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Sustainable Primary Treatment of Textile Wastewater: Evaluating Water Hyacinth—Eichhornia crassipes Biomass as a Low-Cost Bioflocculant

Shoaib Ahmad, Abdul Majid and Bilal Haider*

Institute of Chemical Engineering and Technology, University of the Punjab, Lahore, Pakistan
*Corresponding author. E-mail: bilal.icet@pu.edu.pk

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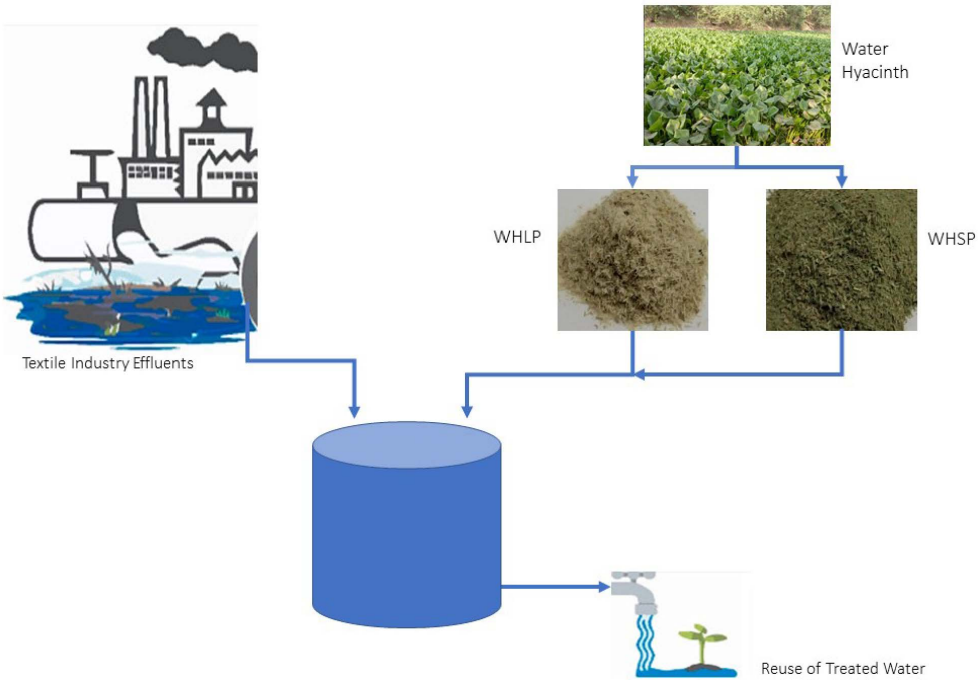
Abstract

Water treatment is required for the textile sector to meet National Environmental Quality criteria (NEQS) and client-specific effluent criteria, such as zero discharge of toxic chemicals (ZDHC). Textile Wastewater suspensions were flocculated or coagulated using ferric chloride, alum sulfate, or poly aluminum chloride (PAC). The Water Hyacinth (WH) plant, which grows mostly on residential Wastewater ponds, is utilized for wetland Wastewater treatment to mitigate the harmful effects of these chemicals on the ecosystem and facilitate the creation of massive chemical sludge. Its efficacy as a flocculent was evaluated in this study. Under specific operating conditions, two consecutive processes that use flocculation and sedimentation treatments were used. Powdered WH stem and leaves were utilized as a bioflocculant for this purpose. The findings of experiments conducted with this biomass were extraordinary in that they sufficiently reduced the levels of total dissolved solids (TDS), total suspended solids (TSS), and chemical oxygen demand (COD). The percentages of reduction for these parameters are as follows: for WH stem powder (WHSP), it was 9.5%, 42.3%, 5.5%, respectively and for WH leaves powder (WHLP), it was 18.2%, 74.4%, 16.4%, respectively. This study's experimental findings confirmed that the Wastewater's initial treatment had resulted in a decrease in COD, TSS, and TDS. This biomass derived from plants has fewer adverse effects

on the environment and produces less sludge. For the initial treatment of textile effluent, this biomass can replace conventional chemicals in an environmentally responsible manner.

