Phytoremediation Potential of Free Floating Plant Species for Chromium Wastewater: The Case of Duckweed, Water Hyacinth, and Water Lilies

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Abstract. Chromium is the second most toxic metal in groundwater, soil, and sediments. Due to its large scale industrial utilization, it exist in various forms in the environment. The present technologies used to eliminate chromium are too expensive and not eco-friendly. Phytoremediation, which is low cost and eco-friendly technology for wastewater treatment was analyzed via Aquatic free-floating plants. This study was conducted to check the phytoremediation capability of three free-floating aquatic plants: Duckweed, Water lilies, and Water hyacinth for the removal of chromium (III) and (VI) in aqueous solutions. The aquatic plants were put in 15 L solution containing 1, 5, and 10 mg/L of Cr (III) and Cr (VI) for 14 days after two weeks acclimation period. The relative growth, tolerance index and chromium uptake by the three plants were measured. The concentrations of chromium in the samples were analyzed using Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). The results showed a significant increase ($P < 0.05$) in accumulation of chromium in the plant's tissues. Maximum total accumulation of 322.57 and 82 mg/kg for plant treated with 10 mg/L for both solution of Cr (III) and Cr (VI) were obtained in Water hyacinth as compared to Duckweed with maximum accumulation of 169.43 and 37.29 mg/kg at 10 mg/L for both Cr (III) and Cr (VI) respectively. Water lilies show a relatively low removal performance with a maximum uptake of 160.82 and 28.78 mg/kg at 5 mg/L for both Cr (III) and Cr (VI) respectively. The relative growth of all plants increase with time but decrease for an increase in concentration of chromium. The study showed that Water hyacinth as an efficient candidate for phytoremediation of chromium compared with Duckweed and Water lilies.

Keywords: Heavy metal · Chromium · Wastewater treatment · Phytoremediation · Water hyacinth · Water lilies · Duckweed

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1 Introduction

The release of untreated sewage and waste into surface water is still a common practice in many countries [1]. All over the world, 80% of used water is not either collected nor treated and is directly released into our water environment [2]. Both organic and inorganic pollutant of water from such action put all marine life and human health at danger and specially intimidate developing region, where between 75 and 90% of their populations are subjected to insecure drinking water [3]. The water contaminant of primary concern are the heavy metals such as lead, arsenic, cadmium, mercury, chromium, and thallium, due to their non-biodegradability and tenacity in the environment [3].

Heavy metals contamination is a primary environmental concern due to their toxicity, non-biodegradability, and high bioaccumulation possibility [4]. Water pollution due to toxic heavy metals and dyes are the major concern for the aquatic environment. Metals and dyes are non-biodegradability and susceptible to form complex, result in very slow degradation [5].

Because of their high degree of toxicity arsenic, mercury, chromium, lead, and cadmium are major concern in term of public health significance [6]. Toxic heavy metals such as As, Pb, Hg, Cd, Cr, Ni, Fe, Cu, Co, and Zn have caused a prevailing water, air, and soil pollution due to industrial and mining activities [7]. Chromium exist mostly in hexavalent and trivalent forms in industrial wastewater [8]. They are used widely in industries such as leather tanning, metallurgical operation, steel production, electroplating, pigment and textile manufacturing, wood preservation, and chromate preparation [9]. Cr (III) and Cr (VI) are the predominate oxidative state found to be stable in an aqueous environment [10]. Cr (VI) is relatively insoluble, carcinogen, and is 500 times more harmful than Cr (III) [11].

Phytoremediation is an economical, no generation of secondary waste, and eco-friendly [12], in that it uses living plants for in situ removal of contaminants from water and soil [3, 13–15]. It depends on the ion uptake mechanism, and the physiological, anatomical and morphological characteristics of each species [16]. Moreover, it allows the restoration of contaminated environments with low costs and minimum collateral impacts [17].

In developing countries, as in Ethiopia and India, the tanning industry is the primary polluting operation. Different research studies shows that chromium is the most toxic heavy metal in these countries. Currently, about 26 tanneries are under operation in Ethiopia [18]. Different concentrations of chromium discharge were reported by different scholars. From Mojo tannery effluent about 32.2 ± 5.7 mg/L were reported, which resulted in a concentration of 2–15 mg/L in downstream [19]. Chromium concentration of about 7.82 mg/L were reported from Sheba Tannery effluent [20] and 3.54 ± 0.55 mg/L from Bahir Dar tannery effluent [21, 22]. The World Health Organization (WHO), set a tolerance limit of 0.1 mg/L Cr (VI) for discharge into inland surface waters and 0.05 mg/L into potable water. For hexavalent chrome, Ethiopian Environmental Protection Authority (EPA) also set a tolerance limit of

0.1 mg/L for industrial effluent [23]. Therefore, removal of chromium from industrial effluents is highly desirable to accord with these legal requirements and to keep the water quality [23].

For removal of heavy metals and organic compounds, different conventional methods are used, such as electrolysis [24], reverse osmosis [25], ion exchange [26], adsorption [27], simultaneous adsorption and bioaccumulation [28], and oxidation-reduction [29]. However, major limitations of such treatments are the production of large amount of sludge and inefficient or expensive processes [30]. Therefore, an effective method to treat Cr contaminated water prior to its discharge is mandatory to address the environmental and public health concerns.

Therefore, the objective of this study was to compare the level of chromium uptake, tolerance index, and relative growth of the plant species in chromium containing aqueous solutions under an ambient air condition.

2 Methodology

2.1 Reagents and Chemicals

All chemicals used were analytical-reagent graded. Diluted stock solutions were used to prepare a hydroponics solution, containing macronutrients and micronutrients for aquatic macrophytes cultivation containing Quarter-strength Hoagland's (($MgSO_4.7H_2O$), 246 mg/L; $Ca(NO_3).4H_2O$, 542.8 mg/L; KH_2PO_4, 68 mg/L; KNO_3, 252.25 mg/L)). The final medium was diluted to half strength before use for plant culture [31]. The PH of solution were adjusted by using 1 N HCl and 1 N NaOH [32]. Chromium chloride $CrCl_3.6H_2O$ and chromium oxide $K_2Cr_2O_7$ were used to prepare a stock solutions of Cr (III) and Cr (VI) ions in glass volumetric flasks by dissolving in deionized water respectively.

