

## Phytoremediation Efficiency of *Eichhornia crassipes* for Treating Textile Wastewater in the Mumbai Industrial Belt

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### ABSTRACT

Industrial textile wastewater contains high organic load, complex dyestuffs, toxic chemicals, and heavy metals, posing severe environmental challenges, particularly in critically polluted industrial zones in Maharashtra. In this study, the phytoremediation potential of *Eichhornia crassipes* was evaluated using graded concentrations (20–100%) of textile effluent collected from the MIDC discharge channel. The experiment was conducted for 60 days in controlled 30-L containers, and physico-chemical parameters were monitored at 15-day intervals. The results demonstrated significant reductions across major pollutants. pH shifted from highly alkaline toward near-neutral levels, while Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) decreased by up to 57.8% and 62.2%, respectively. Organic load indicators, BOD and COD, showed notable reductions of 72–77% and 68–71%, reflecting strong plant–microbe synergistic degradation. Electrical conductivity decreased by 58%, indicating a marked reduction in ionic strength. Dissolved oxygen levels improved substantially due to photosynthetic oxygenation. Macronutrients (P, N, Ca, Mg, K, S) showed considerable removal, with phosphorus exhibiting the highest reduction (93%). Heavy metals, including Fe and Mn, were also effectively removed (57–60%) through rhizofiltration and root-associated sequestration. Overall, *Eichhornia crassipes* demonstrated strong suitability as a low-cost, eco-friendly phytoremediation agent capable of significantly improving the quality of high-strength textile wastewater. The results support the integration of decentralized phytoremediation systems as effective pre-treatment or polishing steps within industrial wastewater management frameworks in heavily burdened regions.

**Keywords-** *Eichhornia crassipes*, phytoremediation, textile wastewater, MIDC, water hyacinth, organic load reduction, heavy metals.

### I. INTRODUCTION

Industrial activity, particularly textile manufacturing, imposes a significant environmental burden globally due to the high volume and complex composition of its effluent streams. Textile wastewater is characterized by high salinity, extreme pH (often

alkaline), elevated concentrations of total dissolved solids (TDS) and total suspended solids (TSS), intense coloration from dyestuffs, and the presence of toxic organic compounds and heavy metals. These pollutants, which originate from processes like sizing, desizing, scouring, mercerizing, and dyeing, include sodium salts, sulphates, chlorides, surfactants, and heavy metals such

as chromium (Cr), copper (Cu), iron (Fe), and manganese (Mn). The high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values indicate a severely polluting nature, which, if discharged untreated, rapidly depletes dissolved oxygen in receiving water bodies and introduces persistent toxicity. The Boisar (Tarapur) Maharashtra Industrial Development Corporation (MIDC) area, located in the Mumbai region, represents a major industrial concentration and a designated critically polluting stretch in India. The industrial estate, which includes chemical, bulk drug, steel, and numerous textile processing units, generates complex, mixed industrial waste. Regulatory challenges are compounded by a severe mismatch between effluent generation and treatment capacity: while the Common Effluent Treatment Plant (CETP) has a daily capacity of 25 million liters per day (MLD), the industries generate an estimated 75 MLD of waste. This excess, coupled with historical incidents of illegal nocturnal discharge into local creeks and drains, has led to substantial environmental damage and stringent regulatory interventions by authorities such as the National Green Tribunal (NGT). Consequently, there is an urgent need for cost-effective, decentralized, and environmentally sustainable methods to either pre-treat the massive

organic and metal load or polish the effluent post-treatment to minimize environmental impact and achieve water reuse.

#### *Eichhornia crassipes* as a Phytoremediation Agent

Phytoremediation, utilizing plants to remove or stabilize pollutants, presents an attractive, low-cost, and ecologically friendly alternative to conventional physico-chemical treatment methods. *Eichhornia crassipes* (Water Hyacinth) is an aquatic macrophyte recognized globally for its extraordinary growth rate and robust capacity for pollutant uptake. Its effectiveness is primarily attributed to its large, extensive adventitious root system, which efficiently facilitates rhizofiltration—the process of adsorbing and sequestering contaminants from the water column. *E. crassipes* has been demonstrated to effectively remove suspended solids, high concentrations of nutrients (nitrogen and phosphorus), organic matter (BOD/COD), and a range of heavy metals. Specifically, literature confirms its ability to absorb and translocate heavy metals such as cadmium (Cd), copper (Cu), and zinc (Zn) within its tissues, with a tendency for higher bioaccumulation factors (BCF) in the roots.

