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# Bioremediation of Industrial Wastewater Using Hydroponics Planted with Vetiver

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**Abstract:** In the modern era, industrialization in developing countries like Bangladesh has significantly polluted groundwater systems. Tannery industry effluent is a major source of water pollution. This study focuses on removing heavy metals, specifically lead, and reducing key physicochemical parameters including pH, Electrical Conductivity (EC), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand ($BOD_5$) from tannery wastewater utilizing the phytoremediation potential of *Vetiveria zizanioides*. The experiment was conducted by hydroponic technique, evaluating the effects of treatment time. Results showed significant pollutant removal efficiencies after 45 days of treatment were pH (24.82%), EC (36.74%), $BOD_5$ (87.07%), COD (84.89%), TSS (84.02%), TDS (73.39%), and Lead (66.13%). Vetiver revealed strong growth and a 95% survival rate. Post-treatment pollutant levels were found to be in compliance with WHO standards, suggesting that vetiver hydroponic bioremediation is a sustainable and environmentally friendly method that presents a viable option for treating wastewater in developing countries like Bangladesh.

**Keywords:** Hydroponics; *Vetiveria zizanioides;* Lead; Physiochemical parameter.

## INTRODUCTION

Water serves as the lifeblood of Earth, much like blood within the human body. Without water, our planet would resemble a lifeless, bleak mass of gray rock, lacking the vibrant ecosystems that sustain life (Spellman, 2017). In the pursuit of urbanization and industrialization, humanity is contaminating the vital life force of our planet i.e. water. Industrial processes are the primary causes of water pollution and the kind of industries involved has a significant impact on the level of contamination. Day by day, clean water is getting harder to come by and more valuable. Industrial effluents released into surface and groundwater sources have a significant impact on the quality of water. Numerous organic and inorganic composites, biodegradable substances, hazardous contaminants, and nutrients are present in these effluents.

The tannery sector in Bangladesh is one of the most polluting industries. Noteworthy quantities of compounds are used throughout the various stages of leather-processing (Dargo and Ayalew, 2014). The tanning process, which is entirely wet, requires a large volume of water, much of which is discharged as effluent, with approximately 90% being unevenly wasted (Chowdhury *et al.*, 2013). Tannery effluents are a rich source of both organic and inorganic contaminants, including oxidizable tanning components, hazardous metallic compounds, colored chemicals, sodium chloride, sulfate etc. (Akan *et al.,* 2007). There are several forms that lead can take, including sulfides, oxides and salts. When effluents containing lead compounds are released into water sources, lead starts to accumulate in sediments, soils, plants, and living beings. According to Mudgal and Gupta, (2016b) this accumulation has a number of negative consequences, including limiting plant growth and contaminating the food supply and drinking water. Lead poisoning has a detrimental impact on the liver, kidneys, and reproductive system in addition to badly affecting the brain's fundamental activities (Kushwaha *et al.,* 2012). Even a little amount of lead in food or water can cause acute poisoning and chronic health issues like paralysis, nerve damage, cancer, colic, and infertility (ATSDR 2020). Untreated Pb in wastewater can severely impact human health and the environment. So, wastewater must be treated to a suitable quality before being discharged to the public water source.

The high costs of conventional treatment methods drive the search for eco-friendly natural alternatives. Bioremediation is an approach that uses biological methods to counteract environmental pollutants, offering a smart alternative to conventional cleanup by harnessing plants and microorganisms to remove pollutants (Ojoawo *et al.,* 2015). Hydroponic bioremediation is suggested for wastewater treatment and reprocess (Haddad *et al.,* 2009).

Growing plants without soil in nutrient-rich solutions using the hydroponic technique is becoming more and more common and attracting the attention of the scientific and business worlds (Papadopoulos *et al.,* 2008). Hydroponic cultivation of emergent macrophytes on floating platforms for wastewater treatment is a novel approach with roots extending through the wastewater (Osem *et al.,* 2007).

Vetiver grass is a versatile macrophytes used in bioremediation practices (Paz-Alberto and Sigua, 2013). Vetiver grass shows promising potential in treating polluted water, stabilizing land, protecting infrastructure, and rehabilitating contaminated areas through bioremediation (Troung *et al.,* 2008). Even though vetiver is not a hydrophyte, it likes damp, moist environments where it can grow and develop, even if it gets submerged in water for an extensive period of time (Boonsong and Chansiri, 2008).