The standard solutions used for calibration were prepared by diluting a stock solution of 1000 mg/L of the given element and stored in glass volumetric flasks for quantitative analysis. The reagents used for sample digestion were HNO_3 (65%) and H_2O_2 (30%). All solutions and dilutions were prepared in distilled water.

2.2 Instrumentation

All sample containers, glassware, and reagent bottles were washed with 10% v/v nitric acid before rinsing with high amount pure water and drying in the air before use. Analyses of all digested samples extracted by hotplate and water-bath were performed by using Optima inductively coupled plasma-optical emission spectrometer (ICP-OES). The ICP-OES instrumental conditions used for the metals determination is presented in Table 1 below.

Table 1. ICP-OES measurement parameters

Parameter	Reading
Power	1500
Plasma flow	PL1
Sheath flow	G1
Auxiliary flow	0
Nebulizer flow	0.66
Nebulization pressure	1.78
Pump speed	30
Analysis element	Ar

2.3 Experimental Plant

This study was conducted by using Water hyacinths (Eichhornia crassipes), Duckweed (Spirodela polyrrhiza), and Water lilies (Nymphaea spontanea) plant species as shown in Fig. 1. The plants were collected from the Lagoon behind Bahir Dar University, Peda Campus, Lake Tana, and from the Blue Nile River, Bahir Dar city, Ethiopia.

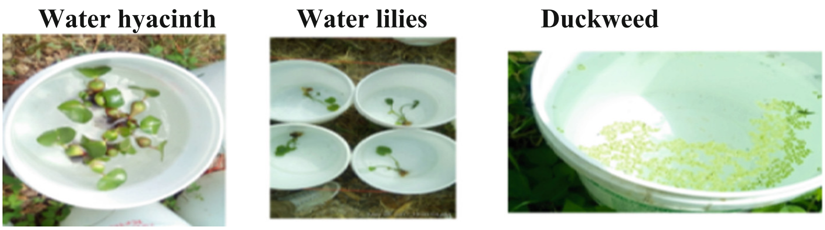

Fig. 1. Free-floating experimental plants

2.4 Experimental Setup and Design

Randomized Block Design were used for the experiment with three factors and three replication, i.e. chromium forms with two level (Cr (III), Cr (VI)), chromium concentrations with three level (1, 5 and 10 mg l^{-1}), and free-floating aquatic plant species with three level (Duckweed, Water hyacinth and Water lilies) with a total of 72 experimental run. The aquatic plants with an equal size and number were treated at different concentration of chromium. The setups were left in the greenhouse undisturbed for 30 days.

2.5 Phytoremediation Study

Phytoextraction study were carried out in a plastic container in the greenhouse. After collection, macrophytes were plentifully cleaned under running tap water to remove any sediment and particles. Healthy plants with equal size and weight were selected and put into a 25-L plastic container containing tap water in a greenhouse for experimental purposes. A two-week acclimation time was allowed to stabilize the collected plant by placing them in a plastic container containing tap water with the addition of nutrient media but not chromium metal to let them adapt to the new environment of the greenhouse. After the suitable acclimation time, plants of similar size and shape were allowed to grow in clean plastic containers containing 15 L solution of chromium metal.

Plastic containers were separated into three groups, Cr (III) contaminated, Cr (VI) contaminated, and control. A control experiment setup with no metal added to half-strength Hoagland nutrient medium were used. Three replicate experiments were set for each test and control. The plastic container was supplemented with tap water, nutrient media, and with the individual addition of 1, 5, and 10 mg l^{-1} chromium metal which was added as their water-soluble salts in the form of their aqueous solutions as waste chemicals. Cr (III) solutions were prepared using $CrCl_3.6H_2O$ while $K_2Cr_2O_7$ was used for Cr (VI).

The experimental concentrations were chosen because they are in the level found in aquatic systems near industrial areas of Bahir Dar Tannery Industry [21]. The plants were left in the greenhouse with an area of 20 m^2 supplemented with tap water, nutrient media, and subjected to chromium metal at 1, 5, and 10 mg l^{-1} concentrations under the conditions of average water temperature ranging between 14 and 26 °C, and with pH of 7.3–7.8. Tap water was added regularly to compensate water losses by plant through transpiration and evaporation to keep the initial volume of water [33]. After two weeks of metal exposure, plants and water sample were collected for metal extraction and analysis.

2.6 Preparation of Sample and Metals Analyses

At the end of the experiment, plants were cut into stems, roots, and leaves and weighed. The element concentrations measured were based on dry weight after correcting for moisture content determined from separate subsamples dried in an oven for 48 h at 60 °C. Digested sample, that could not analyzed immediately were stored at 4 °C until analysis [34]. Triplicate samples (0.5 gm.) of each plant sample variety were accurately weighed in 100 mL conical flasks. About 10 mL of a freshly prepared mixture of concentrated HNO_3–H_2O_2 (2:1, v/v) was added to each flask and kept for 10 min at room temperature. After that, the samples were heated on a hot plate at 80 °C until pure solutions were obtained. Finally, they were evaporated, the semi-dried mass was dissolved in 5 mL 0.2 M HNO_3, filtered through Whatman No.42 filter paper, made up to final volume of 10 mL in volumetric flasks with distilled water, and the metal contents were determined in the diluted solutions by ICP-OES [35]. For metal analysis in water, each collected sample (25 mL) were put in a beaker; 1.25 mL of nitric acid was added and covered with a watch glass. Then, the beakers were placed in a water bath at 90 ± 5 °C for 30 min. After cooling, the digested samples were arranged to a final volume of 25 mL with distilled water. The final suspended mixtures were filtered through 11 μm membrane filter with standard quantitative cellulose filter paper. The samples were then analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES) [34].