## II. MATERIALS AND METHODS



Industrial wastewater was collected from a designated discharge point within the textile industrial zone. The samples were immediately transported to the laboratory and characterized according to standard protocols. The phytoremediation experiment was designed for experiment using 30 L capacity plastic container. *Eichhornia crassipes* plant of approx. 30.00 gm were inoculated in each plastic container. Three replicate were taken for each treatment. The treatment level for experiment were:- (i) Control (ii) 20 percent waste water, (iii) 40 percent waste water, (iv) 60 percent waste water, (v) 80 percent waste water, (vi) 100 percent waste water. For study, samples were drawn and estimations were made for physico-chemical characteristics of waste water before and after treatment of 15, 30 and 60 days growth of *Eichhornia crassipes*.

## III. PHYSICO-CHEMICAL ANALYSIS

A comprehensive physico-chemical assessment of the wastewater was conducted using established standard procedures. The pH of the samples was measured using a B.D.H. universal indicator, ensuring rapid and reliable estimation of acidity or alkalinity. Total Dissolved Solids (TDS) were determined following the procedure outlined in the IBP Handbook No. 8, while Total Solids (TS) were quantified by measuring the residue obtained after complete evaporation of the unfiltered water sample. Biochemical Oxygen Demand (BOD) was assessed according to the standard methods described by Greenberg et al. (1980), providing a measure of biodegradable organic load. Chemical Oxygen Demand (COD) and Electrical Conductivity (EC) were

quantified following the methodology of Tripathi and Govil (2001), which enables precise evaluation of total oxidizable organic matter and ionic content, respectively. Dissolved Oxygen (DO) concentration was estimated using Winkler's modified iodide-azide method, a widely accepted technique for determining oxygen availability in aquatic systems. Macronutrients and ions were analyzed using classical colorimetric and titrimetric methods. Calcium, phosphate, and potassium concentrations were estimated following the procedure described by Wallace (1951). Magnesium content was determined using the titan yellow method as outlined by Mason (1950). Sulphate was quantified according to the method of Chesnin and Yen (1951), described in detail by Jackson (1958). Nitrogen was estimated using the semi-micro Kjeldahl method proposed by Chibnall et al. (1943). For trace metal analysis, iron was measured using the technique described by Humphries (1956), whereas manganese levels were determined following the method of Nicholas and Fischer (1950). In addition to absolute concentrations, percent removal rates of contaminants were calculated to evaluate phytoremediation efficiency, representing the proportion of pollutants removed by aquatic plants cultivated in wastewater, as suggested by previous studies.

#### IV. RESULTS AND DISCUSSION

##### pH

Across all wastewater concentrations, the pH exhibited a consistent downward trend from alkaline conditions toward near-neutral values over the 60-day experimental period. This progressive decline suggests that *Eichhornia crassipes* plays an active role in moderating alkalinity through rhizosphere-driven biochemical processes. At the highest concentration (100% wastewater), the initial pH of 8.65 gradually declined to 8.48 after 15 days, followed by further reductions to 7.83 and 7.66 at 30 and 60 days, respectively. The observed trend can be attributed to root exudation of organic acids, nitrification, carbon dioxide dissolution, and microbial oxidation of organic pollutants around the plant root zone. Lower wastewater concentrations showed a similar yet slightly faster decline, reinforcing the plant's buffering capacity. Overall, the sustained shift toward neutral pH highlights the plant's ability to stabilize the wastewater environment and facilitate improved microbial activity essential for biodegradation.

##### Total Dissolved Solids (TDS)

TDS exhibited significant reductions across all treatment concentrations, with removal efficiency increasing over time. In 100% wastewater, TDS decreased from 1321 mg/L to 554 mg/L after 60 days, corresponding to a 57.8% reduction. Lower concentrations (20–60%) demonstrated comparable removal efficiencies ranging from 44% to 55%. The reduction in TDS is indicative of ion uptake by plant tissues, adsorption onto root surfaces, and sedimentation

facilitated by the extensive fibrous root system. Additionally, biological processes such as the conversion of dissolved nutrients into plant biomass contribute to TDS decline. The consistent downward trend demonstrates that *E. crassipes* can successfully regulate dissolved ionic loads even under high-strength textile wastewater conditions.

