plants in terms of height and increase in number of shoots in the planted microcosm was monitored during the operation of the pilot plant. Both counting and measuring of the plants' heights were carried out on weekly basis. Figure 3 shows that the number of shoots increased gradually from 60 during the first week to 296 after 18 weeks. This represents an average increase of 16 shoots/week or equivalent of about 133 shoots/m^2. The slow increase of shoots (from 60–70) during the first 3 weeks was followed by a rapid increase which was probably caused by plants' nutrient (NH_4-N) uptake from wastewater as also reported by Kaseva (2006). The plants grew taller at the inlet area (0.25 m from the inlet point) and relatively shorter at the outlet area (0.25 m before the outlet point). The differential growth of the wetland plants is attributable to the nutrients gradient, which is characterized by consistently decreasing nutrient concentrations from the inlet to the outlet of a CW unit. The nutrient gradient is in turn caused by removal of the nutrients from the flowing water through retention in the wetland bed and uptake by the wetland plants and other biota.

The average heights of the plants were 144 cm, 125 cm and 91 cm at the inlet, middle and outlet zones, respectively. This trend was likely caused by the fact that at the inlet wastewater contained more nutrients which eventually decreased along the length of the CW unit as argued above.

Chromium removal and pH reduction variations

Figure 4 shows the variation of chromium concentration in the CW units. In the influent (S1) into the two CW units (vegetated and control) the concentration ranged from

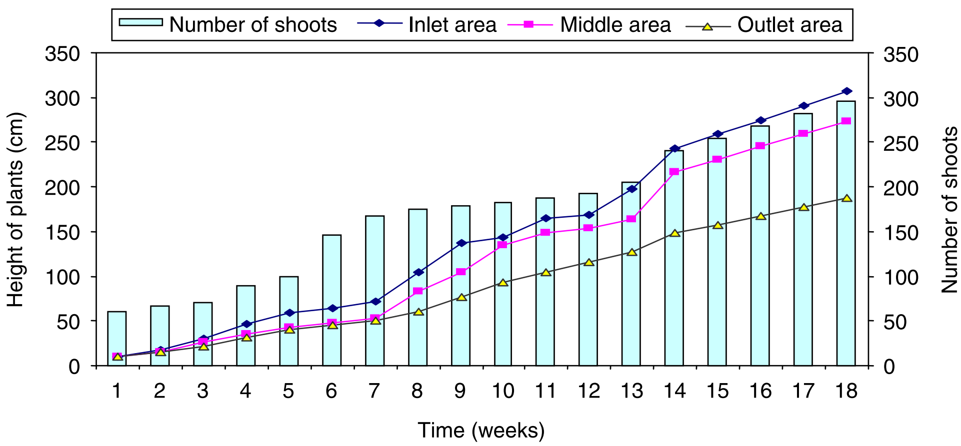

Figure 3 | Height (m) and number of shoots during the period of study.

303 to 420 mg/l with a mean value of 371.70 ± 44.48 mg/l. At the out flow of the vegetated unit (S2v) the Chromium concentration ranged from 0.06 to 2.00 mg/l with a mean value of 0.69 ± 0.65 mg/l, while chromium concentration at the outlet of the control unit (S2c) ranged from 2.00 to 83.55 mg/l with a mean value of 29.06 ± 23.48 mg/l. Based on these concentrations as well as the corresponding wastewater flow rates at the influent and effluent of the mesocosms, chromium loading in the influent (S1) was established to be 16.73 mg/day, while the concentrations in the effluent were 0.03 mg/day and 1.25 mg/day in the vegetated and control HSSF-CW units, respectively as shown in Table 2. The vegetated HSSF-CW unit exhibited a higher removal efficiency of 99.83(±0.19%) as compared to the corresponding value for the control unit which was 92.53(±7.21%).

Findings of this study indicated that chromium removal efficiencies in the two CW units were generally high. None the less, based on a *t*-test, the performance efficiencies of the two CW units were found to be significantly different ($P < 0.05$). An *F*-test performed on the performance data also indicated the same trend ($F > F$ Critical).

As evident from the chromium concentration and performance efficiency data, the vegetated CW unit exhibited more stable performance (variability at 0.19%) than the control CW unit (variability at 7.21%). This suggests that, in CW systems, vegetation has a performance stabilisation effect in addition to the performance efficiency enhancement effect.