2.7 Data Analysis

Translocation Factors

Translocation Factors (TF):- Used to indicate the efficiency of the plant in translocating the accumulated heavy metals from roots to shoots. It is calculated by dividing the concentration of the heavy metal in shoots (leaves or stem) to that in its roots as follows [36, 37].

$$TF = (C\ shoot)/(C\ root) \tag{1}$$

Growth Assessment

Plants growths were studied by measuring the wet weight of the plants at the start and at the end of the experiment. The relative growth of the plants is calculated as- [38].

$$Relative\ growth = (Wf)/(Wi) \tag{2}$$

Where, *Wf* is the final wet weight of plants after exposure to contaminant and *Wi* is the initial weight of the plants.

The Tolerance Index

It indicate the ability of plants to grow in the presence of a given concentration of metal.

Ti is calculated as- [39, 40].

$$\mathrm{Ti} = \frac{(\mathrm{Dry\ weight\ treated\ plant\ (gm)})}{(\mathrm{Dry\ weight\ control\ plant\ (gm)})} * 100\% \tag{3}$$

2.8 Statistical Analysis

The result were analyzed using descriptive statistics (mean and standard deviation). The weight of the plant and metal concentration was given to two decimal places as a means. A significant difference between metal uptake and control was assessed by a one-way analysis of variance (ANOVA). The comparisons of mean using the least significant difference test were calculated for P-values and a value of $P < 0.05$ was considered as significant. Analysis of variance was done by using a statistical package software SPSS, version 20 followed by Turkey's post hoc test between the means of treatments to determine the significant difference.

3 Results and Discussion

3.1 Chromium Accumulation in the Plant

The uptake of chromium ions by Duckweed, Water lilies, and Water hyacinth for different concentrations was analyzed and presented in Figs. 2, 3, and 4 respectively. As can be seen in the Fig. 2, it is clear that chromium uptake by all plant significantly increased ($P < 0.05$) with an increase in chromium concentration up to 5 mg/L. For Duckweed, at chromium concentration of 1, 5, and 10 mg/L, the chromium accumulation significantly increased to 25.12 and 13.39, 167.99 and 33.38, and 169.43 and 37.29 mg/kg for Cr (III) and Cr (VI) respectively. As indicated in Fig. 4, for Water hyacinth the result obtained were increase in Cr concentration from 3.71 mg/kg to 64.02 and 20.07, 306.56 and 79, and 322.57 and 82 mg/kg for Cr (III) and Cr (VI) at 1, 5 and 10 mg/L respectively. The results indicated maximum accumulation was obtained at 10 mg/L for both Cr (III) and Cr (VI). On the other hand, Water lilies show a low uptake of Cr and a decrease in accumulation for an increase in concentration from 5 to 10 mg/L. The result obtained were increase in Cr accumulation from 0.51 mg/L to 21.57 and 15.3, 160.82 and 28.78, and 123.87 and 16.39 mg/kg for Cr (III) and Cr (VI) at 1, 5 and 10 mg/L, respectively. Maximum accumulation obtained at 5 mg/L for Cr (III) and Cr (VI), as indicated in Fig. 3.

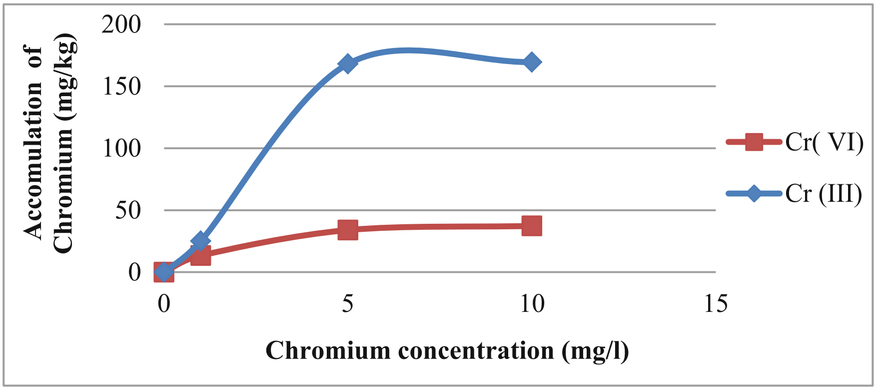

Fig. 2. Accumulation of Chromium in Duckweed

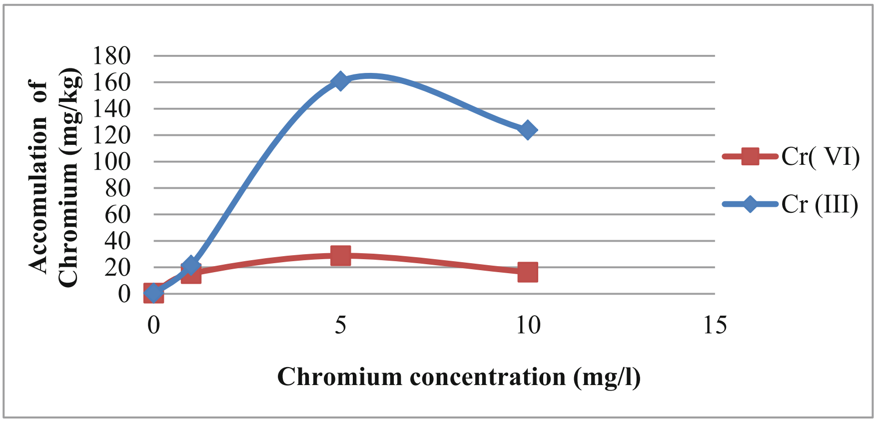

Fig. 3. Accumulation of Chromium in Water lilies

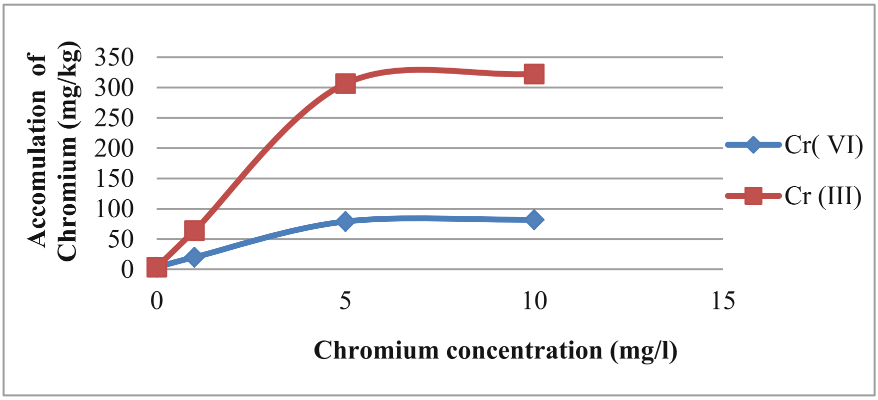

Fig. 4. Accumulation of chromium in Water hyacinth

The result of this study indicates that all plant shows low removal performance for Cr (VI) as compared to Cr (III). This is because Cr (III) is about 300 times less toxic than Cr (VI) [41]. Water hyacinth shows the highest accumulation of Cr for both Cr (III) and Cr (VI) followed by Duckweed, which can be used for effective phytoremediation process in the removal of chromium from wastewater.

