academicJournals

Vol. 9(5), pp. 420-427, May 2015
DOI: 10.5897/AJEST2014.1793
Article Number: D2FF33852160
ISSN 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Evaluation of selected wetland plants for removal of chromium from tannery wastewater in constructed wetlands, Ethiopia

Tadesse Alemu Terfie* and Seyoum Leta Asfaw

Center for Environmental Science, Addis Ababa University, Ethiopia.

Received 22 September, 2014; Accepted 18 March, 2015

Wastewater from leather processing industries is very complex and leads to water pollution if discharged untreated, especially due to its high organic loading and chromium content. In this study, the phytoremediation efficiency of selected wetland plant species in subsurface flow (SSF) constructed wetlands receiving tannery wastewater was investigated. Four pilot units were vegetated with *Cyprus alternifolius*, *Typha domingensis*, *Parawaldeckia karaka* and *Borassus aethiopum* and a fifth unit was left as unvegetated (control). The treatment performance of the systems for total Cr, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and nitrogen under a 5 day hydraulic retention time were analyzed based on HACH manual. The Cr in the plant tissue was analyzed through oven dried milled, weighed, digested and analyzed using atomic absorption spectrophotometer (AAS.) The wastewater analysis showed that Cr in the effluent was reduced up to 99.3% for an inlet average Cr loading rate of 40 mg/L, COD was reduced up to 80% for an inlet organic loading varying between 2202 and 8100 mg/L and BOD_5 was reduced up to 77% for an inlet organic loading varying between 650 and 1950 mg/L. NO_3 and NH_3-N removal achieved 57 and 82%, respectively. Roots accumulate significantly higher Cr in all plant species when compared with shoots. *B. aethiopium* and *P. karaka* shows higher Cr translocation factor than the others. Constructed wetlands are cost effective and environmentally friendly treatment methods in tropical climate hence can be used as an alternative treatment method in developing countries.

Key words: Species in subsurface flow (SSF) constructed wetland, tannery wastewater, chromium uptake, chromium translocation, bioaccumulation factor.

INTRODUCTION

Agro-processing industrial sector in Ethiopia is now the fastest growing center, which offers substantial challenges for the environment and public health. Leather tanning has been ranked as one of the most polluting activities due to the high growth rate and weak regulatory mechanisms. There are more than 26 tanning industries of which 90%

*Corresponding author. E-mail: tadese07@yahoo.cpm.

of them discharge wastewater into nearby surface water without efficient treatment (Seyoum et al., 2004; Dana et al., 2010). Environmental pollution becomes more acute when industries are concentrated in clusters, as in the case along Modjo River. The transformation of raw or semi-pickled skins into commercial products requires high water consumption, roughly 50-150 L and about 300 kg chemicals are added in each ton of hides (Infogate/GTZ, 2002; Anthony, 1997). The major chemicals used in the various processing stages include chromium salts, sulfate, sodium sulfide, lime powder, ammonium sulfate, sodium chloride, sulfuric acid, sulphonated and sulfated oils, formaldehyde, pigments, dyes and anti-fungal agents (Khan, 2001). Most of these chemicals cause the highest toxic intensity per unit of output (Khan, 2001). Chrome tanning is preferred by the majority of leather industry in Ethiopia than vegetable tanning because of its low cost, speed of processing, flexibility and greater stability of the leather (Alves et al., 1997; Hafez et al., 2002). Uptake of the chromium into the leather is not complete and relatively large amounts are found in the effluent; estimated range from 2,000 – 3,000 mg dm^{-3} (Bajza and Vrcek, 2001) to 3 – 350 mg dm^{-3} (Vlyssides and Israilides, 1997) and 12 to 64 mg/L (Seyoum et al., 2004). Chromium is one of the toxic heavy metals to both plants and aquatic organisms.

Treatment of tannery wastewaters is expensive; so many developing countries use a primary and/or secondary treatment which may be biological and physico-chemical processes; such as, ion exchange resins (Kocaoba and Akcin, 2002), reverse osmosis (Hafez et al., 2002), an electrolysis system (Vlyssides and Israilides, 1997) and chemical removal systems such as precipitation, coagulation and adsorption. These methods however, are either expensive and/or produce secondary pollution and are often not considered as cost effective for small sized tannery industries. Therefore, in the case of chromium, further treatment (post treatment) is often required.

Although a significant body of research has been carried out on the removal of selected pollutants including chromium from tannery wastewater treatment using constructed wetland system, information on the rate and efficiency of these plants in absorbing chromium is limited. Therefore, these study aims at evaluating the potential of wetlands for the treatment of chromium rich tannery effluent and the efficiency of selected plants in a constructed wetland system for chromium removal.