High chromium removal in the wetlands might have been contributed by gravitational settling of solids and co-precipitation with insoluble compounds as reported

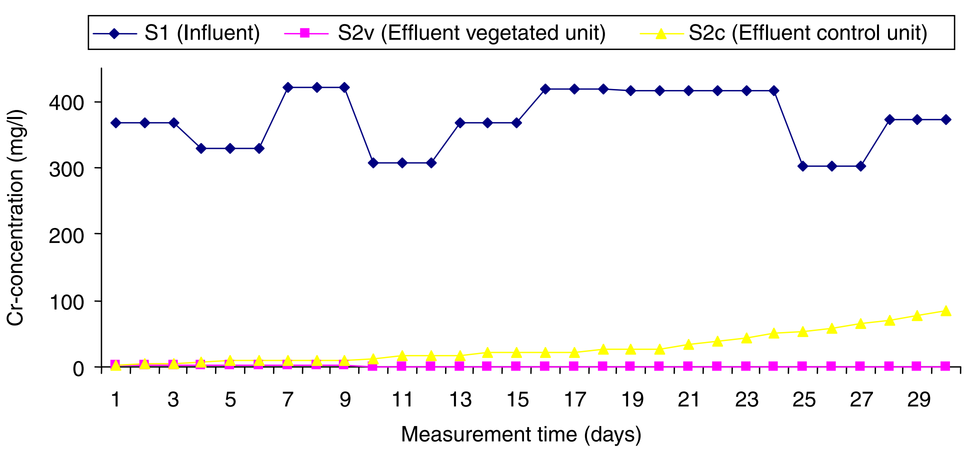

Figure 4 | Variation of Cr-Concentration in the mesocosms.

Table 2 | Cr-loading and percentage removal in the wetland units

Mesocosms	Cr-loading in the influent (mg/day)	Cr-loading in the effluent (mg/day)	Removal efficiency (%)
Vegetated	16.73	0.03	99.83
Control	16.73	1.25	92.53

by Vymazal *et al.* (1998) and Song *et al.* (2000). In the vegetated CWs unit the removal efficiency was higher (99.83%) than in the control CWs unit (92.53%). The superior performance of the vegetated CWs unit can perhaps be attributable to the fact that in this unit the removal was effected through gravitational settling of solids and co-precipitation with insoluble compounds) as well as adsorption on the substrates and plant surfaces (Vymazal *et al.* 1998; Anirudhan & Radhakrishnan 2007). Assimilation by plant tissues which normally increases the removal by phytoremediation process as the plants increase in number, length as well as the microbial transformation might also have contributed to the enhancement of chromium removal in the vegetated constructed wetland unit. Several studies have demonstrated the ability of plants to remove metals from wastewater through uptake and accumulate them in their tissues. For example, Shukla *et al.* (2007) observed significant removal of both chromium and cadmium through uptake by *Bacopa monnieri* both when the two metals were treated together and when each metal was treated separately.

Chromium removal in wastewater treatment plants has also been associated with high pH of the wastewater being treated. According to Sepehr *et al.* (2005), chromium is typically treated by raising the pH of the industrial effluent by adding chemicals. In another study, Anirudhan & Radhakrishnan (2007) reported an enhancement of chromium removal from 19.0 to 99.3% as a result of the increased wastewater pH. In this study, the pH which controls various biological processes as well as determs some important chemical reactions in constructed wetland systems generally increased from the influent to the effluent in all wetland units (Figure 5). The pH of influent wastewater (S1) to the wetland units varied from 3.73 to 6.70 with a mean of 5.13 ± 0.85. In contrast, the pH in the effluent ranged from 6.90 to 8.80 with a mean of 7.62 ± 0.43 in the vegetated CWs unit (S2v), and 6.70 to 9.30 with a mean of 7.83 ± 0.54 in the control CWs unit (S2c). Evidently, the pH was slightly different between the vegetated and control CWs units, perhaps due to organic acids produced by the actions of micro-organisms within the wetland systems. In addition to the pH differences between the vegetated and control CWs units, in each CWs unit pH was consistently higher at the outlet than at the inlet. The increase of pH might have been perhaps due to the limestone nature of the substrate materials used in the HSSFCW beds. The increased alkalinity due to the elimination (oxidation) of part of the volatile fatty acids as well as the amonification of organic nitrogen as the wastewater passed through the HSSFCW units might also have contributed to the increase in the pH of the wastewater.