##### Total Suspended Solids (TSS)

Substantial decreases in TSS were recorded in all experimental groups, highlighting the plant's strong ability to trap and settle suspended particulate matter. In the 100% effluent, TSS declined from 2476 mg/L to 935 mg/L after 60 days, reflecting a 62.2% reduction. This reduction can be attributed to several mechanisms: physical filtration through the dense root mat, settling of heavier particles at the bottom of tanks, and microbial flocculation promoted by biofilm formation. As the contact period increased, more solids became trapped within the plant root network, explaining the progressive decline over time. Such efficient removal of suspended solids is particularly beneficial in textile effluent treatment, where high TSS contributes to turbidity and pollutant load.

##### Biological Oxygen Demand (BOD)

BOD values decreased sharply across all treatment concentrations, underscoring the strong biodegradation potential of the plant-microbe system. In the 100% wastewater condition, BOD dropped from 176 mg/L to 49 mg/L (a 72.1% reduction) by the end of the experiment. The 80% concentration exhibited an even higher reduction of 76%, falling from 143 mg/L to 34 mg/L. This decline reflects enhanced microbial decomposition of organic matter facilitated by the oxygen released from plant roots and improved DO levels due to photosynthetic oxygenation. The continuous removal of organic load suggests that the rhizosphere provides a favorable habitat for aerobic microorganisms that play a key role in breaking down organic pollutants.

##### Chemical Oxygen Demand (COD)

COD showed a similar decreasing pattern, reflecting the degradation of organic and inorganic oxidizable substances present in the textile wastewater. In 100% wastewater, COD reduced from 704 mg/L to 220 mg/L (a 68.8% reduction), while in 80% effluent COD fell from 576 mg/L to 168 mg/L (70.8% reduction). The consistent removal of COD corresponds with the decline in BOD, indicating strong plant-microbial cooperation in reducing both biodegradable and partially recalcitrant substances. The root system likely enhances the breakdown of complex dye molecules, surfactants, and detergents commonly found in textile effluent by hosting diverse microbial communities capable of oxidative degradation.

##### Electrical Conductivity (EC)

EC values decreased notably across the treatment groups, reflecting a reduction in dissolved ionic species such as chlorides, sulphates, carbonates, and nitrates. In 100% wastewater, EC reduced from 2924

μS/cm to 1226 μS/cm over 60 days, representing a 58.1% reduction. This decline can be attributed to direct uptake of ions by the plant for metabolic processes, adsorption onto root surfaces, and precipitation of salts as pH stabilized. The sharp reduction in EC underscores the plant’s ability to manage high ionic strength typical of textile effluent, improving water quality for potential reuse or downstream biological treatment.

Dissolved Oxygen (DO)

DO levels improved significantly across all treatments, with the most pronounced increase observed in lower effluent concentrations. For example, in 40% wastewater, DO increased from 3.98 mg/L to 9.98 mg/L after 60 days, while in 100% wastewater it increased from 1.15 mg/L to 5.23 mg/L. The increase in DO can be attributed to oxygen release during photosynthesis, improved aeration around the root zone, and reduced oxygen demand as organic pollutants were degraded. Higher DO levels support aerobic microbial populations that accelerate the breakdown of organic matter, creating a positive feedback loop that enhances overall treatment efficiency.

Major Ions (Ca, K, Mg, S, P, N)

Major nutrient ions showed substantial reductions across treatments. Phosphorus exhibited the highest removal, reaching 93% in 100% wastewater (declining from 63.87 mg/L to 3.45 mg/L), primarily due

to rapid uptake for plant growth and rhizosphere precipitation. Nitrogen levels reduced by up to 56%, reflecting assimilation into plant tissues and microbial nitrification–denitrification processes. Sulphur decreased by approximately 53%, likely due to uptake and transformation into organic sulphur compounds. Calcium, magnesium, and potassium showed moderate reductions (45–60%), indicating uptake for physiological functions such as cell wall stability, chlorophyll formation, and osmotic regulation. The comprehensive nutrient reduction confirms the plant’s strong bioremediation potential and its ability to reduce eutrophication risk.