MATERIALS AND METHODS

To evaluate chromium phytoremediation efficiency in constructed wetlands (CW), four plant species were selected and collected from wetland area around Modjo tannery, Lake Zway and Addis Ababa University. These plants were selected based on their adaptability to flooding (anaerobic condition) and local climate, indigenous species, easily accessible and tolerant to high pollutants and nutrients (Seyoum et al., 2004; Cristina et al., 2006; Asaye, 2009). The selected plant species can grow in almost all parts of the country.

Design and pilot constructed wetland establishment

The research was carried out at Modjo Tannery Share Company found in Modjo (8° 35' N and 39° 10' E with an altitude of 1,825 m a.s.l), Ethiopia. To evaluate the chromium removal efficiency, four different plant species were planted in four parallel constructed wetland subsurface flow cells, each with a length of 4.2 m, width of 0.8 m and height 0.6 m and a volume of 2.016 m^3. Each CW unit was filled with 15 cm clay soil at the base floor on the cemented floor and 45 cm medium size gravel (15-25 cm) was packed on the top and coarse sized gravels (50-100 cm) were used at the inlet and outlet to avoid clogging. Each wetland cells was treating a volume of about 120 L per day and 530 L of wastewater in 5 days (HRT), (USEPA, 1993; Wood, 1990).

Plant selection and experimental set-up

Four wetlands plants- *Phragmites karka (reeds), Cyprus alternifolius, Typha domingensis* and *Borassus aethiopum* (*Palm*) were selected from swampy of Modjo, Zeway and Addis Ababa an identified based on Sebsibe et al. (1997) criteria. These plants were transplanted in CWs. The hydraulic loading (inflow) and outflow rate was measured for five days of hydraulic retention time (HRT) using a stopwatch and measuring cylinder (Figure 1). The wastewater HRT was calculated based on Darcy's law:

$$T = \frac{Vp}{Q}$$

Where T is residence time (in days), V_p the void or porous volume of constructed wetland (in m^3) at porosity P of the medium (35%) and Q is the flow rate of the constructed wetland (in m^3/day) which is calculated as $(Q_i+Q_o)/2$, where Q_i is inflow and Q_o is outflow (USEPA, 1993).

Wastewater samples collation and analysis

Wastewater characterization was carried out for the following physicochemical parameters; BOD_5, COD, TN, ammonium, sulfate and sulfide was analyzed according to HACH instructions (APHA, 1998). pH and temperature was measured by pH meter and thermometer. Total Cr was analyzed using flame atomic absorption spectrophotometer (AAS) method. The Cr containing wastewater sample was digested using mixed nitric acid digestion (5 ml concentrated HNO_3) and analyzed using flame atomic absorption spectrophotometer (model AAS NOUA-400, Germany). The removal efficiency of the system for selected parameters except control factors was calculated as:

$$\text{\% of Cr removal efficiency} = \frac{Ci - Cf}{Ci} \text{x100 (Seyoum et al., 2004)}$$

Where C_i is the initial concentration and C_f is the final concentration.

Plant sample preparation and analysis

After the last effluent sampling campaign, 10 random plants were carefully dug out of the medium in each bed to estimate final

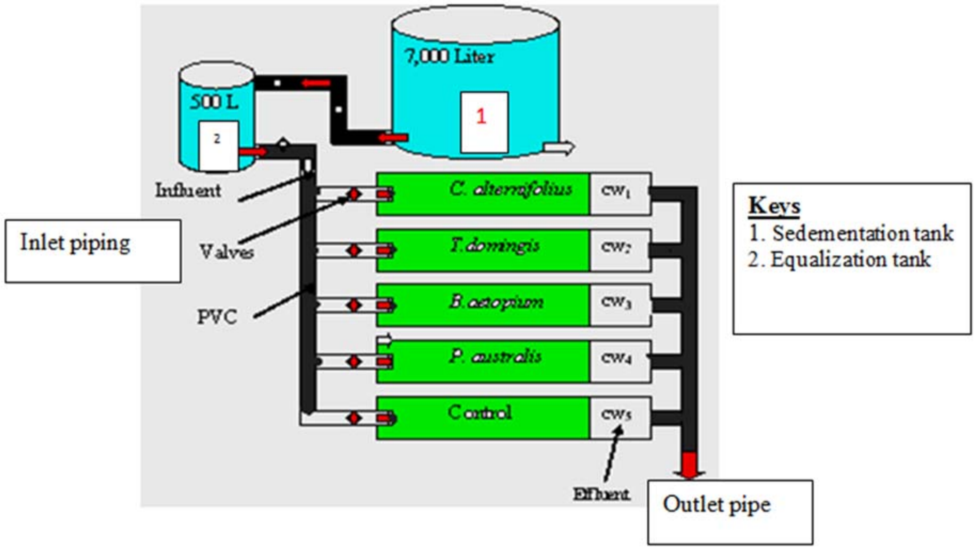

Figure 1. Experimental setup.

biomass and growth rate. Plant samples were collected from each CW and the vegetative parts were separated and washed with tap water followed by distilled water to remove adsorbed soil particulates. Leaves, stems and roots were separated and sliced into smaller pieces. Then, samples were dried in the oven at 65°C until constant weight was obtained. The dried roots, shoots and leaves were measured and grounded to powder and stored in glass flasks at ambient temperature.