Numerous studies globally have explored diverse technologies for treating tannery effluents. Some authors have studied tannery wastewater treatment methods like filtration, ultrafiltration, reverse osmosis, and coagulation (Krishanamoorthi *et al.,* 2009; Islam *et al.,* 2011), while few of them have focused on bioremediation techniques (Haydar *et al.,*2007). In Bangladesh, research on tannery effluents mainly focuses on their characterization and impact assessment (Moral *et al.,* 2002; Mohanta *et al.,* 2010 and Monira *et al.,* 2022), with no prior work on cost-effective and eco-friendly treatment. This study marks the first attempt to assess the efficacy of vetiver in treating tannery wastewater in Bangladesh.

When compared to traditional wastewater treatment techniques, vetiver grass is renowned for its inexpensive installation and maintenance. Conventional treatments like the CETP at Savar Tannery Estate are expensive, with high construction and maintenance costs with significant energy consumption. On the contrary, vetiver technique requires less infrastructure and mostly depend on natural plant development, which results in a significant reduction in initial and ongoing expenditures. They also provide socioeconomic benefits such as job creation, improved public health, and potential agricultural uses for vetiver biomass. Studies by Truong and Hart, 2001, Roongtanakiat and Chairoj ,2001 and Boonsong and Chansiri, 2008 support these findings, highlighting vetiver's efficiency and lower costs. While advanced treatment processes exist worldwide, this study prioritizes the socioeconomic context of Bangladesh by opting for a low-cost technique for tannery wastewater treatment.

## MATERIALS AND METHODS

### Study site and Wastewater Source

The wastewater generated by tannery industries was gathered from the Savar Central Effluent Treatment Plant located in Horindhora, Hemyaetpur, Savar.. According to Mollik (2022), to protect the Buriganga river from additional pollution, over 155 tannery industries of which 132 are engaged in the production of leather goods have been relocated from Hazaribagh, Dhaka to the Savar Tannery Estate at Hemayetpur. Through a pipeline system, the industries release their effluents, which are then treated at the CETP. After treatment, the effluent is discharged from the CETP into the Dhaleshwari River. Unfortunately, the CETP is not adequately treating effluent, with pollutant levels exceeding permissible limits and only 51% removal efficiency (Monira *et al.,* 2023). This poses significant risks to aquatic life, humans, and the environment, necessitating improved and regularly monitored treatment processes. A composite sample of the effluents from the collective pipeline of these tanneries was collected prior to entering the CETP for analysis. The water was collected in containers that were properly washed and dried prior to the collection.

### Planting Materials, Experimental design and operation of the treatment technique

Vetiver slips were collected from hedgerows naturally growing on the bank of the Brahmaputra River in Mymensingh. The plants were trimmed to a length of approximately 22 cm, and the roots were shortened to about 6 cm. Vetiver slips collected from splitting full grown plants were then rinsed with distilled water and disinfected. For three months, they were cultivated in tiny potting bags with sandy soil, much like seedlings, to facilitate proliferation. The hydroponic vetiver technique for treating wastewater started with three month old matured vetiver plants. Clumps of similarly sized bare-rooted vetiver were lifted from potting bags, divided into four tillers, and cleaned of any adhearing soil. The roots and soots of the plants were trimmed to 10 cm long. Figure 1 represents the vetiver preparation for treatment process. Collected tannery wastewater was placed into six 10 liters plastic containers. Polypropylene sheets with four holes were placed on three containers to support the plants. Vetiver plants were inserted into the holes with 10 cm of roots immersed in tannery wastewater, held firmly by sponges. Here, for 45 days, the plants were cultivated in wastewater. There were three experimental sets of vetiver planted for testing and three containers filled with wastewater and with no plant were taken as control. The experimental arrangement is shown in Figure 2.

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a) Collected bare-rooted vetiver slips uplifted

b) Three months old vetiver for wastewater treatment application

**Figure 1.** Vetiver propagation for wastewater treatment technique

**Figure 2.** Experimental Set-up

## Water Quality Analysis

Treatment evaluation involved assessing regularly recorded parameters collected mid-morning. Samples were obtained by pooling water from three locations on the container surface using a 100 mL graduated cylinder. Sampling occurred four times over 45 days: days 0, 15, 30, and 45.

