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Efficiency Removal of Chromium Cr(VI) in Wastewater using Lemon Grass, Elephant Grass, and Vetiver Grass.

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Hexavalent chromium Cr(VI) is a highly toxic and reactive form of chromium commonly found in industrial wastewater. In contrast to trivalent chromium (Cr III), which is less harmful, Cr(VI) is carcinogenic and presents serious risks to the environment and human health. The discharge of partially treated wastewater containing elevated levels of carcinogenic heavy metals like chromium can severely impact aquatic organisms and plant life in receiving water bodies.

The primary objective of this study is to assess the effectiveness of three grass species lemon grass, elephant grass, and vetiver grass in removing Cr VI from wastewater. While traditional methods such as microbial degradation, coagulation, membrane filtration, ion exchange, and chemical precipitation have been widely used for Cr VI removal, this research focuses on phytoremediation as an alternative approach. Furthermore, the study examines recent developments and emerging trends in the application of grass species for treating Cr VI-contaminated wastewater.

* 1. Introduction

The treatment of metal-contaminated wastewater remains a significant challenge, particularly with the tightening of environmental regulations. This has prompted researchers worldwide to develop more effective methods for managing heavy metal concentrations in wastewater. Among these metals, chromium, especially in its hexavalent form Cr(VI), has garnered considerable attention due to its severe environmental and health impacts. Cr(VI) pollution primarily stems from industrial activities like metal finishing, textile, and electroplating. Research has shown that chromium sulfate (chrome), commonly used as a tanning agent, is the primary source of chromium typically found in tannery effluent (Truong et al., 2001).

Chromium exists in two persistent oxidation states, which are trivalent chromium (Cr(III)) and hexavalent chromium (Cr(VI) (Gardea et al., 2000). While Cr(III) is an essential nutrient for humans, playing a key role in glucose processing, Cr(VI) compounds are highly toxic and have been linked to serious health issues, including lung cancer (Nameni et al., 2008). Hexavalent chromium (Cr VI) is more easily absorbed by plants and is significantly more toxic than trivalent chromium (Cr III) due to its higher chemical reactivity, which leads to severe toxic effects (Schiewer et al., 1997).

Tannery effluents are of particular concern in wastewater management due to their high concentration of heavy metals, predominantly chromium, either in Cr(VI) or Cr(III) form (Muwanga and Barifaijo, 2006).

Heavy metals’ presence in wastewater poses a significant environmental threat and severely diminishes microbial activity, negatively impacting biological wastewater treatment processes. Ion exchange methods were commonly used in the past to remove heavy metals from water bodies (Masinire et al., 2021), but these approaches are often cost-prohibitive. Additionally, research has explored the use of dry biomass complexation of heavy metals removal from effluents (Fourest et al., 1996).

Unfortunately, these methods have not been widely implemented on a large scale. Several researchers have investigated biosorption techniques using chemically modified solid surfaces (Barba et al., 2001), though the adsorption of heavy metals, particularly at ppm concentrations, tends to be time-consuming. Therefore, Vetiveria zizanioides, known for its unique morphological and physiological traits, has been effectively utilized for environmental protection due to its high tolerance to heavy metals and extreme environmental conditions (Ash et al., 2004).

Vetiver grass, though not an aquatic plant, can be successfully cultivated and maintained in the hydroponic system. (Hart et al., 2003). Vetiver grass has proven effective in purifying eutrophic water, treating garbage leachates (Percy et al., 2005). Consequently, vetiver shows great potential for application in industrial wastewater treatment (Roongtanakiat et al., 2007).

Research has shown that many industries worldwide cannot afford costly conventional wastewater treatment methods like precipitation and ion exchange (Li et al., 2007). Even those that employ these methods often fail to fully eliminate toxic heavy metals from their effluents. Additionally, conventional treatment techniques generally exhibit limited efficiency at low heavy metal concentrations between 1 and 100 mg/L (Verma et al., 2006). This led to these industries channelling into the water resources, effluent full of heavy metals such as chromium, which is either partially treated or not treated at all. This situation highlights the urgent need for a cost-effective technique to eliminate harmful heavy metals such as chromium from wastewater before it is channeled into the receiving water. Therefore, this study assesses the efficiency of removing Cr(VI) in wastewater using lemon grass, elephant grass, and vetiver grass.

* 1. Materials and Methods
     1. Material and Chemicals

Potassium chromate (K₂CrO₄) was utilized to prepare synthetic Cr(VI) solutions. The 1,5-diphenylcarbazide (DPC) solution was prepared by dissolving a measured amount of DPC in HPLC-grade acetone and storing it in bottle wrapped in aluminum foil. Hydrochloric acid and sodium hydroxide were used for pH adjustment. Tap water was used to replenish the buckets, while distilled water was employed for water sample analysis.