Keywords: Bioflocculation, COD, Suspended solids, Textile wastewater, Water hyacinth

Graphical Abstract



1. Introduction

Pakistan is the fourth-largest textile manufacturer in the world, with over 473 spinning units and 53 composite units, according to a 2012 survey. It is the primary source of income generation in the country [1]. The industries of weaving, hosiery, denim, knit, and towel production have a significant export potential to western nations. Over 50% of Pakistan's total exports are textiles. Pakistan is home to approximately 670 textile industries; sadly, none of these industrial zones have a Wastewater system planned [2, 3]. Lead, nickel, arsenic, chromium, and cadmium have been detected in significant concentrations in this Wastewater. Various fabric types, including cotton, polyester, rayon, silk, wool, and nylon, are produced by the textile industry [3, 4]. For sizing, bleaching, scouring, mercerization, dying, printing, and finishing, textile industries use a variety of chemicals and dyes, such as wetting agents, peroxide, sodium hydroxide, stabilizers, lubricants, peroxide killers,

soda ash, acetic acid, sequestering agents, fixing agents, sodium chloride, dyeing components, and softeners with a lot of water [5, 6]. The properties of textile Wastewater are listed in Table 1. The acceptable limit of Wastewater contents is given in Table 1 which is based on the National Environmental Quality Standards **(NEQS)** [1] .

Table 1. Characteristics and acceptable limits of textile Wastewater.

Parameters	Textile Wastewater contents	Acceptable limit
COD	150–10000 ppm	150 ppm
BOD	100–4000 ppm	80 ppm
TSS	100–500 ppm	200 ppm
Alkalinity	1800–6000 ppm	1500 ppm
pH	6–10	-
Chlorides	1000–6000 ppm	1000 ppm
Sodium	610–2170 ppm	1200 ppm
Temperature	35–45 °C	37 °C
TS	3500 ppm	3700 ppm

Source: [11]; [19].
Source: [21] (NEQS, 2000; ZDHC, 2016).

1.1. Established process for textile Wastewater treatment

Textile Wastewater treatment generally involves pre-treatment, primary or chemical treatment, secondary or biological (both anaerobic & aerobic) treatment, and tertiary treatment. Large particles are removed in primary treatment by using screens and grit chambers. Biological contents are removed by microorganisms during secondary treatment processes. Tertiary treatment is performed before releasing the water to water bodies and includes filtration processes as shown in the Figure 1. Important information about these methods is elucidated in later sections [7–9].

Comparisons of different textile Wastewater limit values are shown in Table 2. The National Environment Quality Standards (NEQS) are compared with standards of WHO and Zero Discharge Hazardous Chemicals (ZDHC) provided by United Nations, as shown in the Table 2.

There is always a concern about the residuals in the water treated with conventional chemicals, which may have a negative impact on the environment and human health. It is therefore prudent to replace these chemical products with natural substances produced from plant material for the coagulation/flocculation processes, given the limitations of these technologies [8]. Prior to the advent of synthetic chemicals, natural coagulants and plant-based bioflocculants were utilized