Standardized processes and established protocols were adhered to in the analysis of water parameters. A pH meter and EC meter was used to analyze pH and EC respectively (Figure 3). To calculate the $BOD_5$, the dilution method was applied. After being diluted with aerated distilled water, collected wastewater samples were incubated for five days at 20°C. Dissolved oxygen (DO) levels were measured both before and after incubation. The BOD value was calculated by finding the difference between the initial and final DO measurements. Closed Tube Reflux Method was employed to measure the COD (AWWA, 1998). Utilizing the gravimetric method, TSS and TDS were determined (APHA, 1998). The heavy metal (Pb) content was measured by atomic absorption spectrophotometer (Figure 3)


a) AAS (Atomic Absorption Spectrophotometer)

b) pH meter

c) Conductivity meter

**Figure 3.** Instruments used in the measurement of parameters

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Utilizing the formula of (Boonsong and Chansiri, 2008), Removal efficiencies of treatment system were calculated.

% Removal Efficiency = $(\frac{C_{inf}-C_{eff}}{C_{inf}})$ ×100 ……….(Eqn. 1)

Where, $C_{inf}$ is the initial parameter concentration, $C_{eff}$ is final parameter concentration.

## RESULTS AND DISCUSSION

### Physico-chemical analysis of tannery wastewater

The features of the tannery effluent used in the investigation are listed in Table 1. The World Health Organization (WHO) and the National Environmental Quality Standards (NEQS, 2000) discharge limit values were compared to the results (Anonymous, 2002). As shown in Table 1, the average pH value in untreated composite tannery wastewater is 9.47, which was above the standard discharge limit of the NQES, 2000 and WHO permissible limit for discharge. The effluent is alkaline since it contains lime, $Na_2CO_3$, $Na_2S$, and NaOH, which are used in the tanning process (Monire *et al.*, 2022). The average EC was far higher than the allowable limit, indicating an extremely toxic habitat for the aquatic organisms. Salts and both inorganic and organic compounds are present in significant amounts in effluent samples with higher EC values. The EC values in Hazaribagh varied widely, from 587 to19000 μs/cm, which aligns with this research findings (Kabir *et al.*, 2017). Higher $BOD_5$ levels signify increased wastewater pollution and decreased oxygen availability for biological organisms. (Verma *et al.*, 2008). The mediocre value of COD observed was 2330 mg/L in the wastewater, which is much higher than discharge standard limits. The TSS value of the tannery wastewater exceeded the prescribed permissible limit, indicates massive amounts of suspended solids present in the wastewater. The results showed that the high TDS concentration ranged from 6799 to 6804 mg/L**,** exceeding the standard permissible limits that indicate the presence of substantial quantity of dissolved solids. Rouf *et al.*, reported that wastewater samples from different sites within the Hazaribagh tannery industrial zone had a TDS value of 3455 mg/l, which was half the concentration observed in this study. The average concentration of chromium found in the wastewater was 1.24 mg/l. According to Needleman, 1999, the World Health Organization (WHO) sets the maximum allowable concentration of lead in drinking water at 3 to 10 micrograms per liter. For inland surface water, the permissible limit is 0.1 milligrams per liter. Pb has to be removed from wastewater since it is bad for the environment and people's health. Pb can have serious detrimental effects on the environment and human health if it is not adequately removed and treated from wastewater. Thus, this wastewater requires treatment before discharging into the environment. Hence, this wastewater needs to undergo treatment prior to being discharged into the environment

**Table 1.** Physicochemical parameters of Tannery industrial wastewater and permissible value

| Parameters | Average Value | NQES, 2000 | WHO |
|---|---|---|---|
| | | Standard | |
| pH units | 9.47 | 6-9 | 5.5-9 |
| EC (mS/cm) | 13.01 | 0.288 | 1.2 |
| $BOD_5$ (mg/l) | 1470 | 50 | 30 |
| COD (mg/l) | 2330 | 200 | 250 |
| TSS (mg/l) | 1259.02 | 150 | 600 |
| TDS (mg/l) | 6801 | 3500 | 2100 |
| Lead (mg/l) | 1.24 | 0.5 | 0.01 |

### Effects of Vetiver on the Characteristics of wastewater

For a period of 45 days, samples were taken every 15 days to evaluate the capability of vetiver grass for detoxifying tannery effluent. The samples were then tested for several water quality indicators. Figures 4 to 10 and Table 2 display the average concentrations of pollutants in the tannery effluent during the 45-day trial period and the removal efficiency.