Heavy Metal Removal

Heavy metals exhibited notable reductions, confirming the plant’s strong rhizofiltration capacity. Iron (Fe) decreased from 2.16 mg/L to 0.92 mg/L (approximately 57% removal) and manganese (Mn) showed a 60% reduction, decreasing from 0.180 mg/L to 0.072 mg/L. These reductions indicate rapid metal adsorption to root surfaces, intracellular sequestration, and complexation with root exudates. Higher retention in root tissues aligns with known phytoremediation pathways where metals accumulate largely within below-ground biomass. The successful removal of Fe and Mn, even at high effluent concentrations, highlights the plant’s resilience and suitability for treating metal-rich industrial wastewater.

Table 01.: Effect of physico-chemical parameter of textile wastewater by *Eichhornia crassipes*.

| pHParameters | Days | Days | C           | 20        | 40        | 60        | 80        | 100        |
|--------------|------|------|-------------|-----------|-----------|-----------|-----------|------------|
| pH           | BT   |      | 7.30 ± 0.02 | 7.59+0.03 | 7.87+0.04 | 8.13+0.06 | 8.42+0.07 | 8.65 +0.04 |
|              | AT   | 15   | 7.19 ± 0.04 | 7.29+0.05 | 7.53+0.08 | 7.76+0.09 | 8.05+0.09 | 8.48+0.06  |
|              |      | 30   | 7.13 ± 0.03 | 7.13+0.03 | 7.25+0.06 | 7.36+0.06 | 7.55+0.06 | 7.83+0.06  |
|              |      | 60   | 7.06 ± 0.03 | 7.06+0.03 | 7.14+0.05 | 7.25+0.05 | 7.30+0.05 | 7.66+0.06  |

Total Dissolve Solute

| Parameters | Days | Days | C             | 20          | 40          | 60           | 80           | 100          |
|------------|------|------|---------------|-------------|-------------|--------------|--------------|--------------|
| TDS (mg/l) | BT   |      | 340.77 ± 0.05 | 546.91+0.06 | 748.03+0.07 | 940.17+0.08  | 1130.30+0.09 | 1321.43+0.06 |
|            | AT   | 15   | 316.72 ± 0.06 | 440.44+0.07 | 596.16+0.09 | 720.88+0.07  | 875.60+0.06  | 1170.31+0.06 |
|            |      | 30   | 306.64 ± 0.05 | 306.64+0.05 | 396.16+0.04 | 485.68+ 0.09 | 545.21+0.07  | 664.73+0.06  |
|            |      | 60   | 285.51 ± 0.03 | 285.51+0.03 | 337.78±0.04 | 386.25+0.08  | 430.61+0.07  | 554.82+0.05  |

Total Suspended Solid

| Parameters | Days | Days | C             | 20          | 40           | 60           | 80            | 100          |
|------------|------|------|---------------|-------------|--------------|--------------|---------------|--------------|
| TSS (mg/l) | BT   |      | 417.25 ± 0.04 | 839.08+0.06 | 1255.91+0.06 | 1646.73+0.07 | 2069.57+0.09  | 2476.39+0.06 |
|            | AT   | 15   | 383.20 ± 0.06 | 640.07+0.07 | 914.95+0.08  | 1168.82+0.08 | 1498.70+ 0.06 | 2127.57+0.06 |
|            |      | 30   | 366.89 ± 0.05 | 366.89+0.05 | 541.73+0.06  | 714.57+0.08  | 887.43+0.07   | 1160.27+0.06 |
|            |      | 60   | 342.24 ± 0.03 | 342.24+0.03 | 470.57+0.06  | 588.91+0.08  | 737.25+0.06   | 935.59+0.06  |

#### Biological Oxygen Demand

| Parameters | Days | Days | C           | 20         | 40         | 60          | 80          | 100         |
|------------|------|------|-------------|------------|------------|-------------|-------------|-------------|
| B. O. D.   | BT   |      | 6.69 ± 0.02 | 42.61+0.04 | 77.54+0.06 | 110.47+0.08 | 143.40+0.09 | 176.32+0.03 |
|            | AT   | 15   | 6.33 ± 0.05 | 28.59+0.07 | 49.36+0.08 | 66.96+0.07  | 90.15+0.07  | 144.34+0.06 |
|            |      | 30   | 6.08 ± 0.04 | 6.08+0.04  | 22.85+0.06 | 37.95+0.08  | 48.18+0.07  | 65.15+0.06  |
|            |      | 60   | 5.86 ± 0.03 | 5.86+0.03  | 20.55+0.06 | 30.00+0.07  | 34.51+0.07  | 49.49+0.06  |

