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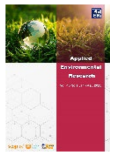

Research Article

Chromium Removal from Tannery Wastewater via a Hydroponic Technique with Vetiver Grass (*Vetiveria zizanioides*)

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Abstract

This research aimed to investigate the effects of hydroponically cultivated vetiver grass (*Vetiveria zizanioides*) on the treatment of tannery wastewater for chromium (Cr) removal in Bangladesh. The field experiment involved 9 containers, which were separated into 3 groups: tannery wastewater with hydroponically planted vetiver, tannery wastewater without vetiver (control), and a group with vetiver grown in tap water. The tap water group was used solely for plant growth assessment, whereas only the control and hydroponic vetiver groups were evaluated for Cr and water quality parameters. Throughout the 45-day trial period, Cr and other water quality parameters were analyzed at 15-day intervals. The findings showed that the floating platform method of cultivating vetiver grass was significantly effective ($p<0.05$) in eliminating pollutants. The observed reduction rate for pH was 15.19%, whereas the treatment efficiencies for electrical conductivity, biological oxygen demand, chemical oxygen demand, turbidity, total suspended solids, total dissolved solids, and Cr were 35.42%, 84.66%, 81.21%, 33.17%, 83.28%, 72.55%, and 79.71%, respectively. With respect to plant growth, vetiver grass is well established and thrives in tannery wastewater, achieving a root length of 22.5 cm after 45 days. Most contaminants significantly decreased ($p<0.05$) after treatment and were below the maximum permissible discharge limits, with only a few parameters remaining above the standards. The results provide evidence to support extensive research and application of the vetiver hydroponic technique as a cost-effective wastewater treatment method in Bangladesh.

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Introduction

Clean water scarcity is a pressing concern in the 21st century and is aggravated by industrial pollution. In Bangladesh, the tannery industry is one of the sectors with the greatest degree of pollution. Substantial amounts of chemicals are used at every step of leather processing [1]. In Bangladesh, almost 90% of tanneries use the chrome tanning process, as it is faster than the vegetative tanning process [2]. The chrome tanning process releases approximately 40% of leftover chromium (Cr) salts into final run-offs, posing a significant ecological risk [2]. During the tanning process, chrome salts are partially bound by the skins, leaving nearly 30% of the original amount of spent tanning solution [3]. According to the World Health Organization (WHO), Cr is widely distributed in the Earth's crust and has various valences, with a provisional guideline value of 50 μg L^{-1} for total Cr in drinking water due to toxicological uncertainties [4]. Furthermore, Cr in the environment ranges from 1 to 100 mg kg^{-1} in soil, with levels above 100 mg kg^{-1} considered hazardous, especially because of the toxicity of hexavalent Cr (Cr(VI)). Exposure to Cr is variable, with higher risks near industrial sites [5]. Excessive Cr exposure can cause vertigo, skin or lung rashes, hypersensitivity, liver disease, and harm to the kidneys or nervous system [6]. In the tanning process, a large amount of water is

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needed, but most of this water is wasted unevenly, and approximately 90% of it is released as effluent [2]. Tannery discharges are a significant source of organic and inorganic contaminants, including Cr salts, hazardous metals, colored chemicals, sodium chloride, sulfate, and oxidizable tanning ingredients [7]. Therefore, before being released into natural water sources, wastewater must be properly treated.

The traditional treatment method involves excessive running and maintenance expenses. Cr-contaminated wastewater is commonly treated by chemical precipitation, which converts Cr into insoluble compounds; ion exchange, which uses resins to extract Cr ions; and adsorption, which involves the binding of Cr to materials such as activated carbon. These methods are typically more costly than biological treatment techniques. Chemical precipitation and ion exchange are expensive for chemicals, resins, and equipment maintenance. Higher expenses are also associated with adsorption via materials such as activated carbon because material replacement or regeneration is needed [8-9]. Therefore, efforts are being made to employ natural devices as environmentally sound techniques for treatment. Several studies have investigated the use of a variety of technologies, such as phytoremediation, electroflotation, electrochemical treatment, sedimentation, coagulation, and filtration, to treat tannery wastewater [10–13]. Phytoremediation is one of the most fruitful methods among them. It is an effective biotechnological method that uses plants to extract and remove complex contaminants from soil or water [14]. This method can treat various types of wastewaters, including industrial effluents, with biodegradable organic materials and heavy metals. Its applications include the treatment of eutrophic water, wastewater from pig farms, and sludge from garbage [15]. One of the macrophytes utilized in phytoremediation is vetiver grass (*Vetiveria zizanioides*) [16]. This vigorous plant can thrive in a variety of environments, making it a useful tool for phytoremediation [16]. Vetiver grass has shown potential in managing and treating contaminated water, rehabilitating contaminated soils, protecting infrastructure, and stabilizing land [17]. The use of vetiver grass for effective wastewater treatment represents a unique approach to phytoremediation [18]. The remaining product after treatment, i.e., leaves, roots, and shoots, can be used for a variety of purposes, such as handicrafts, organic farming material, and feed for animals [19]. Vetiver, despite not being a hydrophyte, thrives in moist, waterlogged environments and can grow submerged for extended periods [20]. Hydroponics, a soil-less cultivation method, is gaining interest from commercial enterprises and the scientific community because of its easy implementation process for phytoremediation [21].

Numerous studies worldwide have explored various technologies for treating tannery wastewater, with some focusing on removing Cr from sugarcane via sawdust treated with formaldehyde and charcoal [22]. Several authors have explored the treatment of tannery wastewater through methods such as filtration, ultrafiltration, reverse osmosis, and coagulation [23–24]. Only a handful of studies have focused on the bioremediation of tannery wastewater [25–26]. However, much of the work done in Bangladesh on tannery effluents has focused on characterizing and assessing their effects [27–29]. In Bangladesh, no one has investigated sustainable and economically viable treatment techniques for tannery effluents. Thus, this research is the first attempt to analyze the efficiency of vetiver grass in treating tannery effluent for Cr removal in Bangladesh. Although there are alternative sophisticated treatment methods globally, this study opted for a low-cost methodology to treat tannery wastewater, taking careful consideration of Bangladesh's socioeconomic circumstances.

