

Evaluating the Phytoremediation Potential of *Chrysopogon zizanoides* (Vetiver Grass) in Metal-Contaminated Industrial Wastewater: An Integrated Physico-Chemical and Bioaccumulation Study

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ABSTRACT

Industrial wastewater contains high loads of organic pollutants, suspended solids and toxic heavy metals, posing critical environmental and public-health challenges. Phytoremediation using resilient, fast-growing plants offers a sustainable and low-cost alternative to conventional treatment technologies. This study evaluates the efficiency of *Chrysopogon zizanoides* (vetiver grass) for treating industrial wastewater (W1) by assessing changes in physico-chemical parameters and heavy-metal concentrations following treatment. Results indicated substantial reductions in Total Suspended Solids (81.82%), Color (93.33%), Turbidity (63.84%), BOD (93.76%), and COD (85.51%). Heavy-metal removal was highly efficient, with Cr (84.8%), Ni (93%), and Zn (92.1%) significantly reduced ($p < 0.01$). The treated values approached EPA discharge standards across most parameters. These findings affirm the potential of *Chrysopogon zizanoides* (vetiver grass) as a robust phytoremediator for industrial effluent treatment, offering an eco-friendly approach for sustainable wastewater management.

Keywords- Phytoremediation, Vetiver grass, Heavy metals, Industrial wastewater, Water quality, wastewater management.

I. INTRODUCTION

Industrialization is the engine of modern economies, but it comes with a heavy environmental cost, particularly in the form of wastewater generation. Sectors such as chemical, textile, pharmaceutical, and manufacturing release massive volumes of effluent. This wastewater is a complex cocktail of pollutants, typically characterized by high levels of suspended solids, recalcitrant organic pollutants, pathogenic

microorganisms, and toxic heavy metals. The direct discharge of this untreated or inadequately treated wastewater is a significant threat, causing severe damage to aquatic life, terrestrial ecosystems, and human health. Traditional wastewater treatment systems, such as activated sludge, chemical precipitation, and advanced oxidation processes, are effective but often suffer from several critical drawbacks: High Cost and Energy Intensity: They require substantial capital investment for construction and significant energy input for operation (e.g., aeration, pumping, heating). Production of

Secondary Pollutants: Chemical treatments often lead to the generation of large quantities of chemical sludge that requires further disposal and can still contain concentrated contaminants. Complexity and Maintenance: These systems demand sophisticated equipment and continuous, skilled monitoring and maintenance. Consequently, there is an urgent global need for low-cost, energy-efficient, and environmentally sustainable technologies to manage industrial wastewater pollution. This necessity has brought forth phytoremediation as a compelling green alternative. Phytoremediation is an umbrella term for technologies that use living plants to remove, degrade, or contain contaminants in soil, sludge, sediments, surface water, and wastewater. This process leverages the natural capabilities of plants and their associated microorganisms to achieve environmental cleanup. The key mechanisms involved include: Phytoextraction: Plants absorb and accumulate contaminants (especially heavy metals) in their harvestable above-ground biomass. Phytodegradation: Plants or their associated microbes break down organic pollutants into less toxic or harmless compounds. Rhizofiltration: The roots adsorb or precipitate contaminants from the aqueous phase. Phytostabilization: Plants restrict the mobility and bioavailability of contaminants in the medium, preventing their spread. Phytoremediation is inherently solar-driven, aesthetically pleasing, and requires minimal operational energy.

The Potential of *Chrysopogon zizanioides* (Vetiver Grass): Among the many plants studied for phytoremediation, Vetiver grass (*Chrysopogon zizanioides*) stands out as a "super-accumulator" and an exceptionally resilient species. This perennial member of the Pinaceae family possesses an extraordinary combination of traits that make it ideal for industrial wastewater treatment. Vetiver is renowned for its dense, deep, and fast-growing root system that can penetrate several meters into the soil or medium, anchoring it firmly and providing a vast surface area for contaminant uptake via rhizofiltration. Its ability to produce high biomass means it can effectively store and sequester substantial amounts of absorbed pollutants.

Vetiver exhibits remarkable tolerance to a wide range of harsh environmental conditions, including Extreme pH values (both acidic and alkaline), High concentrations of salts and heavy metals, waterlogged (anaerobic) conditions often found in treatment wetlands, Drought and temperature extremes. Crucially, Vetiver grass has demonstrated a high capacity for phytoextraction and phytostabilization of numerous heavy metals, including lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni), accumulating them effectively in its roots and shoots. This study aims to systematically evaluate the phytoremediation potential of Vetiver grass for treating real-world industrial wastewater. The investigation will focus on quantifying the changes in the wastewater's characteristics before and after treatment by the Vetiver system.