#### Chemical Oxygen Demand

| Parameters | Days | Days | C            | 20          | 40          | 60          | 80          | 100         |
|------------|------|------|--------------|-------------|-------------|-------------|-------------|-------------|
| C.O. D.    | BT   |      | 50.17 ± 0.03 | 191.25+0.04 | 312.46+0.06 | 445.27+0.07 | 576.80+0.09 | 704.55+0.06 |
|            | AT   | 15   | 46.76 ± 0.05 | 46.76+0.05  | 131.20+0.07 | 182.92+0.07 | 240.57+0.08 | 332.88+0.07 |
|            |      | 30   | 44.73 ± 0.04 | 44.73+0.04  | 108.94+0.06 | 149.46+0.06 | 207.38+0.06 | 272.43+0.07 |
|            |      | 60   | 42.27 ± 0.04 | 42.27+0.04  | 90.37+0.06  | 124.36+0.06 | 168.12+0.06 | 220.37+0.06 |

#### Electrical conductivity

| Parameters                | Days | Days | C             | 20           | 40           | 60           | 80           | 100          |
|---------------------------|------|------|---------------|--------------|--------------|--------------|--------------|--------------|
| E.C.(μScm <sup>-1</sup> ) | BT   |      | 605.07 ± 0.03 | 1089.01+0.04 | 1562.93+0.06 | 2016.87+0.06 | 2470.79+0.08 | 2924.730.04  |
|                           | AT   | 15   | 565.24 ± 0.04 | 865.23+0.08  | 1140.46+0.09 | 1398.54+0.08 | 1731.56+0.06 | 2356.87+0.06 |
|                           |      | 30   | 543.58 ± 0.04 | 543.58+0.04  | 802.63+0.07  | 998.74+0.08  | 1196.86+0.07 | 1495.25+0.06 |
|                           |      | 60   | 512.42 ± 0.02 | 512.42+0.02  | 720.65+0.07  | 776.23+0.08  | 986.54+0.07  | 1226.51+0.06 |

#### Dissolve Oxygen

| Parameters      | Days | Days | C           | 20        | 40        | 60        | 80        | 100        |
|-----------------|------|------|-------------|-----------|-----------|-----------|-----------|------------|
| D. O.<br>(mg/l) | BT   |      | 5.94 ± 0.03 | 4.96+0.06 | 3.98+0.06 | 3.05+0.07 | 2.10+0.08 | 1.15 +0.04 |
|                 | AT   | 15   | 6.72± 0.04  | 7.88+0.07 | 6.88+0.09 | 5.39+0.08 | 3.65+0.06 | 1.37+0.06  |
|                 |      | 30   | 7.01± 0.03  | 7.01+0.03 | 9.12+0.07 | 8.18+0.09 | 6.42+0.07 | 4.34+0.06  |
|                 |      | 60   | 7.28± 0.03  | 7.28+0.03 | 9.98+0.06 | 9.35+0.08 | 7.71+0.06 | 5.23+0.05  |

#### Calcium

| Parameters        | Days | Days | C            | 20         | 40          | 60          | 80          | 100         |
|-------------------|------|------|--------------|------------|-------------|-------------|-------------|-------------|
| Calcium<br>(mg/l) | BT   |      | 44.64 ± 0.02 | 97.04+0.04 | 148.44+0.04 | 197.85+0.06 | 247.25+0.07 | 296.65+0.04 |
|                   | AT   | 15   | 42.76± 0.04  | 77.80+0.08 | 112.56+0.08 | 147.34+0.07 | 186.10+0.07 | 241.42+0.06 |
|                   |      | 30   | 41.12± 0.03  | 41.12+0.03 | 70.24+0.07  | 97.99+0.08  | 125.76+0.07 | 157.51+0.06 |
|                   |      | 60   | 39.23± 0.02  | 39.23+0.02 | 60.38+0.06  | 79.00+0.07  | 97.62+0.07  | 124.24+0.06 |