* + 1. Lemon grass, Elephant grass, and Vetiver grass

Lemon grass was obtained from Mega Paint and Hardware in East gate, Johannesburg South Africa. Elephant grass was obtained from SMR Africa (Pty) Ltd in Bronkhorstspruit, South Africa, while Vetiver grass slips were obtained from Free Choice Progressive learning (Pty) Ltd, Vetiver grass South Africa in White River. The three grasses, which were initially grown in soil, were introduced to the water medium with careful handling to prevent root damage. They were cleaned and set aside in water for two weeks to acclimate. Chemical elements such as nitrogen, phosphorus, and potassium, which are used as nutrients, were introduced to support root and shoot growth to a length of 35 cm. After acclimatization, the shoot length was trimmed to 30 cm.

The grasses were then placed in 2 liters of Cr(VI) solution inside three transparent 5-liter buckets to begin the Cr(VI) removal efficiency experiment. Water level reductions over time were attributed to evaporation and plant uptake. To ensure that concentration changes were not caused by evaporation, water was replenished in each bucket before samples were taken, assuming the evaporated water did not have Cr(VI)

Analysis for the water sample was done every two days, whereas grass samples were gathered at a 10-day interval. The shoots and roots for each grass were carefully separated, thoroughly washed with tap water to remove any unwanted particles, and then rinsed again with distilled water. The washed shoots and roots for the 3 grasses were thoroughly dried at 60°C until all moisture is removed. The grinder and bowl were used to grid the dried shoots and roots.

10 mL of nitric acid and 2 drops of hydrogen peroxide were used to treat 0.1 g of each grass sample for a period of 2 days. Cr(IV) analysis was performed using a SPECTRO Analytical Instruments Genesis ICP-OES Spectrometer after the leachate was filtered through 0.45 μm syringe filters and diluted with 10 mL of distilled water.

The first phase of the study aimed to determine the impact of initial Cr(VI) concentrations on Cr(VI) uptake, chromium accumulation, and its effects on lemon grass, elephant grass vetiver grass growth. To achieve this, twelve 3-litre buckets containing 2-liter Cr(VI) solutions were prepared at initial concentrations of 5 ppm, 10 ppm, and 30 ppm with two slips of lemon grass, elephant grass, and vetiver grass, which were placed in each bucket. The experiment lasted for three months and was conducted in triplicate to minimize the impact of grass harvesting on Cr(VI) uptake rates.

The second phase focused on assessing the impacts of Cr(VI) uptake on the grass density of lemon, elephant, and vetiver grasses. Experiments were performed using 5 ppm, 10 ppm, and 30 ppm concentrations of Cr(VI) solutions in 3-liter buckets, with slip densities categorized into three groups: low (10 slips), medium (15 slips), and high (20 slips) of each grass. Cr(VI) uptake was analyzed by monitoring concentration changes in the buckets and chromium accumulation in different grass parts.

A group of plants in plastic containers

AI-generated content may be incorrect.  

**Lemon Grass Elephant Grass Vetiver Grass**

* + 1. Cr(VI) and total chromium (Cr) Measurement

Cr(VI) concentrations were determined using a UV-Vis spectrophotometer (Biochrom WPA, Light Wave II, Labotech, South Africa) at a wavelength of 540 nm. This measurement followed the reaction of an acidified sample (using 1 N H₂SO₄) with a 0.5% 1,5-diphenylcarbazide (DPC) solution, which produced a violet color in the presence of Cr(VI) (APHA, 2005). Trace amounts of total Cr in plant samples were analyzed using a SPECTRO Analytical Instruments Genesis ICP-OES Spectrometer.

* + 1. Removal Efficiency

Removal efficiency is the measure of the amount of metal removed from the solution. where C0 is the initial concentration of solution and Ct is the final concentration of solution at time t. It was calculated as follows:

* + 1. Bioaccumulation Factor

The Bioaccumulation factor indicates the plant’s ability to accumulate the metal relative to the metal concentration in the external solution. The BAF is an essential parameter for assessing a plant's ability to accumulate heavy metals like Cr(IV) from their surrounding environment. It is calculated using the following equation:

where Cp​ = Concentration of Cr(IV) in the 3 grases (mg/kg or μg/g) while Cw is the initial concentration of Cr(IV) in the wastewater (mg/L or μg/mL)

* 1. Results and Discussion
     1. Effects of varying Cr(VI) concentrations

The rhizofiltration efficiency of lemon grass, elephant grass and vetiver grass at varying Cr(VI) concentrations of 5ppm, 10ppm and 30ppm was assessed to determine the impact of concentration levels on Cr(VI) uptake and plant growth.