The dried plant material (1 g DW sample) was transferred to hot plate and heated at 200°C for 40 min and then calcinated at 450°C for 2 h, as the method described by EEPA (2003) (ash method). The extraction of chromium was performed by adding 5 ml, 6 M HNO_3 (nitric acid) and digested by gently boiling until 1ml remained. Then 5 mL, 3 M HNO_3 was added and reheated for further 30 min. The warm solution was filtered into 100 ml volumetric flask. The extract was recovered through filtration. Deionized water was added to dilute the recovered sample to 100 ml. The concentration of chromium in the extract was determined by AAS (graphite method) in EEPA. A blank was prepared to subtract the Cr contained in the reagent from the plant extract. The Cr bioaccumulation factor (BAF) and translocation factor (TF) of the selected plant species was estimated.

$$\left[\text{BAF} = \frac{\text{mg Cr/kg dw plant}}{\text{mg Cr/L Wastewate r}}\right]$$

$$\left[\text{TF} = \frac{\text{mg Cr/kg dw shoot}}{\text{mg Cr/L dw root}}\right]$$

Gravel and soil sample collection and analysis

After the last effluent sampling, the soil and gravel were carefully dug out of the medium in each bed to estimate the amount of chromium which had been adsorbed to the soil and gravel or the biofilm on the gravel. 1000 cm^3 gravel were measured and washed by the same volume of tap water. The liquid obtained from washed gravel was then analyzed using AAS, the same methods described in wastewater Cr analysis. The total amounts of Cr contained in the gravel were calculated using the formula:

$$TotalCr = \frac{\text{mg Cr in the sample}}{\text{Sample volume}} x\text{Total volume of the gravel}$$

Half kg soil sample was collected from each CW cells bed surface. The samples were air dried to constant weight for a week and large debris and silts were filtered. The ground and homogenized soil samples were analyzed for Cr content. Soil sample were transferred into a 100 mL flask and digested by aqua-regia method (3:1 ratio of HCl to HNO_3) and followed by 1.5 of H_2O_2. A 100 ml supernatant was used for Cr analysis with graphite AAS. The Cr contained in the soil was calculated and expressed in mg /kg dry weight as follows:

$$TotalCr = \frac{\text{mg Cr in the soil sample}}{\text{Soil Sample volume}} x\text{Total volume of soil}$$

Statistical data analysis

Statistical analysis was performed using SPSS program (SPSS; Version 16.0). One-way ANOVA was used to compare the performance efficiency of each CW in organic matter, nutrients and Cr uptake and removal.

RESULTS AND DISCUSSION

The wastewater analysis showed that: average BOD_5 and COD of the influent, which enters into the CWs, were 1054 and 4434 mg/L, respectively and the average pH of the influent was 8.2. The average temperature of the influent wastewater was 23.2°C. Mean composition of influent tannery wastewater from sedimentation tank is summarized in Table 1. The wastewater analysis showed COD reduced by 56-80% for an inlet organic loading

Table 1. Mean composition of Influent wastewater (in mg/L).

	Mean ±SE	Minimum	Maximum
COD	4434 ± 1846	2202	8100
BOD5	1054 ± 448	572.00	1950
SO_4^{2-}	3750 ±106	1900	5600
S^{2-}	152.9 ± 3.3	147	159
TN	780 ± 11	760	800
NO_3^--N	343 ± 17	310	370
NH_4^+	563 ± 4	558	571
Cr	40 ±27	10	90
pH	8.2 ± 2.3	8	8.6

Table 2A. Average effluent concentration and percentage removal of total Cr.

Planted cells	Removal efficiency (%)			
	COD	BOD	TN	NH^+_4
CW1	64.8	67.5	46	64.8
CW 2	56.6	66.7	46.7	53.3
CW 3	58	66	58	80
CW4	80.9	77	61	82.5
CW 5	38.4	64	40.5	62.7

Table 2B. Percentage removal of COD, BOD, TN and NH_4 in each CW.

CW cells	Mean effluent (mg/L)	Removal (%)
CW1	0.84± 0.42	98
CW 2	0.41 ± 0.06	99
CW 3	0.28 ± 0.10	99.3
CW4	0.93 ± 0.37	97.7
CW 5	1.02 ± 0.26	97.4

varying between 2202 and 8100 mg/L and BOD_5 reduced by 66-77% for an inlet organic loading varying between 650 and 1950 mg/L. Nitrate, ammonia-nitrogen, sulfide and sulfate removal ranges from 30 to 57, 53 to 82, 53 to 82 and 82 to 92.4%, respectively. Cr in the effluent also reduced up to 99.3% for an inlet average Cr loading rate of 40 mg/L.