**pH**: Throughout the experiment, the pH measurements were recorded on a time series with a minimum value of 7.12 and a maximum value of 9.47. The vetiver settings' pH values were lower during the treatment period than those of the control sets. This may be resulted from increased organic decomposition, as indicated by higher $BOD_5$ and COD removal rates, leading to $CO_2$ and acid production that lowered the pH of the wastewater treated with vetiver (Bedewi, 2010). The highest removal efficiency was 24.82%, achieved after 45 days of treatment (Figure 4).

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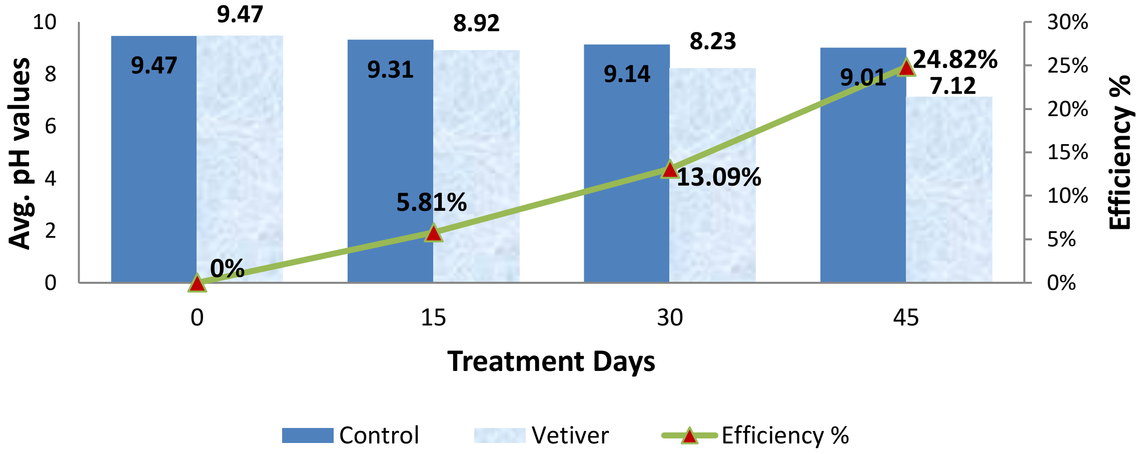


**Figure 4.** The average pH concentration and removal efficiency of treatment system with treatment time

**Electrical Conductivity:** In the hydroponic vetiver treatment, the average EC notably decreased from 13.01 mS/cm to 8.23 mS/cm over 45 days, with a maximum removal efficiency of 36.74 % observed at the end of the period, and vetiver sets consistently showed lower EC values compared to control sets. According to a study, vetiver might lower the EC in domestic wastewater by 39.44% (Hart *et al.*, 2003).