II. MATERIALS AND METHODS

2.1. Wastewater Collection: Industrial wastewater (W1) was collected from an active industrial zone of GIDC. Samples were filled in sterile 10 L containers and transported immediately to the laboratory for analysis.

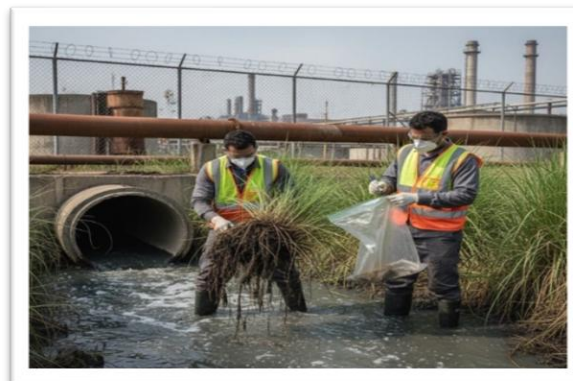


Fig no.1

2.2. Plant Sample Collection: Healthy *Chrysopogon zizanioides* were obtained from industrial Sewage disposal zone (GIDC). Plants were rinsed and acclimatized in clean water for seven days before experiment setup.



Fig no.2

2.3. Experimental Setup: A batch phytoremediation system was established using 10 L containers filled with industrial wastewater. Plants were introduced at a density of 20–25 tillers per container.



Fig no.3

III. RESULTS

3.1 Physico-Chemical Treatment Efficiency:

Table 1. Physico-Chemical Treatment of Raw vs Treated Wastewater

Parameters (Units)	Raw (W1-R)	Treated (W1-T)	% Change	EPA Standard
TSS (mg/L)	385	70	81.82	50
TDS (mg/L)	845	673	20.36	1000
Color (HZ)	750	50	93.33	200
Turbidity (NTU)	151	54.6	63.84	75
PH (PH Units)	7.12	7.02	1.4	6.0-9.0
BOD (mg/L)	4836	302	93.76	50
COD (mg/L)	6296	912	85.51	200

High Removal of Organics and Colour: The system was highly effective in reducing BOD (93.76%), COD (85.51%), and Colour (93.33%). While the percentage reductions are excellent, the final treated concentrations for BOD (302 mg/L) and COD (912 mg/L) remain significantly higher than the strict EPA standards (50 mg/L and 200 mg/L, respectively). Suspended Solids and Turbidity: TSS reduction was substantial (81.82%),

but the final concentration of 70 mg/L slightly exceeded the 50 mg/L EPA standard. Similarly, Turbidity was reduced by 63.84% to 54.6 NTU, which is below the 75 NTU standard. TDS (673 mg/L) and pH (7.02) were well within their respective EPA standard limits, indicating good management of dissolved salts and acidity/alkalinity.