Chromium removal

Effluents from raw hide and skins processing at Modjo Tannery, which produce crust leather and finished leather, contain compounds of trivalent chromium (Cr) (Table 1). The mean total Cr and pH were 40±27 and 8.2±2.3, respectively. The high variability of chromium in the influent was due to variation in the proportion of general wastewater and tanning wastewater at different times. Chromium removal efficiency of the different constructed wetlands was examined first by studying the percentage reduction of Cr in the wastewater phase. Wastewater analysis showed that the average influent Cr concentration was 40 ± 27 mg/L (Table 1). This high variability of Cr in the influent wastewater observed comes from different sources of wastewater (composite sampling) released due to different operations in the industry. The wastewater analysis also showed that COD was reduced up to 80%, BOD_5 was reduced up to77% and NH_3-N removal achieved 57 and 82%.

The maximum chromium removal was observed in CWs planted with *B. aethiopium* (99.3%) followed by *T. domingensis* (99%), *C. alternifolius* (98%) and *P. karka* (97.7%) (Table 2 and Figure 2). The minimum Cr removal was observed in unvegetated CW (control) (97.4%). Cr analysis showed that, no significant difference was observed between the vegetated CW cells and control, but there is an increment in Cr removal efficiency in the vegetated CWs. The mechanism for removal of metals in CWs is through immobilization by the sulfide, sulfate (Weisa and Weisb, 2003), hydro-oxide precipitation in the anoxic waterlogged clay soils and plant uptake. The presence of sulfate and sulfides may convert soluble metals and chromium to precipitates as chromium sulfate and metal sulfide, which agrees with the study by Mitsch and Gosselink (1993).

Chromium partitioning in wetlands

The inlet to outlet analysis of Cr from wastewater showed that there is an average of 99% reduction of Cr in the effluent. The amount of Cr contained in the soil, gravel, plant and effluents were analyzed separately and are displayed as a percentage (Table 3). The total influent Cr that entered into the wetland cells was found to multiply the mean Cr concentration by the total amount of treated wastewater. The mass balance showed that 38 - 59.60% of Cr was contained in the soil, 20-38.15% was contained in gravel and 23-48.68% of the Cr was either up taken by plants or adsorbed on to the root surface (Figure 2). *T. domingensis* showed high Cr content in or on plant tissues followed by *C. alternifolius*. This fact was reflected in plant tissues analysis where *T. domingensis* contained high Cr in its root. This showed that Cr in CWs can be removed by different processes.

The reason why there is no significant difference in Cr removal efficiency between vegetated and un-vegetated CWs is that most of the Cr may be retained in the soil, gravel and biofilms and only a small proportion is up taken by plants. This is because in constructed wetlands, most of the heavy metals are removed using different processes, such as precipitation, cation exchange with