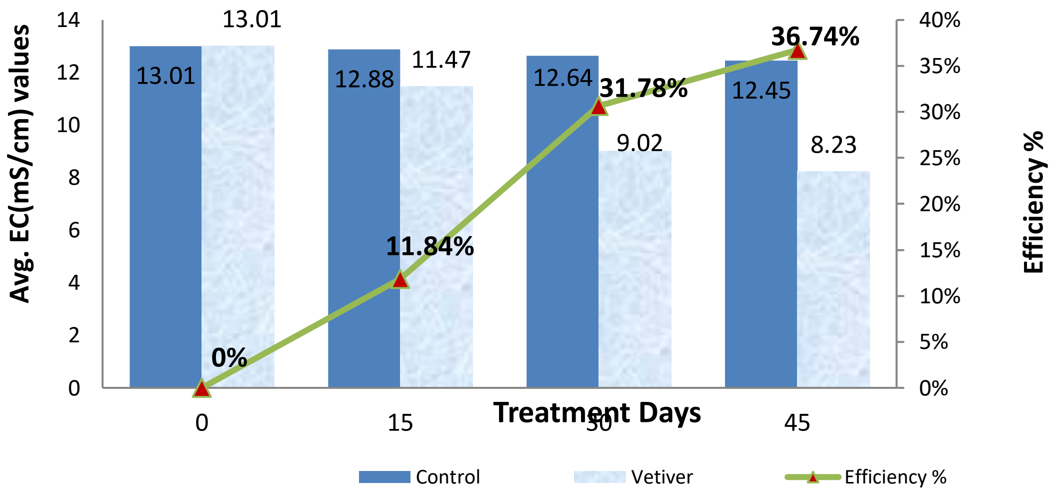


**Figure 5.** The average EC concentration and Removal efficiency of treatment system with treatment time

**Biochemical Oxygen Demand:** $BOD_5$ values decreased from 1470 mg/L to 190 mg/L after 45 days of treatment, achieving 87.07% removal efficiency (Figure 6). Throughout the analysis, BOD concentrations in vetiver-planted hydroponic treatment units were consistently lower than in the control units. This clearly shows the beneficial effect of Vetiver in treating the tannery wastewater. According to research of Darajeh *et al.*, 2014, when vetiver grass was utilized for phytoremediation of the palm oil mill's effluent at varying influent concentrations, the reduction in $BOD_5$ varied between 15% and 96%. One research showed that the decrease in organic matter was due to pollutants being absorbed by plant roots, primarily through the action of microbes that assist in breaking down organic compounds during the phytoremediation process (Vipat *et al.*, 2008).

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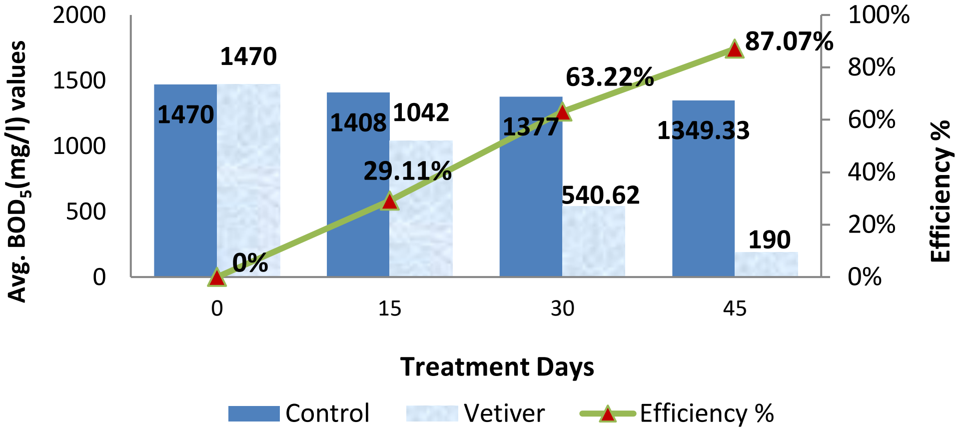


**Figure 6.** The average $BOD_5$ concentration and removal efficiency of treatment system with treatment time

**Chemical Oxygen Demand**: As revealed in Table 2 and Figure 7, COD concentrations decreased from 2330 mg/L by 39.79% in 15 days, 61.85% in 30 days, and 84.89 % in 45 days of hydroponic treatment. Comparable research had also upheld the efficiency of vetiver in diminishing COD levels in paperboard mill wastewater (Davamani *et al.,* 2021). Another study on Palm Oil Mill effluent treatment by vetiver showed up to 39% reduction in COD of the high concentration of POME (Darajeh *et al.*, 2014). Overall, the $BOD_5$ and COD levels in the vetiver-planted experimental sets were consistently lower than those in the control set throughout the study.