*Table 1: Initial Cr(VI) concentration of 5ppm with lemon, elephant and vetiver grass over 15 days*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Time (d)** | **Lemon Grass** | **Elephant Grass** | **Vetiver Grass** |  |  |  |
| **Day 1** | **5.00 (ppm)** | **5.00 (ppm)** | **5.00 (ppm)** |  |  |  |
| **Day 2** | **4.75 (ppm)** | **4.62 (ppm)** | **4.51 (ppm)** |  |  |  |
| **Day 3** | **4.42 (ppm)** | **4.24 (ppm)** | **4.05 (ppm)** |  |  |  |
| **Day 4** | **4.11 (ppm)** | **3.87 (ppm)** | **3.59 (ppm)** |  |  |  |
| **Day 5** | **3.80 (ppm)** | **3.49 (ppm)** | **3.13 (ppm)** |  |  |  |
| **Day 6** | **3.49 (ppm)** | **3.11 (ppm)** | **2.67 (ppm)** |  |  |  |
| **Day 7** | **3.18 (ppm)** | **2.75 (ppm)** | **2.21 (ppm)** |  |  |  |
| **Day 8** | **2.87 (ppm)** | **2.35 (ppm)** | **1.75 (ppm)** |  |  |  |
| **Day 9** | **2.56 (ppm)** | **1.97 (ppm)** | **1.29 (ppm)** |  |  |  |
| **Day 10** | **2.25 (ppm)** | **1.59 (ppm)** | **1.29 (ppm)** |  |  |  |
| **Day 11** | **1.94 (ppm)** | **1.21 (ppm)** | **1.16 (ppm)** |  |  |  |
| **Day 12** | **1.73 (ppm)** | **1.12 (ppm)** | **1.03 (ppm)** |  |  |  |
| **Day 13** | **1.53 (ppm)** | **1.03 (ppm)** | **0.90 (ppm)** |  |  |  |
| **Day 14** | **1.31 (ppm)** | **0.94 (ppm)** | **0.77 (ppm)** |  |  |  |
| **Day 15** | **1.10 (ppm)** | **0.84 (ppm)** | **0.62 (ppm)** |  |  |  |

*Figure 1. Shows Lemon grass, elephant grass and vetiver grass’s removal efficiency of Cr(VI)*

*Table 2: Initial Cr(VI) concentration of 10ppm with lemon, elephant and vetiver grasses over 15 days*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Time (d)** | **Lemon Grass** | **Elephant Grass** | **Vetiver Grass** |  |  |  |
| **Day1** | **10.00 (ppm)** | **10.00 (ppm)** | **10.00 (ppm)** |  |  |  |
| **Day 2** | **9.84 (ppm)** | **9.77 (ppm)** | **9.67 (ppm)** |  |  |  |
| **Day 3** | **9.76 (ppm)** | **9.53 (ppm)** | **9.34 (ppm)** |  |  |  |
| **Day 4** | **9.63 (ppm)** | **9.21 (ppm)** | **9.01 (ppm)** |  |  |  |
| **Day 5** | **9.51 (ppm)** | **9.08 (ppm)** | **8.68 (ppm)** |  |  |  |
| **Day 6** | **9.38 (ppm)** | **8.84 (ppm)** | **8.35 (ppm)** |  |  |  |
| **Day 7** | **9.23 (ppm)** | **8.61 (ppm)** | **8.02 (ppm)** |  |  |  |
| **Day 8** | **9.14 (ppm)** | **8.38 (ppm)** | **7.69 (ppm)** |  |  |  |
| **Day 9** | **9.05 (ppm)** | **8.13 (ppm)** | **7.36 (ppm)** |  |  |  |
| **Day 10** | **8.92 (ppm)** | **7.93 (ppm)** | **7.02 (ppm)** |  |  |  |
| **Day 11** | **8.78 (ppm)** | **7.69 (ppm)** | **6.70 (ppm)** |  |  |  |
| **Day 12** | **8.65 (ppm)** | **7.48 (ppm)** | **6.37 (ppm)** |  |  |  |
| **Day 13** | **8.52 (ppm)** | **7.25 (ppm)** | **6.04 (ppm)** |  |  |  |
| **Day 14** | **8.44 (ppm)** | **7.02 (ppm)** | **5.71 (ppm)** |  |  |  |
| **Day 15** | **8.33 (ppm)** | **6.79 (ppm)** | **5.38 (ppm)** |  |  |  |

*Figure 2. Shows Lemon grass, elephant grass, and vetiver grass removal efficiency of Cr(VI)*