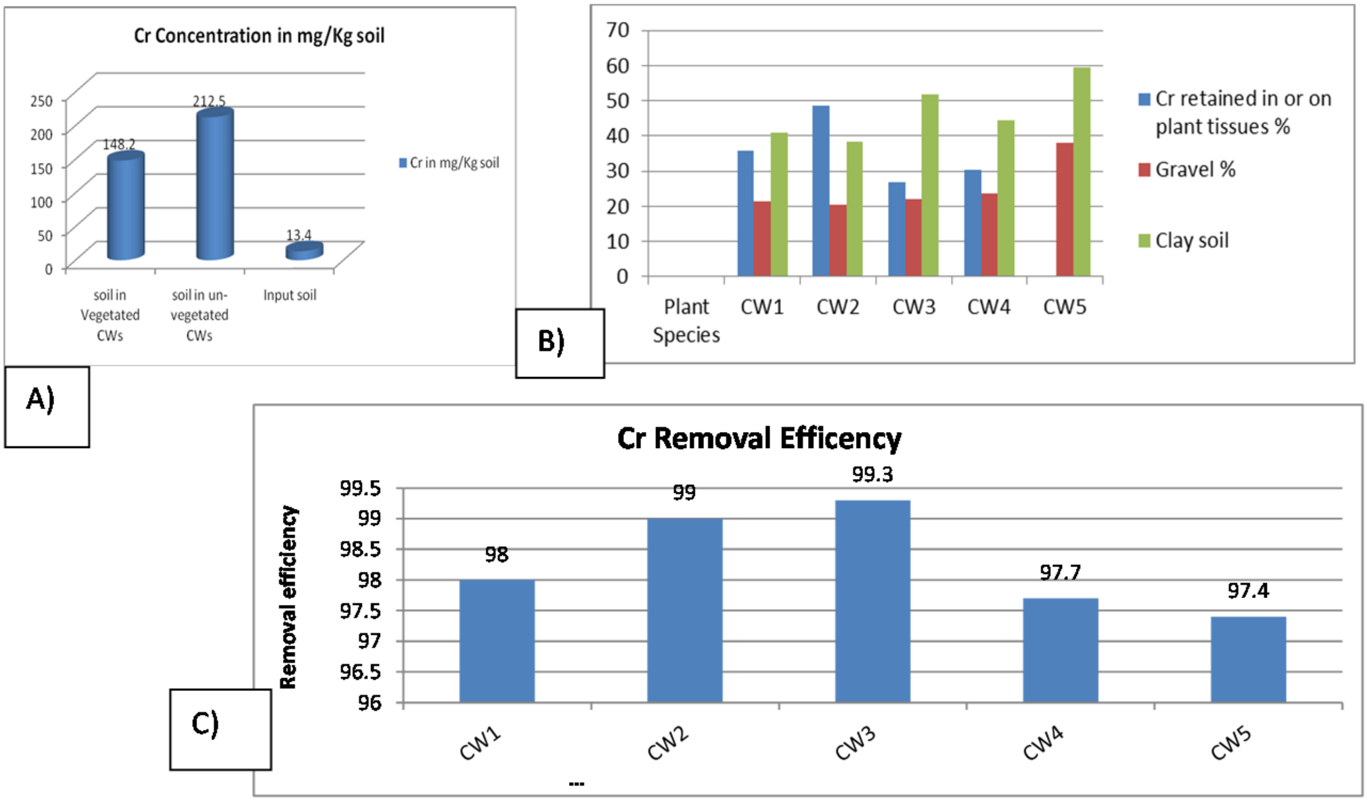

Figure 2. A) Cr adsorbed on clay soil; B) Percentage of chromium partitioning in CWs (in g of Cr); C) Chromium removal efficiency of each CW cells.

Table 3. Percentage of chromium partitioning in CWs (in g of Cr).

Plant species	Cr retained in or on plant tissues (%)	Gravel (%)	Clay soil (%)	Effluent solution (%)
C. alternifolius	35.84	21.54	41.04	1.58
T. domingensis	48.68	20.28	38.23	0.77
B. aethiopium	26.96	21.9	51.67	0.52
P. Karaka	30.26	23.63	44.37	1.8
Control	0	38.15	59.60	2.25

clay soil, adsorption to roots and gravel, bioaccumulation by microorganisms and chemisorption (Collin and Michael, 2002).

Chromium adsorption on clay mineral

The mean Cr concentration retained in clay soil in vegetated CWs was 148.2 mg/kg soil. But, the amount of Cr in the original soil was analyzed and found to be 13.4 mg/kg soil (Figure 2A). This shows that there is a significant difference in Cr concentration between soils in CWs and original input soil. This leads to the conclusion that clay soil has a high potential to adsorb Cr.

The soil in unvegetated CWs showed higher Cr content as compared to vegetated CWs. This may be due to plant uptake, adsorption of Cr on root surface by chelating agents, which reduce Cr availability for cation exchange in vegetated CWs (Mitsch and Gosselink, 1993; Weisa and Weisb, 2003; Reddy, 2004). The adsorption of Cr on the clay soil results from chemical reactions between Cr species and sites at the mineral surface of the clay soil or gravel. Cation exchange capacity (CEC) is responsible for the adsorption of chromium to clay soils (Collin and Michael, 2002). This phenomenon contributes for high chromium removal by the control.

Chromium accumulation in plant tissues

The concentration of Cr in plant roots before introducing tannery wastewater was found to be very low. *T.*

Table 4. Average Cr concentration (mg/kg) in plants tissues (root, stem and leaves), bioaccumulation (BAF) and translocation factor (TF).

Plant tissues		*C. alternifolius*	*T. domingensis*	*B. aethiopium (Palm)*	*P. karka* (Reeds)
Control		0.699	2.07	2.07	0.723
Roots		1472.00	1848.00	180.90	69.24
Stems		96.22	No stem	82.24	16.98
Leaves		162.40	111.70	65.17	34.78
Total		1730.32	1961.77	330.38	121.72
BAF	Root	36	46	4.5	1.7
	Stem	2.4	=	2	0.42
	Leaves	4	2.7	1.63	0.86
TF		0.17	0.06	0.8	0.72