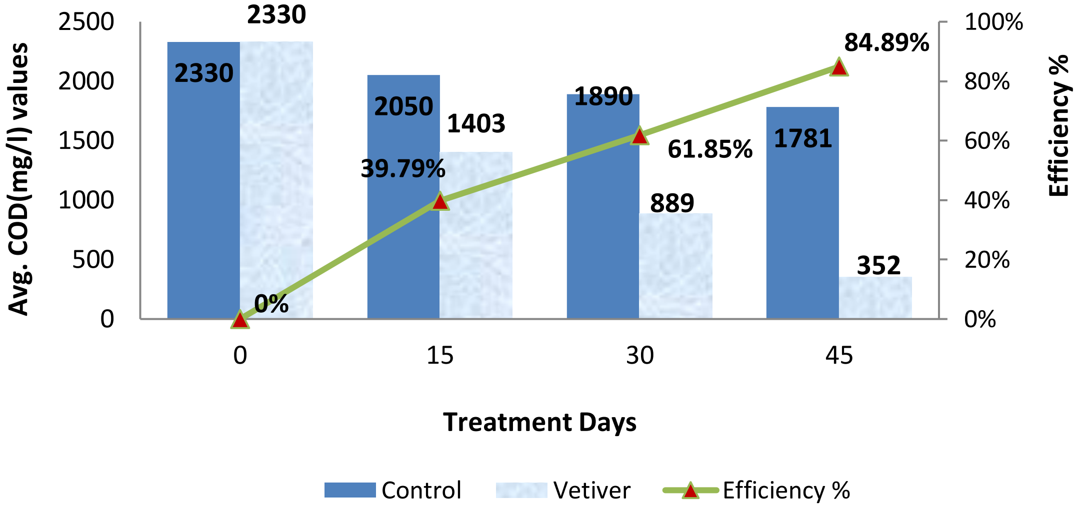


**Figure 7.** The average COD concentration and removal efficiency of treatment system with treatment time

**Total Suspended Solids:** During the hydroponic treatment period, the average TSS concentrations dropped from 1259.02 mg/l to 201.23 mg/l levels, achieving an 84.02% removal efficiency after 45 days (Figure 8). These values were significantly lower than those of the control sample without vetiver, because of the substantial root and shoot growth of vetiver during the treatment duration. Additionally, Seroja *et al.*, (2018) found that combining vetiver grass and zeliac in the tofu production industry resulted in a peak efficiency of around 75.28% for removing TSS from tofu wastewater over 15 days, at a concentration of 38.41%. Moreover, Zhang *et al.*, (2014) reported that Floating Treatment Wetland systems effectively reduced TSS by 66.1%, indicating satisfactory treatment efficiency.

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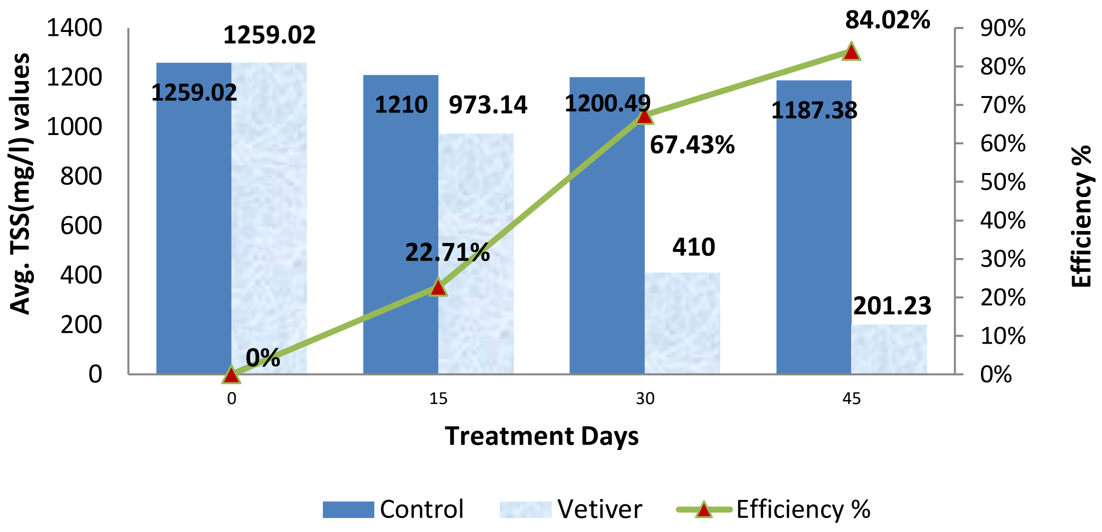


**Figure 8.** The average TSS concentration and removal of treatment system with treatment time

**Total Dissolved Solids:** TDS concentrations dropped from 6801 mg/L to 1810 mg/L during 45 days of hydroponic treatment, yielding a maximum removal efficiency of 73.39 % that was higher than that of TSS. This reduction is attributed to physical, chemical, and biological processes in the root zone, such as sedimentation, filtration, degradation, and adsorption. The treated values were significantly lower than those of the control sample without grass. A certain study indicated that vetiver grass, when used in a floating treatment system, could significantly reduce TDS levels in domestic wastewater (Boonsong and Chansiri, 2008), Again, Truong and Hart, (2001) reported notable TDS removal in different wastewater treatment scenarios using the vetiver system, supporting our findings on its potential for industrial applications.