3.2 Chromium Accumulation in Roots, Stems, and Leaves of Water Hyacinth

Figures 5 and 6 show chromium accumulations in Roots, Stems, and Leaves of Water hyacinth as a function of chromium concentration. As it can be seen in Fig. 5, accumulation of chromium in the root and leaf increase with increasing chromium concentration from 5 to 10 mg/L for Cr (III) treatment with maximum accumulation obtained in the root at 10 mg/L. For Cr (VI), their accumulation increase with an increase in concentration (except for root at 10 mg/L) as presented in Fig. 6. Due to their toxic effect of negatively charged hexavalent Cr ion complexes, which can easily cross cellular membranes, penetrate the cytoplasm and react with the intracellular material leading to the formation of various reactive intermediates which result in reduction of Cr (VI) accumulation [41].

From the results, it is evident that chromium was retained mostly in the root, only little amount was translocated to the stem and leaf of these plants. Chromium accumulation by Water hyacinth increases linearly with the solution concentration in the order of leaves < stems < roots from1 to 5 mg/L for both Cr (III) and Cr (VI) contaminant. Similar result were also reported that metal accumulated by Eichhornia crassipes was largely accumulated in the roots [42]. Lower amount of metal were retained in leaves than roots related with protection of photosynthesis from toxic levels of heavy metals [43]. Plants may retain high concentration of metals in the roots since roots are mostly at the base of the plant and far from the photosynthetic activities for their own tolerance [44].

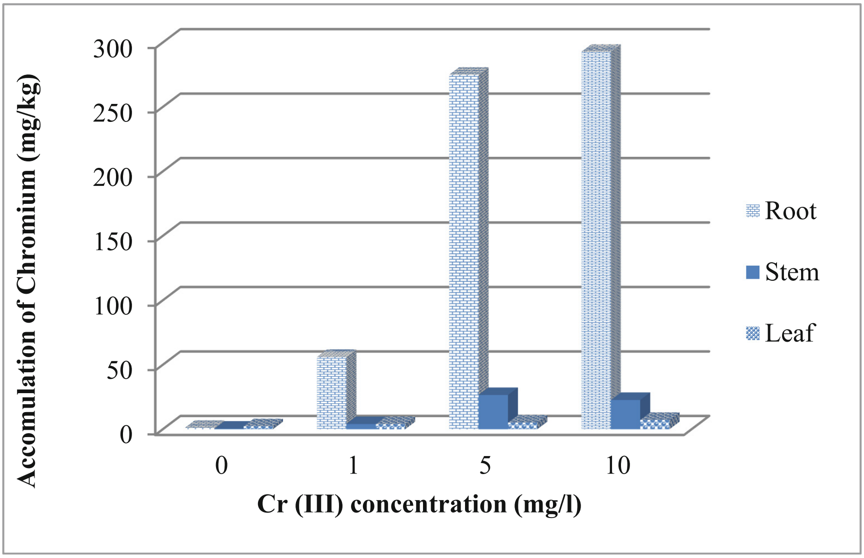

Fig. 5. Accumulation of Cr (III) in Water hyacinth

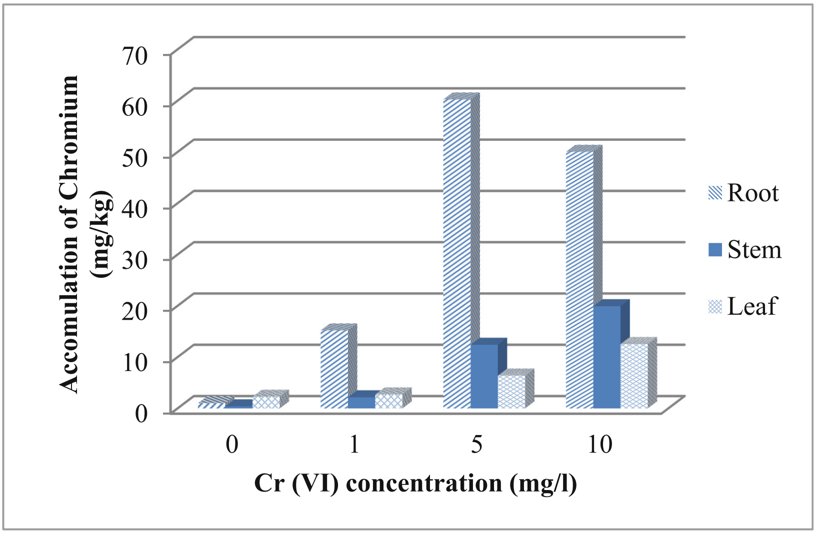

Fig. 6. Accumulation of Cr (VI) in Water hyacinth

3.3 Plant Growth Assessment

Figures 7, 8 and 9 presents the effects of Cr concentration on the relative growth of Duckweed, Water lilies, and Water hyacinth at different Cr concentrations respectively.