Materials and methods

1) Experimental site

The hydroponic vetiver treatment of the tannery wastewater field trial setup was located at Sultana Razia Hall, Bangladesh Agricultural University (BAU), Mymensingh. Positioned on the western bank of the ancient Brahmaputra River, the campus area was over 1200 acres and 120 km north of Dhaka, the capital city of Bangladesh.

2) Wastewater collection

Tannery wastewater was collected from the Savar Central Effluent Treatment Plant of Tannery Industries, which is located in Chamra Shilpo Nogori, Horindhora, Hemyaetpur, Savar (Figure 1). The water was collected in containers that were properly washed and dried prior to collection. The water was brought to the Analytical and Microbiology Laboratory at the Interdisciplinary Institute for Food Security (IIFS), BAU, Mymensingh.

3) Planting materials and experimental setup

First, vetiver slips were collected from vetiver hedge-rows naturally growing on the bank of the Brahmaputra River, Mymensingh, Figure 2(a). The plants were cut at a length of approximately 25 cm, and the roots were cut to 5 cm. The collected slips with 2 tillers (obtained by splitting full-grown vetiver plants) were disinfected and rinsed with distilled water. The plants were grown in small pot bags with sandy soil for three months for multiplication purposes. Once the roots were established, the plants developed quickly. Three-month-old bare-rooted vetiver grass was uplifted, as shown in Figure 2(b). The clumps were carefully split into four tillers to prevent damage. To maintain a length of 10 cm, the roots and shoots were pruned. The use of the hydroponic vetiver technique for treating wastewater began once the vetiver plants reached maturity for three months. Clumps of vetiver same size bare-rooted grass were lifted from potting bags for treatment purposes. The clumps were gently divided into four tillers, and any adhering soil was carefully removed. The collected tannery wastewater was placed into six 15-L plastic containers with dimensions of approximately 30 cm in height and 25 cm in diameter. The vetiver plants were then placed in containers, with the water depth maintained at approximately 25 cm to ensure adequate root submersion while leaving space for plant growth. Three containers were filled with fresh tap water. Polypropylene sheets of the same size with four holes were placed on six (three poured with wastewater and three with freshwater) container surfaces as a floating stage to aid the plants. The plants were set into poly-propylene sheet holes, with roots of approximately 10 cm immersed in tannery wastewater. Each hole was equipped with a sponge designed to firmly hold the vetiver in place (Figure 3). The plants were subsequently grown for 45 days. Three experimental setups were used: three containers with vetiver in wastewater for experimental purposes, three containers with wastewater but no plants marked as controls, and three containers with vetiver in tap water for comparison of plant growth. At the end of the 45-day experiment, the length of the vetiver roots was recorded (Figure 4).

Figure 1 Wastewater collection area in Savars.

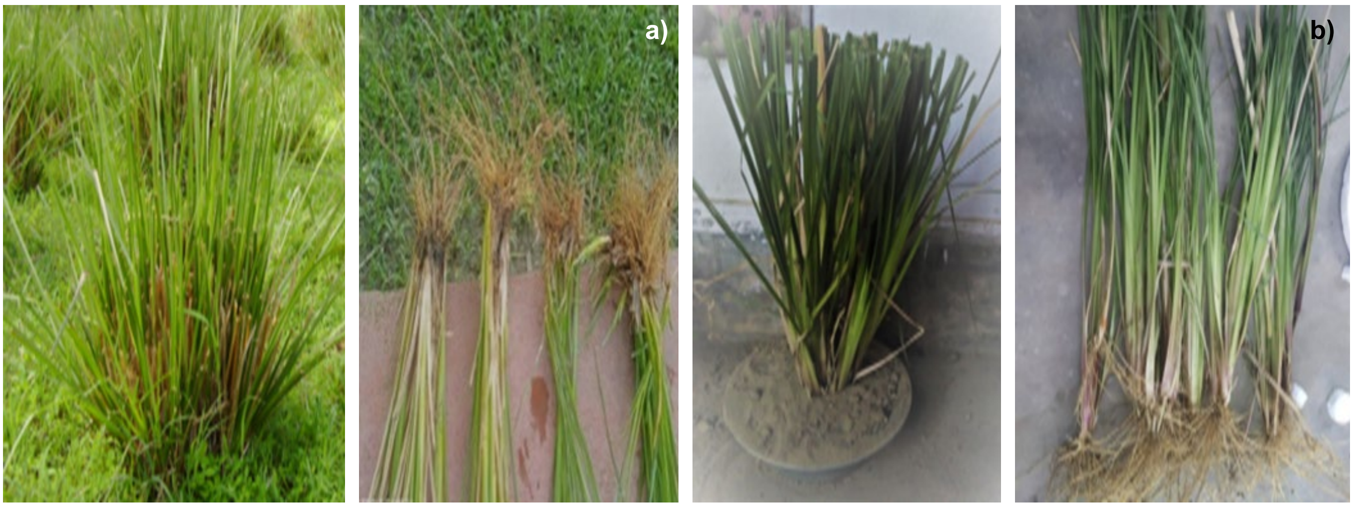


Figure 2 Vetiver grass propagation for treatment system including a) bare-rooted vetiver slips uplifted and transported to the field at Sultana Razia Hall and b) three months old vetiver for wastewater treatment application.

Figure 3 Hydroponic experimental sets.

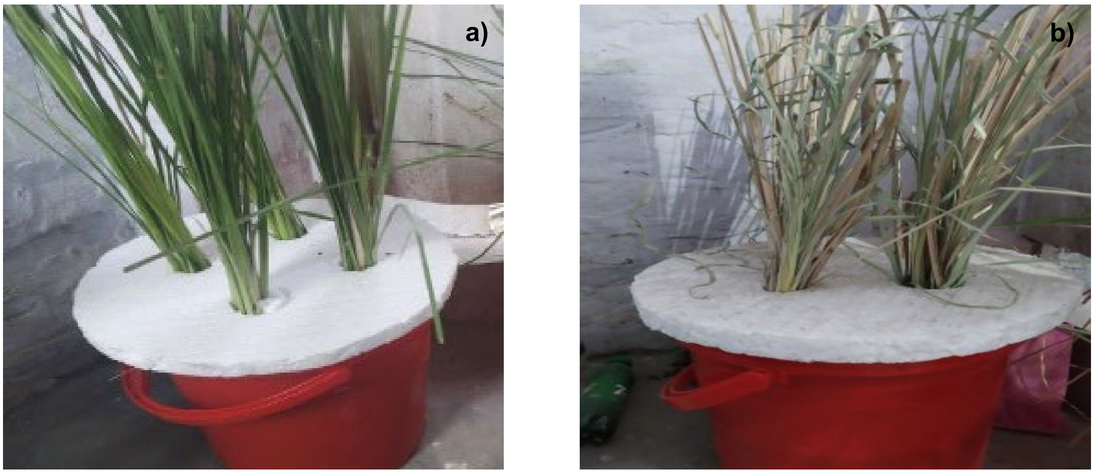


Figure 4 Vetiver plants after 45 days of experimental period including a) vetiver submerged in wastewater and b) vetiver submerged in tap water