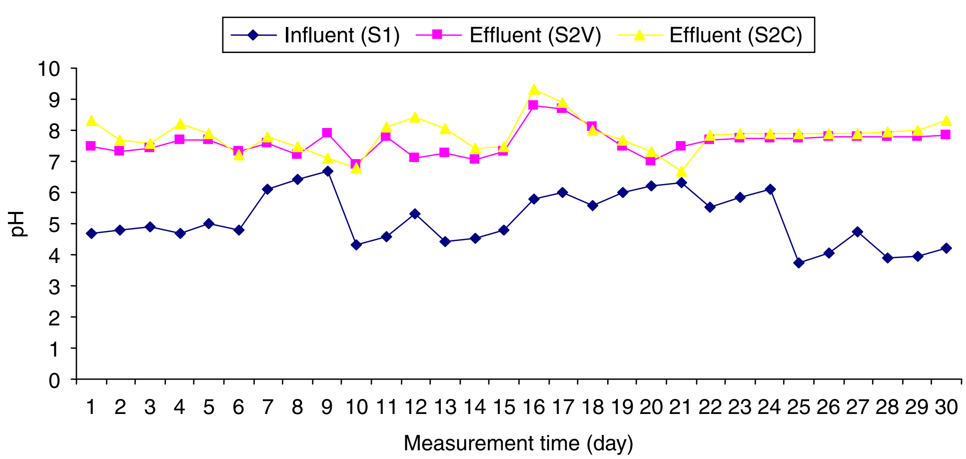

Figure 5 | Variation of pH at the inlet and outlet of vegetated and control cells.

Table 3 | Performance of the CW unit in the removal of TDS, salinity and turbidity

		Effluent			
		Vegetated unit		Control unit	
Parameter	Influent (mean)	Range	Mean	Range	Mean
TDS (mg/l)	10,917.8 ± 632.8	9,714.1–12,354.0	10,641.27 ± 644.3	9,559.5–1,799.0	10,279.7 ± 564.9
Salinity (‰)	9.0 ± 5.25	0.2–13.5	8.0 ± 3.4	0.2–11.8	6.8 ± 3.1
Turbidity (NTU)	188.15 ± 38.74	29.0–79.0	53.7 ± 12.9	26.0–83.0	60.6 ± 12.8

Temperature

Temperature is an important parameter in water quality since it influences many physical, chemical and biological characteristics of the wetlands. Temperature is also of interest since it affects thermal conditions especially for wastewater leaving the treatment units for final disposal in natural receiving water bodies. In this study, the inlet wastewater temperature to the CWs units (S1) ranged from 29.30 to 33°C with a mean value 30.89 ± 1.03°C. After treatment in the vegetated wetland unit (S2v), the wastewater temperature ranged from 27.10 to 31.80°C with a mean value of 29.54 ± 1.12°C, whereas the wastewater temperature at the outlet of the control CWs unit (S2c) ranged from 28.00 to 32.10°C with a relatively high mean value of 29.97 ± 1.07°C. The slightly low temperature in the vegetated wetland might have been caused by the shading effects brought about by the wetland plants in the vegetated CWs unit. On the other hand, high temperatures (above 30°C) in the CWs units might have contributed to high removal rate of chromium concentration through adsorption as reported by Sepehr *et al.* (2005) and Anirudhan & Radhakrishnan (2007).

Electrical conductivity, TDS, salinity and turbidity

The overall performance of the CWs units in the removal of turbidity, TDS and salinity are presented in Table 3. The reduction in turbidity was found to be 71% in the vegetated wetland unit while the corresponding value for the control unit was 66%. These performance efficiencies resulted in effluents with mean turbidly concentrations of 53.7 NTU and 60.6 NTU in vegetated and control CWs units, respectively.

Contrary to the results for the removal of turbidity, removal TDS and reduction in EC were very low. Based on the mean concentrations as well as the mean wastewater flow rates at the influent and effluent of the mesocosms, TDS loading at the influent was established to be 491 g/day while at the effluent of the vegetated CWs unit (S2v) and control CWs unit (S2c) the remaining TDS loads were established to be 468 and 473 g/day, respectively as shown in Figure 6. This represents a removal efficiency of 4.7 and 3.7% in the vegetated and control units, respectively.