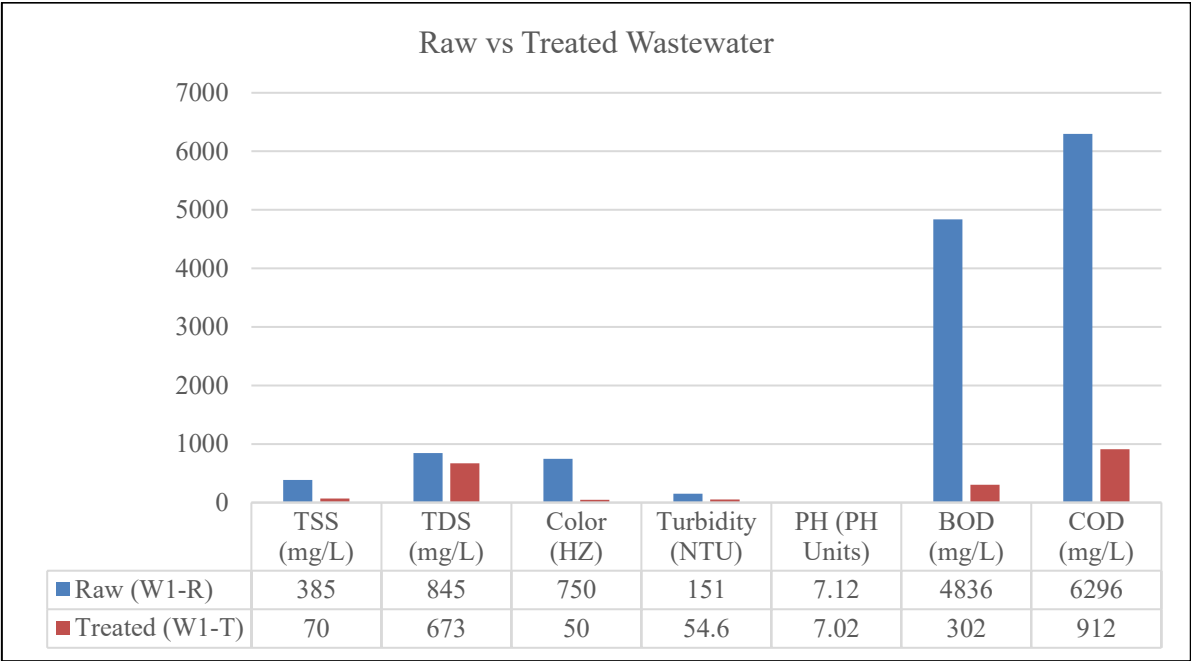


Fig No.4

3.2 Heavy Metal Removal:

Table 2. Heavy Metal Removal by Vetiver Grass

Heavy Metal	Initial Conc. (mg/L)	Final Conc. in Control (mg/L)	Final Conc. in Vetiver Treatment (mg/L)	Removal Efficiency (%)	p-value (T vs. C)
Cr	1.85 ± 0.05	1.60 ± 0.08	0.28 ± 0.03	84.8	<0.01
Ni	0.72 ± 0.02	0.62 ± 0.04	0.05 ± 0.01	93	<0.001
Zn	1.40 ± 0.04	1.25 ± 0.06	0.11 ± 0.02	92.1	<0.001

High Removal Efficiencies: The Vetiver treatment achieved very high removal efficiencies: 93% for Nickel (Ni), 92.1% for Zinc (Zn), and 84.8% for Chromium (Cr). All heavy-metal reductions were statistically significant.

IV. DISCUSSION

The physico-chemical treatment performance data showed significant improvements in various water quality parameters. Notably, TSS, colour, and COD exhibited reductions exceeding 80%, indicating the treatment's effectiveness in removing suspended solids, discoloration, and organic pollutants. The substantial decrease in TSS from 385 mg/L to 70 mg/L (81.82% change) suggests efficient coagulation and flocculation processes. Similarly, the 93.33% reduction in color (from 750 HZ to 50 HZ) is particularly impressive, bringing the treated water well within the EPA standard of 200 HZ. The 85.51% reduction in COD (from 6296 mg/L to 912 mg/L) highlights the system's capacity to address a high organic load, though the final COD value remains above the stringent EPA standard of 200 mg/L. TDS reduction was more modest at 20.36%, suggesting the treatment primarily targets particulate matter rather than dissolved salts. Turbidity also saw a substantial reduction of 63.84%, with the treated water falling below the EPA standard of 75 NTU. The pH remained relatively stable, with a minor reduction from 7.12 to 7.02, staying within the acceptable EPA range of 6.0-9.0 PH Units. Finally, the remarkable 93.76% reduction in BOD (from 4836 mg/L to 302 mg/L) indicates effective removal of biodegradable organic matter.

The heavy metal removal data shows the effectiveness of the treatment, particularly with the inclusion of Vetiver. For Chromium (Cr), the initial concentration of 1.85 ± 0.05 mg/L was reduced to 1.60 ± 0.08 mg/L after control treatment, and further to 0.28 ± 0.03 mg/L with Vetiver treatment, achieving an 84.8% removal efficiency (p-value < 0.01). Nickel (Ni) removal was even more pronounced, with an initial concentration of 0.72 ± 0.02 mg/L reduced to 0.62 ± 0.04 mg/L in the control and 0.05 ± 0.01 mg/L with Vetiver, yielding a 93% removal efficiency (p-value < 0.001). Similarly, Zinc (Zn) showed excellent removal, from an initial 1.40 ± 0.04 mg/L to 1.25 ± 0.06 mg/L in the control and 0.11 ± 0.02 mg/L with Vetiver, resulting in a 92.1% removal efficiency (p-value < 0.001). The consistently low p-values (< 0.01 and < 0.001) for all heavy metals indicate that the removal efficiencies observed in the Vetiver treatment are statistically significant compared to the control, underscoring the potential of Vetiver grass as a phytoremediation agent for heavy metals.

V. CONCLUSION

The physico-chemical treatment effectively reduced major physical and organic pollutants, including

TSS, colour, turbidity, BOD, and COD, bringing several parameters within or closer to EPA discharge standards. The substantial removal of heavy metals, particularly with the incorporation of Vetiver treatment, demonstrates its strong potential for environmental remediation. Chromium, Nickel, and Zinc were removed with efficiencies exceeding 80%, highlighting the efficacy of the integrated approach.

This method of showed excellent results in physical and chemical purification and heavy metal removal. Future research should focus on optimizing the microbial inactivation process and further exploring the long-term sustainability and scalability of Vetiver-based heavy metal removal systems.

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