4) Water quality analyses

The evaluation of the treatments involved the determination of the consistently recorded parameters collected at midnight. The samples were collected by immersing a 100 mL graduated cylinder at three locations across the surface of the container and then pooling them together. Samples were taken from each container of wastewater four times over 45 days: on days 0, 15, 30, and 45. Wastewater quality analyses were performed at the Laboratory of Environmental Engineering under the Department of Farm Structure and Environmental Engineering as well as at the Analytical and Microbiology Laboratory of the IIFS, BAU, Mymensingh.

The analysis of water parameters followed established protocols and standardized procedures. The pH, electrical conductivity (EC), and dissolved oxygen (DO) content were determined through direct measurement. To determine the pH, a pH meter was used (Model: EUTECH pH 2700). An EC meter was used to analyze the EC (Model: EUTECH CON 2700). A turbidimeter was used to measure turbidity. A DO meter (Model: Hanna HI98193) was used to determine the DO concentration. The biological oxygen demand (BOD) was measured via the dilution method. The method involved diluting wastewater samples with aerated distilled water, followed by incubation for five days at 20°C. The DO values were measured before and after this incubation period. The BOD was then calculated on the basis of the change between the initial and final DO concentrations. To determine the chemical oxygen demand (COD), the closed tube reflux method was used [30]. The total dissolved solids (TDS) and total suspended solids (TSS) were measured via the gravimetric approach [31]. The Cr content was measured via an atomic absorption spectrophotometer (Model: HACH DR 3900) in the IIFS laboratory.

The following formula given by Boonsong and Chansiri [32] was used to calculate the removal efficiency of the treatment system.

$$\% \text{ Removal Efficiency} = \left(\frac{C_{inf} - C_{eff}}{C_{inf}}\right) \times 100 \qquad \text{(Eq. 1)}$$

Here, C_{inf} is the initial concentration, and C_{eff} is the final concentration.

Figure 5 below presents a flowchart outlining the methodology for a visual representation of the process.

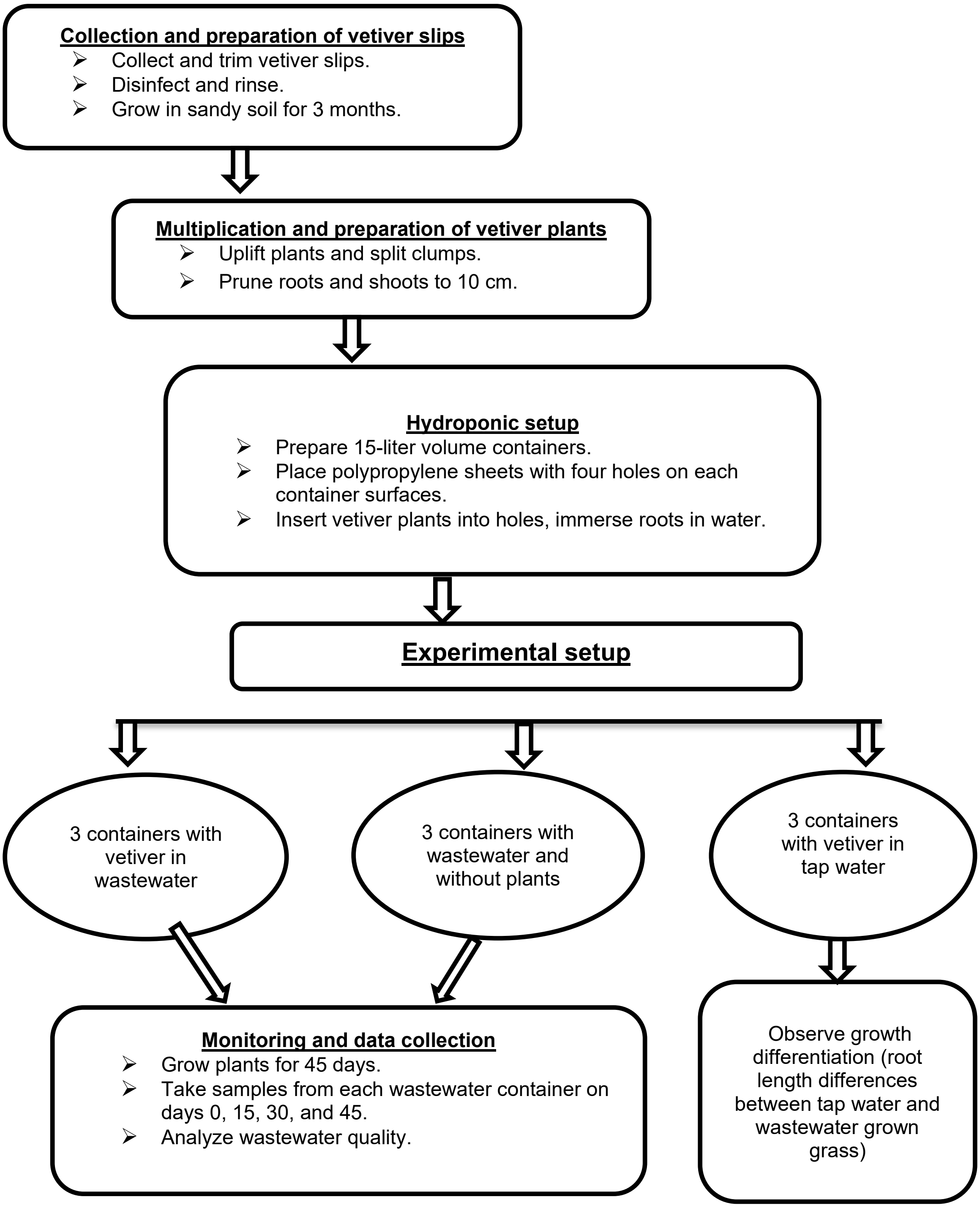


Figure 5 Flowchart of vetiver preparation and setup for phytoremediation.