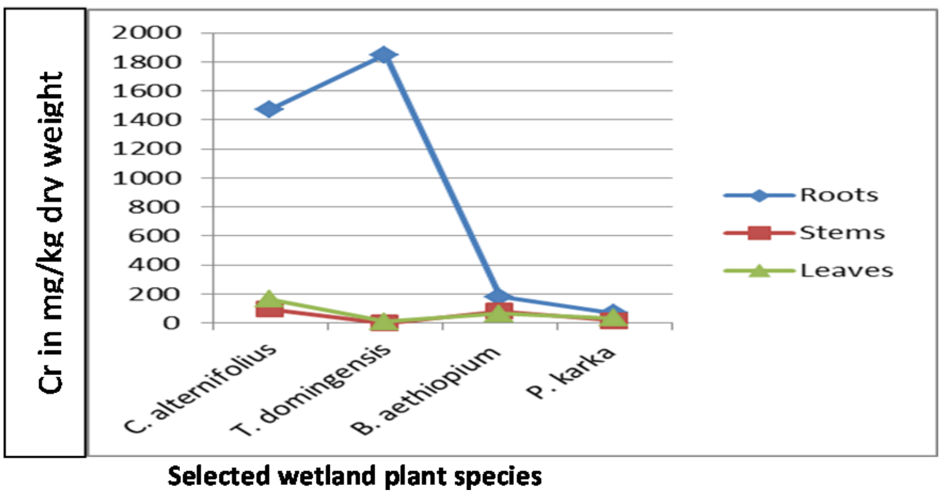

Figure 3. Average Cr concentrations (mg/kg) in plans tissues (root, stem and leaves).

domingensis and *B. aethiopium* has 2.07 mg/kg DW and *C. alternifolius* and *P. karka* has 0.699 and 0.723 mg/kg DW, respectively (Table 3). Plant analysis showed that most of the chromium taken up by the plants remained in the root (up to 83%) and the plant species differ signify-cantly in Cr uptake capacity and distribution within the plant.

Results revealed that there is a significant difference in chromium uptake, Cr concentration and accumulation between roots, roots and stems and between shoots and leaves of each experimental plant (Table 4). The maximum chromium concentration in the root was observed in *T. domingensis* (1848 mg/kg DW*)* followed by *C. alternifolius (*1472 mg/kg DW). These plants have significantly greater chromium concentration in their roots than any other plants. The reason why *T. domingensis* has high concentration of Cr in its roots may be that the plants have fast growing and spongy root which enables the plant to absorb more Cr as compared to other plants. *C. alternifolius* also has higher chromium concentration in the root as compared to *B. aethiopium* and *P. karka* due its high growth rate. However, all plant species used in this study accumulated more Cr in their roots than stem and leaves. This is because chromium can be adsorbed at the extracellular negatively charged sites (COO^-) of the root cell walls (Weisa and Weisb, 2003) and Cr immobilization in the vacuoles of the root cells (Shanker et al., 2004). Root to stem Cr concentration ratios were in the range of 4 to 15 (Table 4).

The biomass of the aerial parts of *C. alternifolius* contained significantly more chromium than any other plants in the CWs (Figure 3). Although *T. domingensis* do not have aerial stem to accumulate Cr in their stems (due to the short underground rhizome), they accumulated more Cr in their roots. The highest value of Cr accumulation in leaves was recorded in *C. alternifolius* (162.4 mg/kg DW) followed by *T. domingensis* (111.7 mg/kg DW) *and B. aethiopium* (65.17 mg/kg DW) and the minimum was recorded in *P. karka* (34.78). The maximum Cr accumulation in stems was recorded in *C. alternifolius*

(96.22 mg/kg DW) and the minimum was recorded in *P. karka* (16.98). All plants leaves accumulated more Cr than stems, this might be during translocation up wards; Cr destination is the leaf, where it is stored.

Selection of potential chromium phytoextractor plant

*Chromium bioaccumulation factor (*BAF*)*

Chromium uptake in different parts of the plants was calculated using the bioaccumulation factor (BAF). According to Nandakumar et al. (1995), the BAF provides an index of the ability of the plant to accumulate a particular metal with respect to its concentration in the medium. The roots of all plants have the greatest tendency to concentrate Cr than stems and leaves. Statistical data analysis showed that there is also a significant difference in BAF between roots of experimental plants. *T. domingensis* had a higher BAF than any of the experimental plants followed by *C. alternifolius*. The Cr BAF in roots of *T. domingensis* is 46 times and *C. alternifolius* is 36 times greater than in the surrounding wastewater; whereas *B. aethiopum* and *P. karka* showed the least BAF (4.5 and 1.7, respectively) (Table 4).

The findings in this study showed that plant roots accumulated more Cr than shoots and have a higher bioaccumulation factor. Shoot bioaccumulation factor for Cr were less than 3 for all plant species. Plants with a bioaccumulation factor greater than 1 will remove metals in wastewater with each plant harvest (Ghejua et al., 2009). Therefore, the selected plants have the potential to remove Cr contaminated effluents, however *P. karka* showed a lower BAF (<1). The highest chromium accumulation and concentration in roots, compared with stems, is due to Cr immobilization in the vacuoles of the root cells (Shanker et al., 2004). The results of this study concur with those reported by other researchers, who reported high chromium accumulation in roots (Shanker et al., 2004; Ghejua et al., 2009).