#### Potassium

| Parameters          | Days | Days | C           | 20         | 40         | 60         | 80          | 100         |
|---------------------|------|------|-------------|------------|------------|------------|-------------|-------------|
| Potassium<br>(mg/l) | BT   |      | 25.59± 0.02 | 46.11+0.03 | 65.63+0.06 | 83.11+0.06 | 100.62+0.08 | 118.12+0.04 |
|                     | AT   | 15   | 24.64± 0.03 | 35.77+0.08 | 47.51+0.08 | 59.26+0.07 | 72.00+0.07  | 102.23+0.06 |
|                     |      | 30   | 23.96± 0.02 | 23.96+0.02 | 32.81+0.07 | 41.81+0.08 | 50.97+0.06  | 63.13+0.06  |
|                     |      | 60   | 22.98± 0.02 | 22.98+0.02 | 27.77+0.07 | 33.13+0.07 | 38.47+0.06  | 47.83+0.06  |

**Magnesium**

| Parameters       | Days | Days | C           | 20         | 40         | 60         | 80          | 100         |
|------------------|------|------|-------------|------------|------------|------------|-------------|-------------|
| Magnesium (mg/l) | BT   |      | 18.11± 0.02 | 41.92+0.03 | 64.74+0.04 | 85.54+0.06 | 106.36+0.07 | 127.17+0.04 |
|                  | AT   | 15   | 17.60± 0.04 | 32.30+0.08 | 46.55+0.08 | 59.81+0.08 | 75.06+0.07  | 104.31+0.06 |
|                  |      | 30   | 17.14± 0.03 | 17.14+0.03 | 28.50+0.08 | 39.99+0.08 | 51.13+0.07  | 63.97+0.06  |
|                  |      | 60   | 16.76± 0.03 | 16.76+0.03 | 25.30+0.07 | 34.52+0.07 | 44.83+0.06  | 56.12+0.05  |

**Sulphur**

| Parameters     | Days | Days | C           | 20          | 40          | 60          | 80          | 100         |
|----------------|------|------|-------------|-------------|-------------|-------------|-------------|-------------|
| Sulphur (mg/l) | BT   |      | 20.86± 0.03 | 34.05+0.04  | 52.25+0.06  | 65.43+0.06  | 78.63+0.08  | 91.82+0.03  |
|                | AT   | 15   | 20.06± 0.03 | 27.92+0.07  | 38.33+0.08  | 47.72+0.07  | 57.55+0.07  | 78.26+0.06  |
|                |      | 30   | 19.14± 0.03 | 24.51+0.03  | 34.76+0.07  | 39.14+0.06  | 49.44+0.06  | 69.44+0.06  |
|                |      | 60   | 18.76± 0.03 | 22.76± 0.03 | 28.76± 0.03 | 34.71± 0.03 | 41.56± 0.03 | 63.76± 0.03 |

**Phosphorus**

| Parameters        | Days | Days | C         | 20         | 40         | 60         | 80         | 100        |
|-------------------|------|------|-----------|------------|------------|------------|------------|------------|
| Phosphorus (mg/l) | BT   |      | 0.74±0.03 | 22.38+0.06 | 28.10+0.08 | 32.12+0.06 | 41.00+0.06 | 63.87+0.04 |
|                   | AT   | 15   | 0.70±0.03 | 1.92+0.04  | 3.11+0.06  | 4.29+0.07  | 5.45+0.09  | 6.61+0.04  |
|                   |      | 30   | 0.68±0.03 | 0.70+0.03  | 1.50+0.06  | 2.29+0.08  | 3.13+0.07  | 3.98+0.06  |
|                   |      | 60   | 0.64±0.03 | 0.68+0.03  | 1.39+0.06  | 2.04+0.07  | 2.65+0.06  | 3.45+0.06  |