5) Statistical analysis

Using the statistical program SPSS, the experimental data were statistically analyzed to determine the effects of the treatments and other factors via two-way ANOVA. The interpretation of the data was performed via the significance difference value calculated at the 0.05 significance level.

Results and discussion

1) Physicochemical characterization of tannery wastewater

As shown in Table 1, the pH of the untreated wastewater varied between 8.30 and 8.41, with an average of 8.36±0.03. This value falls within the acceptable range for inland water as defined by the Department of Environment, Bangladesh (DoE, BD), the National Environmental Quality Standards for municipal and liquid industrial effluents (NEQS), and the WHO [29, 33–34]. Owing to the use of lime, Na_2CO_3, Na_2S, and NaOH during the tanning process, wastewater has an alkaline nature [29]. A relatively high EC indicates that adequate quantities of salts and both inorganic and organic compounds are present, which may have increased the EC of the effluent samples [35]. The mean EC was far greater than the allowable limit, indicating an extremely toxic habitat for aquatic organisms. In the Hazaribagh region, the EC value varied between 587 and 19000 μS cm^{-1}, which aligns with the findings of the present research [36]. The DO levels ranged from 1.87 to 1.91 mg L^{-1}, with an average of 1.89±0.01 mg L^{-1}, much lower than the recommended standards [33-34]. Poor DO values indicate high levels of organic pollutants in wastewater, potentially harming aquatic life, whereas high BOD_5 values indicate severe pollution and poor oxygen availability for organisms [37]. The average concentration of COD found in the wastewater was 1869.67±1.76 mg L^{-1}, which was nine times greater than the DoE discharge guidelines. The TSS value of the tannery wastewater exceeded the prescribed permissible limit, indicating that massive amounts of suspended solids were present in the wastewater [29]. The high TDS value, which ranged from 6,704 to 6,708 mg L^{-1}, also exceeded permissible limits, indicating substantial levels of dissolved solids. According to Rouf et al. [38], wastewater samples from separate locations inside the Hazaribagh tannery industrial zone had a TDS value of 3,455 mg L^{-1}, which was two times lower than the TDS concentration in this study. The average concentration of Cr found in the wastewater was 7.69± 0.02 mg L^{-1}. Coincidentally, Jahan et al. [34] reported comparable results for Cr concentrations in tannery effluents. A high concentration of Cr may have been caused by wastewater from tanneries that were high in chrome [29]. For this reason, treatment must be performed before this wastewater can be released into the environment.

2) Impact of vetiver grass treatment on wastewater properties

This study assessed the efficacy of vetiver grass in treating tannery wastewater by collecting samples every fifteen days over a 45-day period. Table 2 shows significant differences (p<0.05) in the mean contaminant concentrations of the tannery wastewater observed throughout the 45-day experimental duration.

2.1) pH

Throughout the experiment, the pH values were recorded in a time series, with the lowest value of 7.09±0.01 and the highest value of 8.36±0.03. In the vetiver settings, the pH values were significantly lower (p<0.05) during the experimental period than in the control sets. The analysis revealed that there was no significant change in the pH value of wastewater without vetiver. This might have resulted from a faster rate of organic decomposition, as indicated by the higher rates of BOD and COD removal, which produced CO_2 and acid and reduced the pH of the wastewater in vetiver settings [39]. After 45 days, the maximum pH reduction observed was 15.19% (Figure 6).

2.2) Electrical conductivity

A substantial decrease (p<0.05) in the average EC value was observed in the hydroponic treatment group compared with the control group. After 45 days of hydroponic treatment, the EC decreased from 12,900± 20.82 μS cm^{-1} to 8,330.33±51.41 μS cm^{-1}. A reduction was noted from 12,900±20.82 μS cm^{-1} to 11.09% after 15 days, 31.78% after 30 days, and 35.42% after 45 days of hydroponic treatment (Table 2 and Figure 6). The decrease in the EC value was due to the absorption of dissolved ions by the vetiver grass during the hydroponic treatment. As the plants took up nutrients and ions from the wastewater for their growth, the total concentration of these dissolved components in the water decreased, resulting in a lower EC. This process reveals the plant's effectiveness in reducing pollutants and improving water quality. In each hydroponic treatment, the vetiver sets' EC values were lower than those of the control sets. The EC value of the control set did not significantly change (p>0.05) until the 15-day period. After that, there was a slight decrease in the EC value, which was significantly lower than that of the vetiver set.

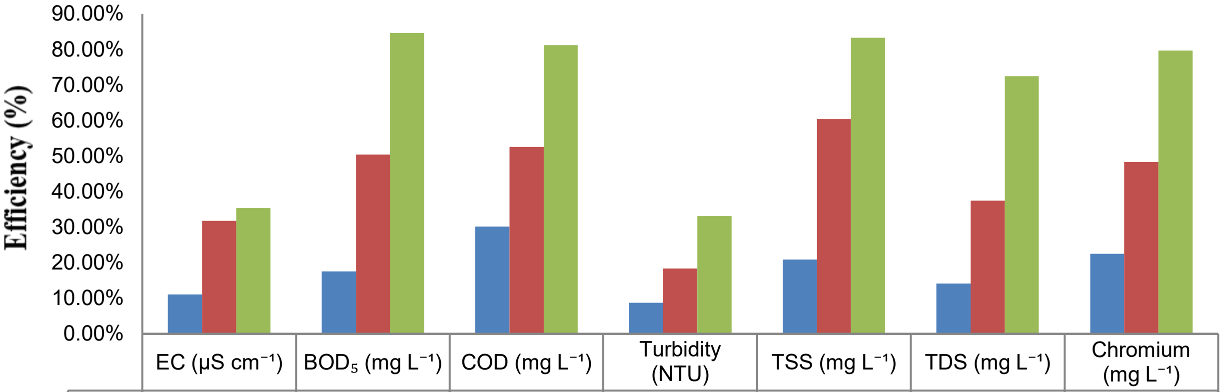
Table 1 Physicochemical parameters of tannery industrial wastewater and permissible values