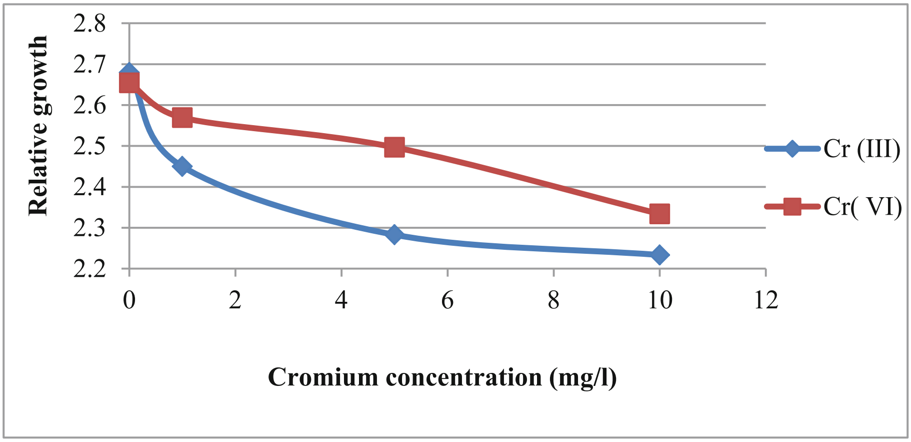

Fig. 7. Relative growth of Duckweed

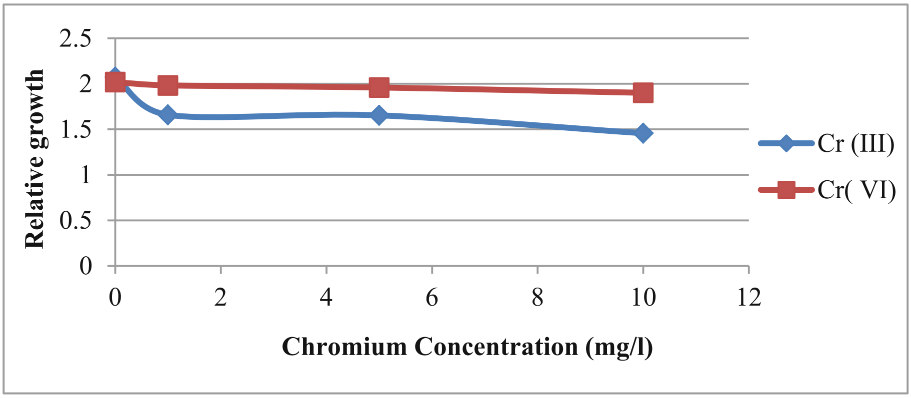

Fig. 8. Relative growth of Water lilies

The relative growth of control plants significantly increased ($P < 0.05$) with time. As presented in Fig. 7, the relative growth of Duckweeds is 2.45, 2.28, and 2.23 for Cr (III) and 2.57, 2.50, and 2.33 for Cr (VI) at 1, 5, and 10 mg/L respectively. Whereas for Water lilies, the relative growth obtained was 1.66, 1.65, and 1.46 for Cr (III) and 1.98, 1.99, and 1.90 for Cr (VI) at 1, 5, and 10 mg/L respectively as shown in Fig. 8. In Water hyacinth plant, a relative growth of 2.36, 2, and 1.85 for Cr (III) contaminant and 2.92, 2.46, and 2 for Cr (VI) were obtained as presented in Fig. 9. The result indicates that Duckweed with the highest relative growth followed by Water hyacinth for both Cr (III) and Cr (VI) contaminant.

With an increase in chromium concentration a decrease in relative growth was observed in all plants, this agree with several other finding [45]. Since, the top leaves of a plant shades the lower leaves and restricting the uptake of nutrients as well as the

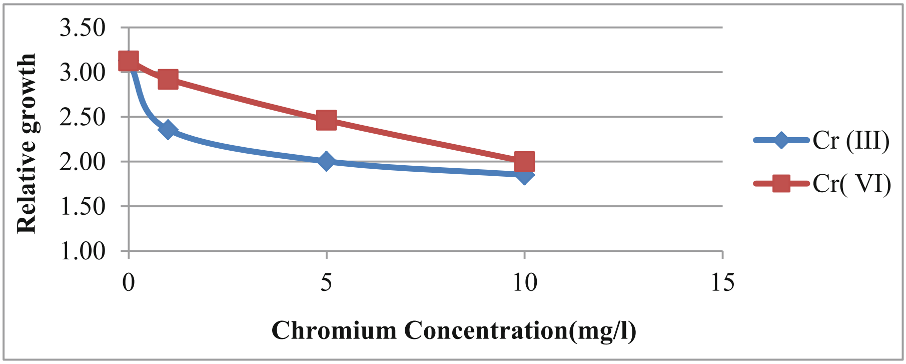

Fig. 9. Relative growth of Water hyacinth

increase of plant and non-photosynthetic biomass (roots and stems) resulting in a decrease of the relative growth rate (RGR) over time. Because, the relative growth of all plants is greater than one, which indicates their ability to accumulate the acceptable amount of chromium and survive in a contaminated condition [37].

3.4 Tolerance Index (TI)

Figures 10 and 11, shows the percentage of Tolerance index (Ti) value for Duckweed, Water lilies, and Water hyacinth after 14 days of treatment in chromium contaminate. The Ti value of all plant shows a decrease with an increase in Cr concentration. As shown in Fig. 10 a decrease in Ti value from 83.6% (in 1 mg/L) to 81.8% (in 5 mg/L), 81.8% (in 5 mg/L) to 79.9% (in 10 mg/L) were obtained for Duckweed when feeding with Cr (III) contaminant. For Water lilies a decrease in Ti value from 82.9% (in 1 mg/L) to 81.1% (in 5 mg/L), 81.1% (in 5 mg/L) to 68.2% (in 10 mg/L) were obtained. For Water hyacinth the Ti value decrease from 72.9% (in 1 mg/L) to 58.5% (in 5 mg/L), 58.5% (in 5 mg/L) to 56.2 (in 10 mg/L). Figure 11 shows decreased in Ti in Cr (VI) contaminant for Duckweed from 77.6% (in 1 mg/L) to 72.4% (in 5 mg/L), 72.54% (in 5 mg/L) to 1.5% (in 10 mg/L). For Water lilies the Ti value decrease from 86.4% (in 1 mg/L) to 82.7% (in 5 mg/L), 82.7% (in 5 mg/L) to 80.2% (in 10 mg/L). Water hyacinth shows a Ti value reduction with increase in Cr (VI) concentration from 91.4% (in 1 mg/L) to 76.5% (in 5 mg/L), 76.5% (in 5 mg/L) to 66.4% (in 10 mg/L). The result shows that, their exist a significant difference ($P < 0.05$) in the Ti value of the plant for an increase in Cr concentration.