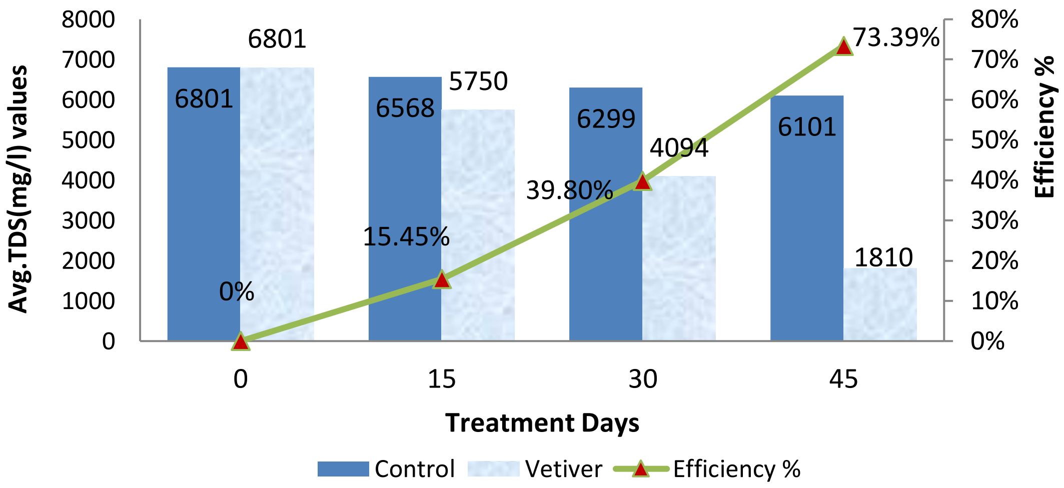


**Figure 9.** The average TDS concentration and removal efficiency of treatment system with treatment time

**Lead Content:** Lead concentration in raw wastewater decreased from 1.24 mg/L to 0.42 mg/L after 45 days of treatment, with a 66.13% removal efficiency. Coincidentally Davamani *et al.*, (2021) reported similar result for paperboard mill effluent treatment through floating platform vetiver technique. According to his study the lead concentration was dropped by 65.63%. Werner and Kadlec, 1996 stated that Roots accumulated more lead than leaves due to their high cation exchange capacity.

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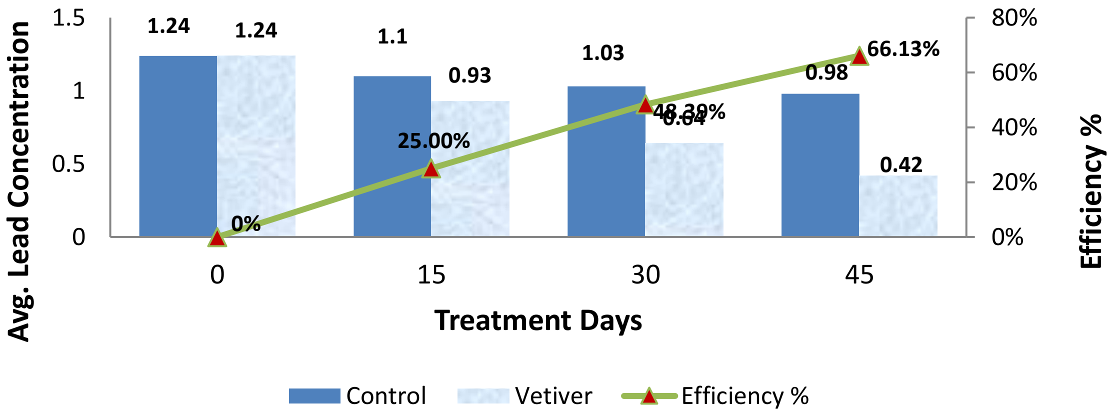