Parameters	Mean	Standards		
		DoE [29]	NEQS [33]	WHO [34]
pH units	8.36±0.03	6-9	6-9	5.5-9
EC (μS cm^{-1})	12,900±20.82	1,200	288	1,200
DO (mg L^{-1})	1.89±0.01	4-6	4-6	4.5
BOD (mg L^{-1})	1,290.33±1.45	50	50	30
COD (mg L^{-1})	1,869.67±1.76	200	200	250
Turbidity (NTU)	550.67±1.20	5-25	-	-
TSS (mg L^{-1})	1,230.33±1.76	150	150	600
TDS (mg L^{-1})	6,706±1.15	2,100	3,500	2,100
Cr (mg L^{-1})	7.69±0.02	0.05-1.00	-	0.05

Table 2 Changes in the mean concentrations of Cr and other physicochemical parameters of tannery wastewater from the control units and hydroponic treatment units featuring vetiver grass cultivation

Variable	Control				Vetiver				*p* value		
	D_0	D_15	D_30	D_45	D_0	D_15	D_30	D_45	Treatment	Days	T × D[1]
pH	8.36±0.03[a]	8.26±0.04[a]	8.25± 0.04[a]	8.23±0.02[a]	8.36±0.03[a]	7.97±0.01[b]	7.56±0.02[c]	7.09±0.01[d]	<0.001	<0.001	<0.001
EC (μS cm^{-1})	12,900±20.82[a]	12,860±3.79[a]	12,640.33 ±70.57[b]	12,410.33 ±15.17[c]	12,900 ±20.82[a]	11,469.67 ±25.30[d]	8,800 ±10.15[e]	8,330.33 ±51.41[f]	<0.001	<0.001	<0.001
DO (mg L^{-1})	1.89±0.01[g]	3.47±0.01[e]	5±0.07[c]	5.93±0.01[a]	1.89±0.01[g]	2.91±0.02[f]	4.40±0.01[d]	5.20±0.02[b]	<0.001	<0.001	<0.001
BOD (mg L^{-1})	1,290.33 ±1.45[d]	1,479.67 ±0.88[a]	1,354.67 ±1.45[b]	1,320.67 ±1.76[c]	1,290.33 ±1.45[d]	1,063.33 ±0.88[e]	639.67 ±1.45[f]	198 ±1.53[g]	<0.001	<0.001	<0.001
COD (mg L^{-1})	1,869.67 ±1.76[c]	2,310.33 ±2.33[a]	1,997.33 ±2.03[b]	1,690 ±2.08[d]	1,869.67 ±1.76[c]	1,304.67 ±1.20[e]	886±1.73[f]	351.33 ±1.76[g]	<0.001	<0.001	<0.001
Turbidity (NTU)	550.67 ±1.20[a]	540.33 ±1.76[b]	523.67 ±1.76[c]	497.67 ±2.40[d]	550.67 ±1.20[a]	502.33 ±1.76[d]	449.67 ±2.33[e]	368±0.57[f]	<0.001	<0.001	<0.001
TSS (mg L^{-1})	1,230.33 ±1.76[a]	1,215.67 ±2.03[b]	1,197 ±1.15[c]	1,173.33 ±2.03[d]	1,230.33 ± 1.76[a]	973±2.52[e]	486.33 ±2.85[f]	205.67 ±1.86[g]	<0.001	<0.001	<0.001
TDS (mg L^{-1})	6,706 ±1.15[a]	6,558 ±2.08[b]	6,299.33 ±5.55[c]	6,101.33 ±4.48[d]	6,706±1.15[a]	5,754.33 ±1.76[e]	4,193.67 ±2.85[f]	1,840.67 ±1.86[g]	<0.001	<0.001	<0.001
Cr (mg L^{-1})	7.69±0.02[a]	7.58±0.01[a]	6.87±0.02[b]	6.12±0.03[c]	7.69±0.02[a]	5.96±0.03[d]	3.97±0.04[e]	1.56±0.02[f]	<0.001	<0.001	<0.001
Root length (cm)	10.00±0.00[e]	12.00±0.29[d]	12.40±0.21[d]	13±0.32[d]	10.00±0.00[e]	18.50±0.76[c]	20.30±0.15[b]	22.50±0.29[a]	<0.001	<0.001	<0.001

Remark: The values are the means ± SEMs, n = 3 per treatment group.
[a-g] means in a row without a common superscript differ significantly (p<0.05), as analyzed by two-way ANOVA and the Tukey test.
T × D[1] = Treatment × Days interaction effect.



	EC (µS cm⁻¹)	BOD₅ (mg L⁻¹)	COD (mg L⁻¹)	Turbidity (NTU)	TSS (mg L⁻¹)	TDS (mg L⁻¹)	Chromium (mg L⁻¹)
D 15	11.09%	17.59%	30.22%	8.78%	20.92%	14.19%	22.50%
D 30	31.78%	50.43%	52.61%	18.34%	60.47%	37.46%	48.37%
D 45	35.42%	84.66%	81.21%	33.17%	83.28%	72.55%	79.71%

Figure 6 Percentage changes in the removal efficiency of each parameter in the treatment systems with different treatment times (Day 15, 30, and 45).

2.3) Dissolved oxygen (DO)

During the hydroponic treatment, the DO significantly increased from 1.89±0.01 mg L^{-1} at the beginning of the experiment to 5.20±0.02 mg L^{-1}. DO may increase because of wind aeration, the photosynthesis process by algae, and the movement of oxygen from aerial parts to the root system. The DO levels in the experimental groups planted with vetiver remained consistently lower than those in the control set throughout the entire study period (Table 2) because, in the control set, no plants blocked sunlight and wind from penetrating the water column. A remarkably similar result was reported in the thesis paper of Bedewi [39].