Plants tolerance to heavy metal related with the potential of plants to restrict heavy metals movement to the cell walls and activation of antioxidant defense mechanisms [46]. Different plant species develop different system to tolerate excess levels of metals. Plants limit metals uptake or metal transport or develop internal tolerance mechanism to tolerate high concentration of heavy metal as phytochelatins (PCs) in plants produce oligomers of glutathione, which synthase enzyme for Cd detoxification [47].

The result of this study shows that Duckweed has more tolerance to Cr (III) compared to both Water lilies and Water hyacinth. For instance, the Ti vale is 79.9% (in

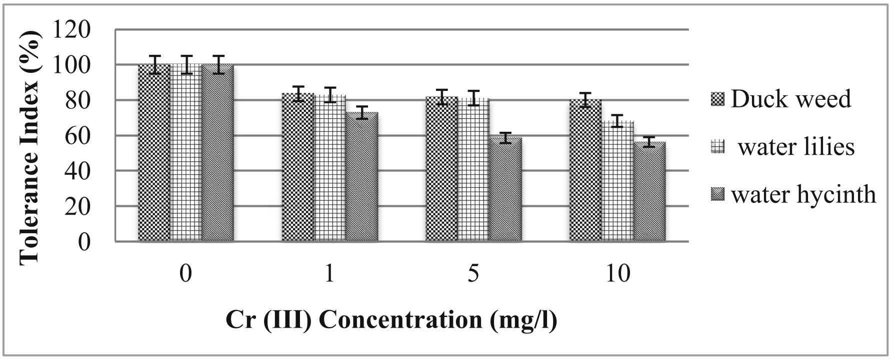

Fig. 10. Tolerance index (Ti) of plants in Cr (III) contaminant

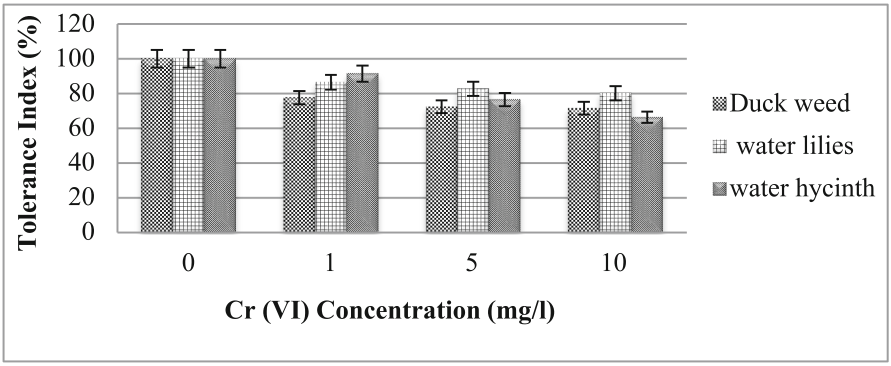

Fig. 11. Tolerance index (Ti) of plants in Cr (VI) contaminant

10 mg/L) for Duckweed, but it is 68.2% and 56.2% in 10 mg/L for Water lilies and Water hyacinth respectively. In contrast to Water hyacinth with Ti value of 58.5% (in 5 mg/L), Water lilies have a good Ti value of 81% (in 5 mg/L). The order of tolerance for Cr (III) contaminant were Duckweed > Water lilies > Water hyacinth. For Cr (VI) contaminant, Water hyacinth has a good Ti value of 91.4% (in 1 mg/L) as compared to Ti value of 86.4 and 77.6% for Water lilies and Duckweed respectively. However, in 5 and 10 mg/L Water lilies have good Ti value to that of Water hyacinth and Duckweed. The order of tolerance follows that Water hyacinth > Duckweed at 5 mg/L and Water hyacinth < Duckweed at 10 mg/L. Generally, plants with high Ti value have a good ability to grow in the presence of a given concentration of chromium.

3.5 Statistical Analysis

The analysis of variance (ANOVA) test was done for the differences in the accumulation of chromium between the experiment (with plants), between chromium type, and between chromium concentration. As shown in Tables 2, 3 and 4, the experiment (with plants) has a significant difference in chromium accumulation for the aquatic plants of Duckweed, Water lilies and Water hyacinth (P-value < 0.05). The accumulations between different concentrations of Cr for the three aquatic plants were proved statistically significant (P < 0.05). As presented in Table 2, there exists a significant difference (P < 0.05) in chromium accumulation for plant type, chromium

Table 2. ANOVA table showing the performance of plants in term of accumulation of chromium metal

Tests of between-subjects effects					
Dependent variable: plant chromium uptake					
Source	Type III Sum of squares	df	Mean square	F	Sig.
Corrected model	125202.071[a]	5	25040.414	8.508	.001
Intercept	158522.036	1	158522.036	53.860	.000
Plant type	24836.087	2	12418.044	4.219	.041
Cr type	59593.027	1	59593.027	20.248	.001
Concentration	40772.956	2	20386.478	6.927	.010
Error	35318.450	12	2943.204		
Total	319042.556	18			
Corrected total	160520.520	17			

a. R Squared = .780 (Adjusted R Squared = .688)

Table 3. Showing pairwise comparisons of plants performance in term of accumulation of chromium metal

Pairwise comparisons						
Dependent variable: plant chromium uptake						
(I) Plant type	(J) Plant type	Mean difference (I-J)	Std. error	P-value	95% confidence interval for difference[b]	
					Lower bound	Upper bound
Duckweed	Water lilies	13.495	31.322	.674	−54.750	81.740
	Water hyacinth	−71.178[a]	31.322	.042	−139.423	−2.934
Water lilies	Duckweed	−13.495	31.322	.674	−81.740	54.750
	Water hyacinth	−84.673[a]	31.322	.019	−152.918	−16.429
Water hyacinth	Duckweed	71.178[a]	31.322	.042	2.934	139.423
	Water lilies	84.673[a]	31.322	.019	16.429	152.918