**Figure 10.** The Lead concentration and Removal Efficiency of treatment system with treatment time

**Table 2.** Average concentrations of tannery wastewater of the hydroponic treatment units and control units featuring vetiver grass cultivation and Removal Efficiency of treatment system

| Parameters | Raw Waste Water | | 15 Days | | | | 30 Days | | | | 45 Days | | | | Avg. Removal Efficiency % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vetiver | | Control | | Vetiver | | Control | | Vetiver | | Control | | |
| | Trial set | Mean | Trial set | Mean | Trial set | Mean | Trial set | Mean | Trial set | Mean | Trial set | Mean | Trial set | Mean | |
| **pH** | 9.38 | 9.47 | 8.86 | 8.92 | 9 | 9.31 | 7.99 | 8.23 | 8.74 | 9.14 | 6.94 | 7.12 | 8.62 | 9.01 | 5.81 |
| | 9.49 | | 8.88 | | 9.44 | | 8.32 | | 9.31 | | 7.01 | | 9.19 | | 13.09 |
| | 9.54 | | 9.02 | | 9.49 | | 8.38 | | 9.37 | | 7.41 | | 9.22 | | 24.82 |
| **EC (mS/cm)** | 12.96 | 13.01 | 11.44 | 11.47 | 12.85 | 12.88 | 8.97 | 9.02 | 12.56 | 12.64 | 8.2 | 8.23 | 12.39 | 12.45 | 11.84 |
| | 13.02 | | 11.45 | | 12.89 | | 9.01 | | 12.58 | | 8.24 | | 12.41 | | 30.67 |
| | 13.05 | | 11.52 | | 12.9 | | 9.08 | | 12.78 | | 8.25 | | 12.55 | | 36.74 |
| **$BOD_5$ (mg/l)** | 1468 | 1470 | 1039 | 1042 | 1397 | 1408 | 536.45 | 540.62 | 1372 | 1377 | 187 | 190 | 1347.23 | 1349.33 | 29.11 |
| | 1469 | | 1041 | | 1410 | | 541.31 | | 1378 | | 190 | | 1348.76 | | 63.22 |
| | 1473 | | 1046 | | 1417 | | 544.1 | | 1381 | | 193 | | 1352 | | 87.07 |
| **COD (mg/l)** | 2327 | 2330 | 1399 | 1403 | 2045 | 2050 | 886 | 889 | 1884 | 1890 | 350 | 352 | 1779 | 1781 | 39.79 |
| | 2331 | | 1403 | | 2051 | | 890 | | 1892 | | 353 | | 1780 | | 61.85 |
| | 2332 | | 1407 | | 2054 | | 891 | | 1894 | | 353 | | 1784 | | 84.89 |
| **TSS (mg/L)** | 1256.18 | 1259.02 | 970.19 | 973.14 | 1205 | 1210 | 408 | 410 | 1198.89 | 1200.49 | 200.03 | 201.23 | 1185 | 1187.38 | 22.71 |
| | 1259 | | 972.07 | | 1211 | | 409 | | 1200.47 | | 203.21 | | 1188.33 | | 67.43 |
| | 1261.88 | | 977.16 | | 1214 | | 413 | | 1202.11 | | 200.45 | | 1188.81 | | 84.02 |
| **TDS (mg/l)** | 6799 | 6801 | 5746 | 5750 | 6566 | 6568 | 4087 | 4094 | 6289 | 6299 | 1805 | 1810 | 6095 | 6101 | 15.45 |
| | 6800 | | 5751 | | 6568 | | 4096 | | 6300 | | 1811 | | 6099 | | 39.8 |
| | 6804 | | 5753 | | 6570 | | 4099 | | 6308 | | 1814 | | 6109 | | 73.39 |
| **Lead (mg/l)** | 1.11 | 1.24 | 0.89 | 0.93 | 0.98 | 1.1 | 0.58 | 0.64 | 0.97 | 1.03 | 0.38 | 0.42 | 0.94 | 0.98 | 25 |
| | 1.29 | | 0.93 | | 1.14 | | 0.63 | | 1.08 | | 0.41 | | 0.99 | | 48.39 |
| | 1.32 | | 0.97 | | 1.18 | | 0.71 | | 1.04 | | 0.47 | | 1.01 | | 66.13 |

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## CONCLUSION

Tannery effluents should not be discharged directly into surface water bodies, as they pose significant risks to human health and the environment. Vetiver technology can effectively bioremediate tannery wastewater. In a hydroponic system, vetiver's growth and biomass increase over time, enhancing its treatment potential. The study found that vetiver adapts to wastewater, improving pollutant removal. Based on the findings, we recommend for continued research and collaborative efforts among researchers, policymakers, and industry stakeholders, aimed at advancing the integration of vetiver bioremediation technology into mainstream wastewater treatment practices. This will enable vetiver technology's broad application and encourage long-term sustainability in industrial processes.

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