2.4) Biological oxygen demand (BOD) and chemical oxygen demand (COD)

The BOD and COD values decreased from 1,290.33 ±1.45 mg L^{-1} to 198±1.53 mg L^{-1} and from 1,869.67±1.76 mg L^{-1} to 351.33±1.76 mg L^{-1}, respectively. Across all the treatment groups, there were significant differences in both BOD and COD (Figure 6). ANOVA revealed that throughout the observation period, the values of BOD and COD in the treatment groups were consistently lower than those in the control groups (p<0.05). Significant removal efficiencies were found for BOD (84.66%) and COD (81.21%) when the formula given by Boonsong and Chansiri [32] was used to calculate removal efficiencies. The removal efficacy notably decreased for the vetiver-planted hydroponic treatment sets. When vetiver grass was used for phytoremediation of the effluent of palm oil mills with different influent concentrations, the BOD_5 reduction ranged from 15% to 96%, whereas the COD decrease varied from 10% to 94% [40]. Various physicochemical and biological mechanisms, including sedimentation, filtration, biological breakdown, and adsorption, are likely to occur within the wastewater in the treatment unit root zone [41]. Research has also revealed that a decrease in organic matter is caused by pollutants being absorbed by plant roots, mostly by accompanying microbes that aid in the breakdown of organic compounds during the phytoremediation process [41].

2.5) Turbidity

The wastewater from the tannery smelled awfully and was dark blue. Compared with the control treatment, the vetiver treatment significantly improved turbidity (p<0.05). In the control set, the turbidity was reduced from 550.67±1.20 to 497.67 ±2.40 NTU after 45 days, when there were no plants. However, in the vetiver treatment set, it was reduced from 550.67±1.20 to 368±0.57 NTU after 45 days, which was a significant difference between the vetiver set and the control set. After 45 days of treatment, a maximum effectiveness of 33.17% was reached.

2.6) Total suspended solids (TDS)

After 45 days of hydroponic treatment, the mean concentration of TSS decreased from 1,230.33±1.76 to 205.67±1.86 mg L^{-1}. The removal efficiency was greater at 45 days of treatment, which was 83.28%. According to Zhang et al., 2014, for floating treatment wetland (FWS) systems, the elimination of TSS (66.1%) was satisfactory in terms of treatment efficiency [42]. In the tofu production industry, employing both vetiver grass and zeliac resulted in a maximum efficiency of approximately 75.28% for the removal of TSS from tofu wastewater after 15 days and at a wastewater concentration of 38.41% [43]. However, after 45 days of treatment, the value of the vetiver set was 205.67±1.86 mg L^{-1}, which was notably lower (p<0.05) than the control set value of 1,173.33±2.03 mg L^{-1}. This may have occurred because of the enormous growth of the roots and shoots during the trial.

The reduction in both turbidity and TSS during hydroponic treatment is attributed to the ability of vetiver grass to filter and absorb suspended particles through its root system. As the vetiver grows, its dense root system entraps and removes particulate matter from the water, thus reducing turbidity and TSS over time.

2.7) Total dissolved solids (TDS)

The TDS significantly decreased (p<0.05) throughout the 45-day hydroponic treatment period, from 6,706±1.15 mg L^{-1} to 1,840.67±1.86 mg L^{-1}. After 45 days of treatment, the maximum removal efficiency was 72.55%, which was lower than the removal efficiency of TSS. This could be because wastewater undergoes various physicochemical and biological transformations, including adsorption, filtration, sedimentation, and biological breakdown within the root zone of hydroponic treatment units. Through these processes, contaminants are removed or degraded, resulting in cleaner water suitable for safe disposal. In this instance, the values were significantly lower than those of the control (p< 0.05).

2.8) Root length

The length of the roots was measured with a measuring tape during the treatment period. The root length increased from 10.00±0.00 cm to 22.50±0.29 cm when the root was submerged in tannery wastewater for the hydroponic treatment process. However, the control unit, in which vetiver grass was grown in normal water, presented significantly lower root growth (p<0.05), as there were no nutrients for plant growth.

2.9) Chromium (Cr) content

The Cr concentrations significantly decreased (p<0.05) from 7.69±0.02 mg L^{-1} to 5.96±0.03 mg L^{-1} after 15 days, 3.97±0.04 mg L^{-1} after 30 days, and 1.56±0.02 mg L^{-1} after 45 days of treatment. This corresponds to efficiencies of 22.50% after 15 days, 48.37% after 30 days, and 79.71% after 45 days. On the other hand, in the control set, the value decreased to 7.58±0.01 mg L^{-1}, 6.87±0.02 mg L^{-1}, and 6.12±0.03 mg L^{-1} after 15 days, 30 days, and 45 days, respectively, which indicates that there were no significant changes (p>0.05) in the control set. Owing to the high cation exchange capacity of roots, which allows them to absorb Cr when they come into direct contact with wastewater and subsequently transfer it to leaves, Cr accumulation in roots is greater than that in leaves [44]. The study revealed that, over a 45-day period without chemical treatment, the pH decreased from 8.36±0.03 to 7.09±0.01, revealing that the main reason for Cr reduction was the biological processes of vetiver grass. There was no notable Cr precipitation, as the pH remained within a range that does not normally promote precipitation. Masinire et al. [45] investigated the ability of vetiver grass to remove Cr(VI) from water via phytoremediation. The vetiver was placed in containers with Cr(VI) concentrations of 5, 10, 30, and 70 ppm. Cr(VI) removal was monitored over 7 weeks via spectrophotometry. The 5 ppm bucket showed an 87% decrease in Cr content. The 10 ppm container resulted in a 51% reduction in Cr(VI) content. The removal efficiency of the 30 ppm bucket was 28% after 5 weeks, whereas the removal efficiency of the 70 ppm bucket was 12% after 4 weeks. Vetiver effectively reduces Cr(VI) at lower concentrations, with higher efficiency at concentrations below 30 ppm. It accumulates heavy metals in roots and shoots, proving effective in phytoremediation but less tolerant of heavy metals above 30 ppm [45]. The mean Cr concentration in the riverine waters of Bangladesh was 0.29±0.64 μg L^{-1}, ranging from 0.003 to 3.20 mg L^{-1}, which exceeded the WHO and DoE standards (below 0.05 mg L^{-1}) [46]. In this study, when the Cr level was reduced to 1.56 mg L^{-1}, which does not yet meet the WHO and DoE standards, this significant decrease highlights the potential of the vetiver hydroponic technique as an effective treatment method. Further optimization and extended treatment may be needed to meet the precise standards, but the progress observed in this study is promising. Other key water quality parameters, including pH, EC, BOD_5, COD, turbidity, TSS, and TDS, significantly improved and either met or approached the established permissible limits. These results show the efficacy of the vetiver hydroponic system as an environmentally friendly solution for treating tannery wastewater in Bangladesh.