Based on estimated marginal means

a. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 4. Univariate tests for plants performance in term of chromium accumulation

Univariate tests					
Dependent variable: plant chromium uptake					
	Sum of squares	df	Mean square	F*	Sig.
Contrast	24836.087	2	12418.044	4.219	.041
Error	35318.450	12	2943.204		

*The F tests the effect of Plant Type. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

concentration and chromium type between the groups. Table 3 shows the pairwise comparisons of plants performance in term of accumulation of chromium metal. The result indicated that there exists a significant difference ($P < 0.05$) in the accumulation of chromium between Duckweed and Water hyacinth, also within Water lilies and Water hyacinth. However, there exists no significant difference in chromium accumulation between Duckweed and Water lilies. In Table 4, F test for the plan type were given and the result shows that there exists a significant difference ($P < 0.05$) in chromium uptake by the plants.

4 Conclusion

The potential of three living free-floating aquatic plants species, Duckweed, Water lilies, and Water hyacinth for removal chromium from chromium waste solutions was investigated. It was observed that the uptake of chromium by all plant is significantly increased ($P < 0.05$) for an increase in chromium concentration. It was found that, Water hyacinth with higher total accumulation of 322.57 and 82 mg/kg for plant treated with 10 mg/L for both solution of Cr (III) and Cr (VI). In contrast, Water lilies show a relatively low removal performance with the maximum uptake of 160.82 and 28.78 mg/kg at 5 mg/L for both Cr (III) and Cr (VI). However, Water lilies show good tolerance for Cr (VI) for an increase in concentration from that of Water hyacinth and Duckweed.

The highest percentage removal of chromium was 96.7% of Cr (III) at 10 mg/L for Water hyacinth; 92% of Cr (VI) at 5 mg/L for Duckweed; and 96.7% of Cr (VI) at 10 mg/L for Water lilies. The relative growth of all plant, increase with the passage of time but decreases for an increase in chromium concentration. These results indicated that the biomass of the plant is suitable for the development of efficient accumulator for the removal of Cr from wastewater at a lower concentration.

However, Water hyacinth was proven an efficient candidate for removal of chromium metals from contaminated water body with great potential for future applications. This study suggests, the tested living aquatic plants species were found to have a potential for phytoremediation and can be used for removal of chromium metal from industrial effluent.

5 Recommendation

Further studies on the recovery of chromium metals by employing a controlled condition and investigating the **synergic effect** of the different plant species will be useful for large-scale industrial application of laboratory work.

References

1. Ismail, Z., Beddri, A.: Potential of water hyacinth as a removal agent for heavy metals from petroleum refinery effluents. Water Air Soil Pollut. **199**(1–4), 57–65 (2009)
2. Corcoran, E.: Sick water?: the central role of wastewater management in sustainable development: a rapid response assessment. UNEP/Earthprint (2010)
3. Sood, A., et al.: Phytoremediation potential of aquatic macrophyte. Azolla. Ambio **41**(2), 122–137 (2012)
4. Mishra, A., Dubey, A., Shinghal, S.: Biosorption of chromium (VI) from aqueous solutions using waste plant biomass. Int. J. Environ. Sci. Technol. **12**(4), 1415–1426 (2015)
5. Geetha, K.S., Belagali, S.: Removal of heavy metals and dyes using low cost adsorbents from aqueous medium-, a review. IOSR J. Environ. Sci., Toxicol. Food Technol. **4**(3), 56–68 (2013)
6. Machado, M.D., Soares, H.M., Soares, E.V.: Removal of chromium, copper, and nickel from an electroplating effluent using a flocculent brewer's yeast strain of Saccharomyces cerevisiae. Water Air Soil Pollut. **212**(1–4), 199–204 (2010)
7. Choo, T., et al.: Accumulation of chromium (VI) from aqueous solutions using water lilies (Nymphaea spontanea). Chemosphere **62**(6), 961–967 (2006)
8. Bonanno, G., Giudice, R.L.: Heavy metal bioaccumulation by the organs of Phragmites australis (common reed) and their potential use as contamination indicators. Ecol. Ind. **10**(3), 639–645 (2010)
9. Greger, M.: Metal availability and bioconcentration in plants. In: Prasad, M.N.V., Hagemeyer, J. (eds.) Heavy Metal Stress in Plants, pp. 1–27. Springer, Heidelberg (1999). https://doi.org/10.1007/978-3-662-07745-0_1
10. Xia, H., Ma, X.: Phytoremediation of ethion by water hyacinth (Eichhornia crassipes) from water. Biores. Technol. **97**(8), 1050–1054 (2006)
11. Abbasi, T., Abbasi, S.: Factors which facilitate waste water treatment by aquatic weeds–the mechanism of the weeds' purifying action. Int. J. Environ. Stud. **67**(3), 349–371 (2010)
12. Alkorta, I., Garbisu, C.: Phytoremediation of organic contaminants in soils. Biores. Technol. **79**(3), 273–276 (2001)
13. Tatar, Ş.Y., Öbek, E.: Potential of Lemna gibba L. and Lemna minor L. for accumulation of boron from secondary effluents. Ecol. Eng. **70**, 332–336 (2014)
14. Goswami, C., et al.: Arsenic uptake by Lemna minor in hydroponic system. Int. J. Phytorem. **16**(12), 1221–1227 (2014)
15. Sasmaz, M., et al.: The potential of Lemna gibba L. and Lemna minor L. to remove Cu, Pb, Zn, and As in gallery water in a mining area in Keban, Turkey. J. Environ. Manage. **163**, 246–253 (2015)
16. Rahman, M.A., Hasegawa, H.: Aquatic arsenic: phytoremediation using floating macrophytes. Chemosphere **83**(5), 633–646 (2011)
17. Ibañez, S., et al.: Transgenic plants and hairy roots: exploiting the potential of plant species to remediate contaminants. New Biotechnol. **33**(5), 625–635 (2016)