*Table 3: Initial Cr(VI) concentration of 30ppm with lemon, elephant and vetiver grasses over 15 days*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Time (d)** | **Lemon Grass** | **Elephant Grass** | **Vetiver Grass** |  |  |  |
| **Day 1** | **30.00 (ppm)** | **30.00 (ppm)** | **30.00 (ppm)** |  |  |  |
| **Day 2** | **29.96 (ppm)** | **29.88 (ppm)** | **29.79 (ppm)** |  |  |  |
| **Day 3** | **29.91 (ppm)** | **29.77 (ppm)** | **29.56 (ppm)** |  |  |  |
| **Day 4** | **29.88 (ppm)** | **29.64 (ppm)** | **29.35 (ppm)** |  |  |  |
| **Day 5** | **29.83 (ppm)** | **29.52 (ppm)** | **29.13 (ppm)** |  |  |  |
| **Day 6** | **29.81 (ppm)** | **29.39 (ppm)** | **28.94 (ppm)** |  |  |  |
| **Day 7** | **29.76 (ppm)** | **29.28 (ppm)** | **28.82 (ppm)** |  |  |  |
| **Day 8** | **29.72 (ppm)** | **29.16 (ppm)** | **28.71 (ppm)** |  |  |  |
| **Day 9** | **29.67 (ppm)** | **29.05 (ppm)** | **28.59 (ppm)** |  |  |  |
| **Day 10** | **29.64 (ppm)** | **28.94 (ppm)** | **28.46 (ppm)** |  |  |  |
| **Day 11** | **29.59 (ppm)** | **28.76 (ppm)** | **28.34 (ppm)** |  |  |  |
| **Day 12** | **29.56 (ppm)** | **28.69 (ppm)** | **28.23 (ppm)** |  |  |  |
| **Day 13** | **29.53 (ppm)** | **28.54 (ppm)** | **28.11 (ppm)** |  |  |  |
| **Day 14** | **29.47 (ppm)** | **28.41 (ppm)** | **27.99 (ppm)** |  |  |  |
| **Day 15** | **29.43 (ppm)** | **28.32 (ppm)** | **27.85 (ppm)** |  |  |  |

*Figure 3. Shows Lemon grass, elephant grass and vetiver grass’s removal efficiency of Cr(VI)*

Figures 1-3 illustrate Cr(VI) removal at varying concentrations over a 15-days period. At an initial concentration of 5 ppm, Cr(VI) levels decreased to 1.10 ppm for lemongrass, 0.84 ppm for elephant grass, and 0.62 ppm for vetiver grass, corresponding to removal efficiencies of 78%, 83.2%, and 87.6%, respectively. At the second concentration of 10 ppm, Cr(VI) levels dropped to 8.33 ppm for lemongrass, 6.79 ppm for elephant grass, and 5.38 ppm for vetiver grass, reflecting removal efficiencies of 16.7%, 32.1%, and 46.2%, respectively. For the highest concentration of 30 ppm, Cr(VI) levels decreased slightly to 29.43 ppm for lemongrass, 28.32 ppm for elephant grass, and 27.85 ppm for vetiver grass, indicating removal efficiencies of 1.9%, 5.6%, and 7.2%, respectively. These results align with previous research findings, confirming that Cr(VI) removal efficiency is significantly higher at lower concentrations, while a noticeable decline in efficiency occurs as Cr(VI) concentrations increase

* 1. Conclusion

This research supports Sustainable Development Goals (SDG) 6 and 14. SDG 6 targets to ensure the supply and sustainable control of water and sanitation for all, while SDG 14 pursues to preserve and sustainably use the oceans, seas, and marine resources for sustainable development.

Lemon grass, elephant grass, and vetiver grass exposed to lower Cr(VI) concentrations of 5 ppm exhibited increased chromium uptake. This enhanced absorption is likely due to the greater mobility of Cr ions from the dilute Cr(VI) solution to the root cell walls via a diffusion-driven, non-metabolic, and passive process. However, at higher Cr(VI) concentrations of 10 ppm and 30 ppm, all three grasses showed a decline in chromium uptake. This reduction is attributed to the toxic effects of chromium, which cause early plant desiccation, ultimately halting Cr(VI) absorption.

Among the three species, vetiver grass demonstrated the highest removal efficiency, achieving rates of 87.6%, 46.2%, and 7.2% at Cr(VI) concentrations of 5 ppm, 10 ppm, and 30 ppm, respectively. Elephant grass followed with removal efficiencies of 83.2%, 32.1%, and 5.6%, while lemongrass showed the lowest rates at 78%, 8.33%, and 1.9% for the same concentration levels. Further research is recommended on a pilot scale, involving similar experiments on soil not previously exposed to any of these grasses, to better evaluate their treatment performance in more natural conditions.

* 1. Acknowledgments

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