3) Postharvest management and safe disposal of Cr-contaminated vetiver

Appropriate postharvest management is crucial to prevent environmental contamination or health hazards once the vetiver grass completes its phytoremediation phase by accumulating Cr and other toxic compounds. Vetiver biomass containing heavy metals such as Cr should not be used in animal or agricultural feed because of toxicity concerns. It poses potential risks if introduced into the food chain [47].

In this study, vetiver biomass, which absorbs Cr during phytoremediation, was safely used in flower gardens, reducing the risk of Cr contamination since these gardens are ornamental and not part of the food chain. Cr, especially when confined in plant biomass, has a lower risk of leaching into the soil under normal gardening conditions, especially in nonagricultural applications. Therefore, the use of vetiver as mulch in flower beds is an environmentally sustainable and safe technique. Furthermore, research indicates that managing heavy metal-contaminated plant material with such biomass in nonedible landscaping or ornamental horticulture is feasible if adequate precautions are taken to keep it away from edible crops or areas of livestock grazing [47].

Conclusions

Research on the phytoremediation of tannery wastewater via a hydroponic approach with vetiver grass on a floating stand revealed that vetiver significantly reduced contaminants, especially Cr, compared with those in the control unit. Additionally, the characteristics of wastewater influence vetiver growth. The properties of wastewater notably influence the development of vetiver. The study also revealed that as the treatment time increased, the efficiency of the treatment system increased. This was clearly connected to the continual development and growth of the vetiver, which led to successive increases in biomass and its ability to adapt to the wastewater environment over time. Vetiver grass must be utilized in sufficient quantities to reduce the amount of pollutants adequately. This research was conducted on a pilot scale over a shorter period. Large-scale trials with long-term treatments are needed to fully maximize the vetiver's potential for pollutant removal.

References

[1] Dargo, H., Ayalew, A. Tannery wastewater treatment: A review. International journal of Emerging Trends in Science and Technology, 2014, 1(9), 1488–1494.

[2] Chowdhury, M., Mostafa, M. G., Biswas, T.K., Saha, A.K. Treatment of leather industrial effluents by filtration and coagulation processes. Water Resources and Industry, 2013, 3, 11-22.

[3] Cassano, A., Della Pietra, L., Drioli, E. Integrated membrane process for the recovery of chromium salts from tannery effluents. Industrial & Engineering Chemistry Research, 2007, 46(21), 6825–6830.

[4] World Health Organization. Guidelines for drinking-water quality. 4th Editions., WHO Chronicle, 2011, 38 (4), 104–108.

[5] World Health Organization. Chromium in drinking-water (No WHO /HEP /ECH /WSH / 2020.3). World Health Organization, 2020.

[6] Guya, G.L.T.T.K. Impacts of tannery effluent on environments and human health. Journal of Environment and Earth Science, 2017, 7(3), 88–97.

[7] Akan, J.C., Moses, E.A., Ogugbuaja, V.O., Abah, J. Assessment of tannery industrial effluents from Kano metropolis, Kano State, Nigeria. Journal of Applied Sciences, 2007, 7(19), 2788–2793.

[8] Kurniawan, T.A., Chan, G.Y., Lo, W.H., Babel, S. Physico–chemical treatment techniques for wastewater laden with heavy metals. Chemical Engineering Journal, 2006, 118(1-2), 83–98.

[9] Fu, F., Wang, Q. Removal of heavy metal ions from wastewaters: A review. Journal of Environmental Management, 2011, 92(3), 407–418.

[10] Kassaye, G., Gabbiye, N., Alemu, A. Phytoremediation of chromium from tannery wastewater using local plant species. Water Practice & Technology, 2017, 12(4), 894–901.

[11] Naumczyk, J., Rusiniak, M. Physicochemical and chemical purification of tannery wastewaters. Polish Journal of Environmental Studies, 2005, 14(6).

[12] Priya, P.G., Ramamurthi, V., Anand, P. Degradation studies of tannery effluents using electro flotation technique. Journal of Chemical Engineering & Process Technology, 2011, 2(1), 2–5.

[13] Moorthi, K.S. Studies on treatment and reuse of tannery wastewater by embedded system. Thesis, Faculty of Civil Engineering, Anna University, 2011.

[14] Kavamura, V.N., Esposito, E. Biotechnological strategies applied to the decontamination of soils polluted with heavy metals. Biotechnology Advances, 2010, 28(1), 61-69.

[15] Kong, X., Lin, W., Wang, B., Luo, F. Study on vetiver's purification for wastewater from pig farm. In Proceeding of the 3rd International Vetiver Conference, Guangzhou, China, October 2003.

[16] Paz-Alberto, A.M., Sigua, G.C. Phytoremediation: A green technology to remove environmental pollutants. American Journal of Climate Change, 2013, 2, 71–86.

[17] Gnansounou, E., Alves, C.M., Raman, J.K. Multiple applications of vetiver grass–A review. International Journal of Education and Learning Systems, 2017, 2, 125–141.

[18] Mahmoudpour, M., Gholami, S., Ehteshami, M., Salari, M. Evaluation of phytoremediation potential of vetiver grass (chrysopogon zizanioides (L.) roberty) for wastewater treatment. Advances in Materials Science and Engineering, 2021(1), 3059983.

[19] Alayu, E., Yirgu, Z. Advanced technologies for the treatment of wastewaters from agro-processing industries and cogeneration of by-products: A case of slaughterhouse, dairy and beverage industries. International Journal of Environmental Science and Technology, 2018, 15, 1581–1596.

[20] Rahman, M. Potential application of vetiver grass for sustainable environmental management in Hill Tracts region of Bangladesh. Doctoral dissertation, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka, 2020.