Chromium translocation factor (TF)

The moment wetland plants translocate metals from root to aerial tissue, they accumulated in stems and leaves. The degree of upward translocation is dependent on the plant species and the particular metal (Shanker et al., 2004). Uptake of metals into root cells, the point of entry into living tissues, is the first step for the process of phytoextraction. However, for phytoextraction to occur continuously, metals must also be transported from the root to the shoot. The highest TF is assumed by *B. aethiopium* and followed by *P. karka,* which showed their higher Cr translocation efficiency (Table 4). These plants have high biomass per meter square area than *Typha* and *Cyprus*. This fact is reflected in the Cr and nutrient removal efficiency in the water phase of parallel study, where *B. aethiopium* has the highest Cr removal efficiency and *P. karka* has the highest BOD_5, COD and nitrogen removal efficiency (Table 1).

Plants with high BAF coupled with high TF values are efficient in the removal of Cr from CWs because harvesting the areal part removes Cr from the system. Plants must have the ability to translocate Cr from the root to the shoot, in order for a plant to continue absorption of Cr from the medium, since a higher concentration of Cr in the root is toxic to plants (Skeffington et al., 1976; Perk, 2006). Translocation may reduce Cr concentration, and thus reduce toxicity potential to the root and it is also one of the mechanisms of resistance to Cr, because the high concentration of Cr will be lost during harvesting or leaf fall.

It is important to note that, in the total amount of chromium ions associated with the root; only a part is absorbed into cells. A significant ion fraction is physically adsorbed at the extracellular negatively charged sites (COO^-) of the root cell walls (Lasat, 2000). The cell wall-bound fraction cannot be translocated to the shoots, therefore, cannot be removed by harvesting shoot biomass (phytoextraction). Thus, it is possible that a plant exhibiting significant metal accumulation into the root, expresses a limited capacity for phytoextraction. To support this, Blaylock and Huang (1999) concluded that the limiting step for metal phytoextraction is the long distance translocation from roots to shoots.

Chromium tolerance of the selected plant species

The concentration of chromium in the plants and whether they appear healthy or not can indicate the tolerance of that plant to the metal concerned, and therefore their potential for phytoremediation (Mant et al., 2006). During the study period, *B. aethiopium* and *P. karka* did not shown signs of toxicity. They tolerated high Cr concentration in the tannery wastewater ranging from 8 to 95 mg/L total Cr. However, *C. alternifolius and T. domingensis* leaves and some stems of *C. alternifolius* died after being exposed to a high Cr content of tannery wastewater (95 mg/L). The ability of *B. aethiopium* and *P. karka to* withstand greater concentrations was by minimizing these effects which indicate plants tolerance to the chromium. The ability of the plants to stay healthy and their grow rate is also an important factor in the choice of plants for phytoremediation. Tolerance to metals in plants may be achieved by sequestering them in tissues or cellular compartments (e.g. central vacuoles) that are insensitive to metals and adsorbed at the extracellular negatively charged sites (COO^-) of the root cell walls (Weisa and Weisb, 2003). The translocation of excessive metals into old leaves before their shedding and detoxification by roots may also be considered as tolerance mechanisms (Ernst et al., 1992).

Conclusion

The purpose of this study was to investigate the phytoremediation efficiency of selected wetland plant species in subsurface flow (SSF) constructed wetlands receiving tannery wastewater. Constructed wetland systems can be used to treat high-strength Cr rich tannery wastewater. SSF constructed wetlands planted with *C. alternifolius, T. domingensis, B. aethiopium* and *P. karka* are capable of removing Cr and organic pollutants from tannery wastewater. In terms of BOD and nutrient removal, CWs with vegetation showed better removal efficiency than un-vegetated CWs. However, there was no significant difference in Cr removal efficiency between the control and vegetated CWs. The Cr removal efficiency of vegetated CWs ranged from 97.7% at CW_4 to 99.3% at CW_2. Plant roots accumulated more Cr than shoots and have a higher bioaccumulation factor than leaves and stems. *P. karake* and *B. aethiopium* were the plants that establish successfully and show higher BOD_5, COD and nutrient removal. Reeds can tolerance Cr and stay healthy and therefore continue to grow in the system. The removal efficiency of Cr in CWs is higher than organic matter, therefore should be used as a tertiary treatment for efficient removal of both Cr and organic matter.

Conflict of interests

The authors did not declare any conflict of interest.

REFERENCES

Alves MM, Gonzalez CG, Guedes D, Carvalho R, Castanheira JM, Sol Pereira MC, Vasconcelos LAT (1993). Chromium Removal in Tannery Wastewaters: 'Polishing', Pinus Sylvestris Bark. Water Res. 27(8):1333-1338.

Anthony DC (1997). Modern Tanning Chemistry, British School of Leather Technology, Nene College of higher education, Boughton Green Road. Mountain Park Northampton, UK NN2 7AL. Chemical Society Review. pp. 111-126.

APHA (1998). Standard Methods for the Examination of Water and Wastewater: Twentieth ed. American Public Health Association/ American Water Works Association/Water Environment Federation; Washington DC; USA.