18. Wassie, A.B., Srivastava, V.C.: Teff straw characterization and utilization for chromium removal from wastewater: Kinetics, isotherm and thermodynamic modelling. J. Environ. Chem. Eng. **4**(1), 1117–1125 (2016)
19. Leta, S., Assefa, F., Dalhammar, G.: Characterization of tannery wastewater and assessment of downstream pollution profiles along Modjo River in Ethiopia. Ethiop. J. Biol. Sci. **2**(2), 157–168 (2003)
20. Gebrekidan, A., Gebresellasie, G., Mulugeta, A.: Environmental impacts of Sheba tannery (Ethiopia) effluents on the surrounding water bodies. Bull. Chem. Soc. Ethiop. **23**(2), 269–274 (2009)
21. Wosnie, A., Wondie, A.: Bahir Dar tannery effluent characterization and its impact on the head of Blue Nile River. Afr. J. Environ. Sci. Technol. **8**(6), 312–318 (2014)
22. Alemu, A., Gabbiye, N.: Assessment of chromium contamination in the surface water and soil at the riparian of Abbay River caused by the nearby industries in Bahir Dar city Ethiopia. Water Pract. Technol. **12**(1), 72–79 (2017)
23. Belay, A.A.: Impacts of chromium from tannery effluent and evaluation of alternative treatment options. J. Environ. Prot. **1**(01), 53 (2010)
24. Hamdan, S.S., El-Naas, M.H.: Characterization of the removal of Chromium (VI) from groundwater by electrocoagulation. J. Ind. Eng. Chem. **20**(5), 2775–2781 (2014)
25. Lin, L., et al.: Sorption of metals and metalloids from reverse osmosis concentrate on drinking water treatment solids. Sep. Purif. Technol. **134**, 37–45 (2014)
26. Cavaco, S.A., et al.: Removal of chromium from electroplating industry effluents by ion exchange resins. J. Hazard. Mater. **144**(3), 634–638 (2007)
27. Gupta, A., Balomajumder, C.: Simultaneous adsorption of Cr (VI) and phenol onto tea waste biomass from binary mixture: multicomponent adsorption, thermodynamic and kinetic study. J. Environ. Chem. Eng. **3**(2), 785–796 (2015)
28. Gupta, A., Balomajumder, C.: Simultaneous removal of Cr (VI) and phenol from binary solution using Bacillus sp. immobilized onto tea waste biomass. J. Water Process Eng. **6**, 1–10 (2015)
29. Dittert, I.M., et al.: Integrated reduction/oxidation reactions and sorption processes for Cr (VI) removal from aqueous solutions using Laminaria digitata macro-algae. Chem. Eng. J. **237**, 443–454 (2014)
30. Szczygłowska, M., et al.: Use of brassica plants in the phytoremediation and biofumigation processes. Int. J. Mol. Sci. **12**(11), 7760–7771 (2011)
31. Carvalho, K.M., Martin, D.F.: Removal of aqueous selenium by four aquatic plants. J. Aquatic Plant Manage. **39**, 33–36 (2001)
32. Clark, R.B.: Characterization of phosphatase of intact maize roots. J. Agric. Food Chem. **23** (3), 458–460 (1975)
33. Maine, M.A., et al.: Kinetics of Cr (III) and Cr (VI) removal from water by two floating macrophytes. Int. J. Phytorem. **18**(3), 261–268 (2016)
34. Chand, V., Prasad, S.: ICP-OES assessment of heavy metal contamination in tropical marine sediments: a comparative study of two digestion techniques. Microchem. J. **111**, 53–61 (2013)
35. Camin, F., et al.: Characterisation of authentic Italian extra-virgin olive oils by stable isotope ratios of C, O and H and mineral composition. Food Chem. **118**(4), 901–909 (2010)
36. Padmavathiamma, P.K., Li, L.Y.: Phytoremediation technology: hyper-accumulation metals in plants. Water Air Soil Pollut. **184**(1–4), 105–126 (2007)
37. Adesodun, J.K., et al.: Phytoremediation potentials of sunflowers (Tithonia diversifolia and Helianthus annuus) for metals in soils contaminated with zinc and lead nitrates. Water Air Soil Pollut. **207**(1–4), 195–201 (2010)

38. Lamaia, C., et al.: Toxicity and accumulation of lead and cadmium in the filamentous green alga Cladophora fracta (OF Muller ex Vahl) Kutzing: A laboratory study. Sci. Asia **31**(2), 121–127 (2005)
39. Lux, A., et al.: Differences in structure of adventitious roots in Salix clones with contrasting characteristics of cadmium accumulation and sensitivity. Physiol. Plant. **120**(4), 537–545 (2004)
40. Bianconi, D., et al.: Uptake of Cadmium by Lemna minor, a (hyper?-) accumulator plant involved in phytoremediation applications. In: E3S Web of Conferences. EDP Sciences (2013)
41. Gikas, P., Romanos, P.: Effects of tri-valent (Cr (III)) and hexa-valent (Cr (VI)) chromium on the growth of activated sludge. J. Hazard. Mater. **133**(1), 212–217 (2006)
42. Hammad, D.M.: Cu, Ni and Zn phytoremediation and translocation by water hyacinth plant at different aquatic environments. Aust. J. Basic Appl. Sci. **5**(11), 11–22 (2011)
43. Landberg, T., Greger, M.: Differences in uptake and tolerance to heavy metals in Salix from unpolluted and polluted areas. Appl. Geochem. **11**(1), 175–180 (1996)
44. Kamal, M., et al.: Phytoaccumulation of heavy metals by aquatic plants. Environ. Int. **29**(8), 1029–1039 (2004)
45. Paine, C., et al.: How to fit nonlinear plant growth models and calculate growth rates: an update for ecologists. Methods Ecol. Evol. **3**(2), 245–256 (2012)
46. Sharma, P., Dubey, R.S.: Lead toxicity in plants. Braz. J. Plant. Physiol. **17**(1), 35–52 (2005)
47. Akpor, O., Muchie, M.: Remediation of heavy metals in drinking water and wastewater treatment systems: Processes and applications. Int. J. Phys. Sci. **5**(12), 1807–1817 (2010)