[21] Papadopoulos, I.I., Chatzitheodoridis, F., Papadopoulos, C., Tarelidis, V., Gianneli, C. Evaluation of hydroponic production of vegetables and ornamental pot-plants in a heated greenhouse in Western Macedonia, Greece. American Journal of Agricultural and Biological Science, 2008.

[22] Dhungana, T.P., Yadav, P.N. Determination of chromium in tannery effluent and study of adsorption of Cr (VI) on saw dust and charcoal from sugarcane bagasses. Journal of Nepal Chemical Society, 2009, 23, 93–101.

[23] Krishanamoorthi, S., Sivakumar, V., Saravanan, K., Prabhu, T.S. Treatment and reuse of tannery wastewater by embedded system. Modern Applied Science, 2009, 3(1), 129–134.

[24] Islam, K.N., Misbahuzzaman, K., Majumder, A. K., Chakrabarty, M. Efficiency of different coagulants combination for the treatment of tannery effluents: A case study of Bangladesh. African Journal of Environmental Science and Technology, 2011, 5(6), 409–419.

[25] Sugasini, A., Rajagopal, K., Banu, N. A study on biosorption potential of Aspergillus sp. of tannery effluent. Advances in Bioscience and Biotechnology, 2014, 5(10), 853.

[26] Haydar, S., Aziz, J.A., Ahmad, M.S. Biological treatment of tannery wastewater using activated sludge process. Pakistan Journal of Engineering and Applied Sciences, 2007.

[27] Ali, M.F., Naher, U.H.B., Chowdhury, A.M., Rahman, G.M., Hasan, M.M. Investigation on physicochemical parameters of tannery effluent. Universal Journal of Environmental Research & Technology, 2015, 5(3).

[28] Mohanta, M.K., Salam, M.A., Saha, A.K., Hasan, A., Roy, A.K. Effects of tannery effluents on survival and histopathological changes in different organs of Channa punctatus. Asian Journal of Experimental Biology and Science, 2010, 1(2), 294–302.

[29] Monira, U., Sattar, G.S., Mostafa, M.G. Characterization of tannery effluent of Savar Tannery Estate in Bangladesh. BAUET Journal, 2022, 11, 67–76.

[30] AWWA, WEF, APHA. Standard methods for the examination of water and wastewater (Methods: 5220 C. Closed Reflux Titrimetric Method), 1998.

[31] APHA (American Public Health Association). Standard methods for the examination of water and wastewater. 20th ed. APHA, Washington, DC, USA, 1998.

[32] Boonsong, K., Chansiri, M. Domestic wastewater treatment using vetiver grass cultivated with floating platform technique. AU Journal of Technology, 2008, 12(2), 73-80.

[33] NEQS. National Environmental Quality Standards for municipal and liquid industrial effluents. [Online] Available from: http://www.emc.com.pk/pdf/3-NEQS(New).pdf [Accessed 23 September 2012]

[34] Jahan, M.A.A., Akhtar, N., Khan, N.M.S., Roy, C.K., Islam, R. Characterization of tannery wastewater and its treatment by aquatic macrophytes and algae. Bangladesh Journal of Scientific and Industrial Research, 2014, 49(4), 233–242.

[35] Muthukkauppan, M., Parthiban, P. A study on the physicochemical characteristics of tannery effluent collected from Chennai. International Research Journal of Engineering and Technology (IRJET), 2018, 5(3), 24–28.

[36] Kabir, M.M., AN M,F., MAZ, C., Islam, R. Characterization of tannery effluents of Hazaribagh area, Dhaka, Bangladesh. Pollution, 2017, 3(3), 395–406.

[37] Verma, T., Ramteke, P.W., Garg, S.K. Quality assessment of treated tannery wastewater with special emphasis on pathogenic E. coli detection through serotyping. Environmental Monitoring and Assessment, 2008, 145, 243–249.

[38] Rouf, M.A., Islam, M.S., Haq, M.Z., Ahmed, N., Rabeya, T. Characterization of effluents of leather industries in Hazaribagh area of Dhaka city. Bangladesh Journal of Scientific and Industrial Research, 2013, 48(3), 155–166.

[39] Abdulkerim, B. The potential of vetiver grass for wastewater treatment. MSc Thesis, Haramaya University, 2010.

[40] Darajeh, N., Idris, A., Truong, P., Abdul Aziz, A., Abu Bakar, R., Che Man, H. Phytoremediation potential of vetiver system technology for improving the quality of palm oil mill effluent. Advances in Materials Science and Engineering, 2014.

[41] Vipat, V., Singh, U.R., Billore, S.K., Sengupta, M., Dalwani, R. Efficacy of rootzone technology for treatment of domestic wastewater: field scale study of a pilot project in Bhopal (MP), India. In Proceedings of Taal2007: The 12th World Lake Conference, 2008, 995, 1003.

[42] Zhang, D.Q., Jinadasa, K.B.S.N., Gersberg, R. M., Liu, Y., Ng, W.J., Tan, S. Application of constructed wetlands for wastewater treatment in developing countries–A review of recent developments (2000–2013). Journal of Environmental Management, 2014, 141, 116–131.

[43] Seroja, R., Effendi, H., Hariyadi, S. Tofu wastewater treatment using vetiver grass (Vetiveria zizanioides) and zeliac. Applied water science, 2018, 8, 1–6.

[44] Masinire, F. Phytoremediation of Cr (VI) and Pd (II) using vetiver grass (Chrysopogon zizanioides). MSc Thesis, University of Pretoria, 2022.

[45] Masinire, F.F., Adenuga, D.O., Tichapondwa, S.M., Chirwa, E. Remediation of chromium (VI) containing wastewater using Chrysopogon zizanioides (Vetiver Grass). Chemical Engineering Transactions, 2020, 79, 385–390.

[46] Pandit, D., Haque, M.M., Bhuyan, M.S., Harun-Al-Rashid, A., Barman, P.P., Roy, R., Kunda, M. A. comprehensive scenario of heavy metals pollution in the rivers of Bangladesh during the

last two decades. Environmental Science and Pollution Research, 2024, 1–18.

[47] Chintani, Y.S., Butarbutar, E.S., Nugroho, A.P., Sembiring, T. Uptake and release of chromium and nickel by Vetiver grass (Chrysopogon zizanioides (L.) Roberty). SN Applied Sciences, 2021, 3(1), 1–13.