Asaye K (2009). Evaluation of Selected Plant Species for the Treatment of Tannery Effluent in a Constructed Wetland System; (Unpublished Thesis), AAU, Addis Ababa. Avilable at: en.wikipidia.org/winki/ITRC.

Bajza Z, Vreck IV (2001). Water Quality Analysis of Mixture Obtained From Tannery Waste Effluent. Ecotoxicol. Environ. Saf. 50(1):15-18.

Collin B, Michael C (2002). Environmental Chemistry; 4th ed. New York.

Cristina SCC, Rangel AOS, Castro PML (2006). Constructed Wetland System Vegetated With Different Plant Applied to the Treatment of Tannery Wastewater. Water Res. 41(8):1790-1798.

Dana TH, Quangb LN, Chiemc NH, Brixd H (2010).Treatment of high-strength wastewater in tropical constructed wetlands planted with Sesbania sesban: Horizontal subsurface flow versus vertical downflow. Ecol. Eng. 37:711-720.

EEPA (2003). Environmental Protection Authority. Annual Report; Addis Ababa, Ethiopia.

Ernst WHO, Verkleij JAC, Schat H (1992). Metal Tolerance in Plants. Acta Bot. Neerl. 41:229-248.

Ghejua M, Balcub I, Ciopeca M (2009). Analysis of Hexavalent Chromium Uptake by Plants in Polluted Soils, Ovidius University Press, Romania. Volume 20, Number 1, Pp. 127-131,

Hafez AI, El-Manharawy MS, Khedr MA (2002). RO Membrane Removal of Unreacted Chromium from Spent Tanning Effluent: A Pilot- Scale Study, Part 2.

Infogate/GTZ (2002). Treatment of Tannery wastewater. Germen Appropriate Technology (GATE) information system. Available at: http://www.gtz.de/gate/gateid.afp.

Khan AG (2001). Relationships between Chromium Biomagnification Ratio, Accumulation Factor, and Mycorrhizae in Plants Growing on Tannery Effluent-Polluted Soil. Environ. Int. 26: 417-423.

Kocaoba S, Akcin G (2002). Removal and Recovery of Chromium and Chromium Speciation with MINTEQA2. Talanta 57: 23-30.

Lasat M (2000). The Use of Plants for the Removal of Toxic Metals from Contaminated Soil; American Association for the Advancement of Science: Environmental Science and Engineering Fellow.

Mant C, Costa S, Williams J, and Tambourgi E (2005). Studies of Removal of Chromium by Model Constructed Wetland. Braz. J. Chem. Eng. 22(3): 381-387.

Mitsch WJ, Gosselink JG (1993). Wetlands, 2nd Edition. Van Nostar and Reinhold, New York.

Nandakumar PBA, Dushenkov V, Motto H, and Raskin I (1995). Phytoremediation: The Use of Plants to Remove Heavy Metals from Soils. Environ. Sci. Technol. 29:1232-1238.

Perk MVD (2006). Soil and Water Contamination: From Molecular to Catchments Scale. London; JK.

Reddy K (2004). Nitrification-Denitrification at the Plant Root–Sediment Interface in Wetlands. Limnol. Oceanogr. 34 (6):1004-1013.

Sebsibe D, Sue E, Inga H (1997). Flora of Ethiopia and Eritrea; Hydrocharitaceae to Arecaceae. Addis Abeba Ethiopia. Vol. 6. and Vol. 7.

Seyoum L, Fasil A, Gumaelius L, Dalhammar G (2004). Biological Nitrogen and Organic Matter Removal from Tannery Wastewater in Pilot Plant Operations in Ethiopia. Appl. Microbiol. Biotechnol. 66(3):333-339.

Shanker AK, Djanaguiraman M, Sudhagar R, Chandrashekar CN, Pathmanabhan G (2004). Differential antioxidative response of ascorbate glutathione pathway enzymes and metabolites to chromium speciation stress in green gram (*Vigna radiata* (L.) R. Wilczek. cv CO 4) roots. Plant Sci. 166 (4): 1035-1043.

Skeffington R, Shwery PA, Peterson PJ (1976). Chromium Uptake and Transport in Barely Seedlings (*Hordeum vulgare* L.). Planta (Ber) 132:209-214.

USEPA (1993). Subsurface Flow Constructed Wetland for Wastewater Treatment. A Technology Assessment. EPA/832/R/93/008.

Vlyssides A, Israilides CJ (1997). Detoxification of Tannery Waste Liquors with an Electrolysis System. Environ. Pollut. 97(1-2):147-152.

Weisa JS, Weisb P (2003). Metal Uptake, Transport and Release by Wetland Plants: Implications for Phytoremediation and Restoration. Environ. Int. 30(5):685-700.

Wood A (1990). Constructed Wetlands For Wastewater Treatment - Engineering And Design Considerations; In: Cooper, P. F. and Findlater, (eds) (1990); Constructed wetlands in water pollution control. pp. 481-494.