EC at the outlet of the vegetated CWs unit (S2v) ranged from 10,563 to 24,215 μS/cm with a mean value 20,017 ± 2,733 μS/cm or equivalent to 0.3% reduction efficiency, whereas EC in the effluent from the control CWs unit (S2c) ranged from 10,236 to 23,937 μS/cm with a mean value of 19,751 ± 2,737 μS/cm which is equivalent to 1.6% reduction efficiency (Figure 7). A similar trend was also observed for salinity removal whereby the mean in the influent to the CWs units was 9.0‰, while effluent salinity values were 8.0‰ (11% removal efficiency) and 7.0‰ (22% removal efficiency) in the vegetated and control wetland units, respectively. These results suggest that in terms of EC and salinity removal, the control CWs unit performed better than the vegetated one.

EC and salinity removal in the vegetated unit might have been contributed by the fact that CWs also operate as filters. Klomjek & Nitisoravut (2005) have also reported that

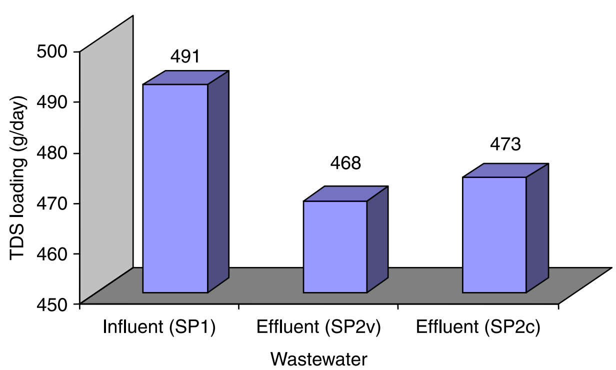

Figure 6 | TDS loading in the mesocosms.

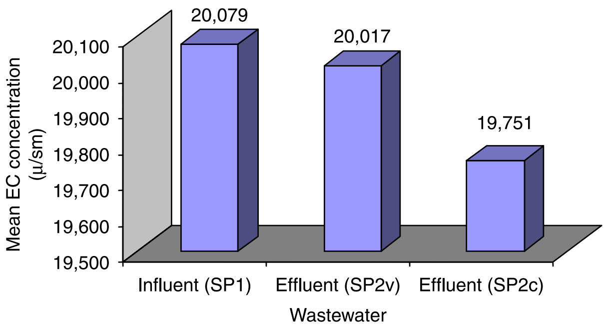

Figure 7 | Mean values of EC concentrations in the Mesocosms.

wetland plants facilitate filtration and sedimentation by encouraging quiescent conditions in constructed wetland units. The suspended solids at the cell inlet were thus filtrated resulting into reduction of EC and salinity.

The EC reduction and salinity removal efficiencies in the two CWs units can also be attributed to a decrease in ions such as ammonium and phosphate in the CWs as reported by Schaafsma *et al.* (2000). Poorer performance in EC reduction in the vegetated (as compared to the control) CWs units might have been due to loss of water as a result of evapotranspiration, which in turn resulted in the increase in concentration of ionic species present in the effluent wastewater. The similarity of reduction trends of EC and TDS is likely due to the two parameters being related. Dissolved solids, which are quantified as TDS, contribute to electrical conductivity in the wastewater (Metcalf & Eddy 2003).

CONCLUSION

This study has attempted to study the performance of a constructed wetland system in the treatment of tannery wastewater. Raw tannery wastewater used in the study was characterized by high chromium and TDS concentrations and high EC. The constructed wetland system units used in this study achieved a chromium removal efficiency of up to 99.83% at a HRT of less than 2 days, which signifies the potential of constructed wetland systems to be used as an option for treating tannery wastewater. The study also indicated that both pH and temperature are associated with elevated chromium removal in constructed wetland system units. Reduction efficiencies of TDS, salinity and EC in this were very low. This suggests that CWs units based on the design and specifications used in this study are not suitable for reduction of TDS and EC. Modifications in the design and specification of the CWs to achieve the desired reduction in TDS and EC could be established by further studies.

On the whole, vegetation seems to enhance not only performance efficiency, but also performance stability of CW systems. With respect to chromium removal, the performance of the vegetated CW unit was more than 37 times more stable than that of the control unit.

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