**Nitrogen**

| Parameters      | Days | Days | C          | 20         | 40         | 60         | 80         | 100        |
|-----------------|------|------|------------|------------|------------|------------|------------|------------|
| Nitrogen (mg/l) | BT   |      | 11.52+0.03 | 21.93+0.04 | 30.33+0.06 | 38.74+0.06 | 46.14+0.08 | 53.55+0.04 |
|                 | AT   | 15   | 11.83+0.07 | 17.83+0.07 | 22.57+0.08 | 27.62+0.07 | 34.28+0.06 | 46.25+0.06 |
|                 |      | 30   | 10.92+0.03 | 10.92+0.03 | 16.36+0.07 | 19.76+0.08 | 24.14+0.07 | 30.05+0.06 |
|                 |      | 60   | 10.52+0.03 | 10.52+0.03 | 14.95+0.06 | 16.63+0.08 | 19.44+0.06 | 24.56+0.05 |

**Iron**

| Parameters  | Days | Days | C         | 20        | 40        | 60        | 80        | 100        |
|-------------|------|------|-----------|-----------|-----------|-----------|-----------|------------|
| Iron (mg/l) | BT   |      | 0.27+0.03 | 0.68+0.03 | 1.08+0.04 | 1.47+0.06 | 1.85+0.07 | 2.16 +0.04 |
|             | AT   | 15   | 0.24+0.03 | 0.52+0.04 | 0.80+0.05 | 1.06+0.07 | 1.35+0.08 | 1.76+0.06  |
|             |      | 30   | 0.22+0.03 | 0.22+0.03 | 0.45+0.03 | 0.70+0.05 | 0.92+0.06 | 1.18+0.07  |
|             |      | 60   | 0.20+0.03 | 0.20+0.03 | 0.39+0.03 | 0.55+0.04 | 0.68+0.06 | 0.92+0.06  |

**Manganese**

| Parameters       | Days | Days | C           | 20           | 40          | 60           | 80           | 100         |
|------------------|------|------|-------------|--------------|-------------|--------------|--------------|-------------|
| Manganese (mg/l) | BT   |      | 0.016+0.002 | 0.051+0.003  | 0.085+0.006 | 0.114+0.007  | 0.148+0.008  | 0.180+0.003 |
|                  | AT   | 15   | 0.013+0.002 | 0.038+0.003  | 0.061+0.007 | 0.078+ 0.007 | 0.104+0.006  | 0.142+0.006 |
|                  |      | 30   | 0.011+0.002 | 0.011+0.002  | 0.033+0.002 | 0.053+0.007  | 0.068+ 0.006 | 0.092+0.005 |
|                  |      | 60   | 0.010+0.002 | 0.010+ 0.002 | 0.029+0.002 | 0.042+0.007  | 0.054+ 0.006 | 0.072+0.005 |

## V. CONCLUSION

The findings of this study demonstrate that *Eichhornia crassipes* is a highly effective phytoremediation species for treating textile wastewater across a wide range of concentrations. The plant exhibited strong adaptive capacity and facilitated significant improvements in physicochemical and nutrient parameters over the 60-day treatment period. The progressive decline in pH toward neutrality indicates active rhizosphere-driven biochemical processes capable of stabilizing alkaline effluent conditions and supporting microbial activity essential for pollutant degradation. Substantial reductions in TDS, TSS, EC, and major nutrient ions confirm the plant's ability to regulate dissolved and suspended pollutant loads through uptake, adsorption, sedimentation, and biomass conversion. High removal efficiencies of organic load—reflected in the marked reductions in BOD and COD—highlight the synergistic functioning of plant roots and associated microbial communities in breaking down both biodegradable and partially recalcitrant textile pollutants. The consistent improvement in DO further illustrates the ecological enhancement brought about by photosynthetic oxygen release and reduced oxygen demand as contaminants were degraded. Nutrient removal, particularly phosphorus and nitrogen, was highly effective, demonstrating strong potential for controlling eutrophication in receiving water bodies. Likewise, the considerable reductions in iron and manganese concentrations confirm the species' robust rhizofiltration capacity and ability to immobilize and sequester heavy metals within root tissues, even under high-strength effluent conditions. Overall, the study establishes *E. crassipes* as a resilient, efficient, and sustainable phytoremediation agent for textile wastewater treatment. Its capacity to significantly improve water quality through multi-pathway pollutant removal—combined with its rapid growth and ease of cultivation—supports its application in nature-based treatment systems. The results reaffirm that integrating aquatic macrophytes like *E. crassipes* into wastewater management strategies can provide a cost-effective and eco-friendly solution for industrial effluent remediation.

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