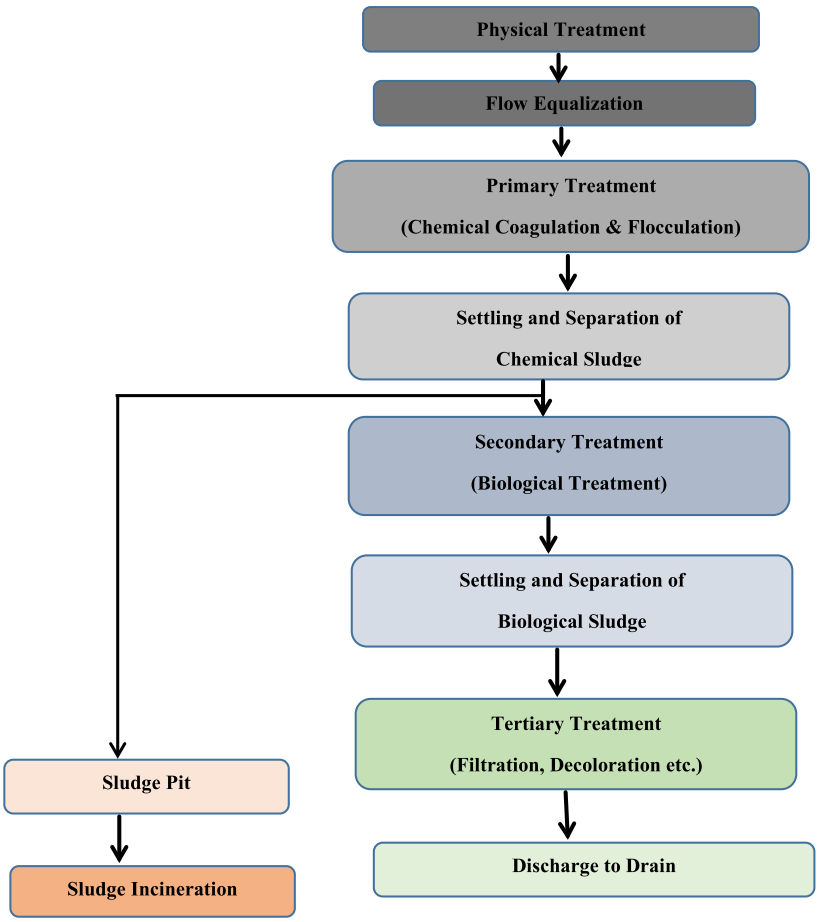


Figure 1. A typical sequence of operations involved in textile Wastewater treatment [2].

in the treatment of water and Wastewater [10, 11]. Due to their abundance, safety characteristics for human health, and other advantages, they have a promising future and are actively studied. They also yield less voluminous and biodegradable sludge [12, 13].

On residential Wastewater ponds, the free-floating perennial aquatic plant (hydrophyte), water Hyacinth (WH) (*Eichhornia crassipes*) grows rapidly. WH can reach a height of one meter over the surface of water and Wastewater ponds due to their thick, broad, glossy, and ovate leaves [14–16]. The buoyant bulb-like nodules at the foot of WH's stem allow the leaves, which measure 10 to 20 cm in diameter, to float above the surface of water [17, 18].

Therefore, this study's goal was to substitute the chemical coagulant or flocculants used in the textile effluent treatment process. Total suspended solids (TSS), chemical oxygen demand (COD) reduction and total dissolved solids (TDS) were used to assess the effectiveness of this treatment.

Table 2. Comparison of different textile Wastewater limit values (WHO, AbwV, 1997; NEQS, 2000; ZDHC, 2016).

(mg/l) unless otherwise noted	NEQS	WHO	AbwV	ZDHC Foundational	ZDHC Progressive	ZDHC Aspirational
Temperature (°C)	≤3*			≤35**	≤30**	≤25**
COD	150	≤125	160	160	80	40
BOD_5	80	≤20	25	30	15	5
TDS	3500					
TSS	200			50	15	5
Total-N		20	20	20	10	5
NH4-N	40		10	10	1	0.5
Total-P		1.0	2	3	0.5	0.1
Sulphite			1			
AOX			0.5	5	1	0.1
Colour (436 nm) (m^{-1})			7	7	5	2
Colour (525 nm) (m^{-1})			5	5	3	1
Colour (620 nm) (m^{-1})			3	3	2	1
Oil and Grease	10			10	2	0.5
Phenol	0.1			0.5	0.01	0.001
Coliform (bacteria/100 ml)				400	100	25

*The effluent should not result in temperature increase more than 3 °C (...) (NEQS, 2000).

**Degrees above ambient temperature of receiving water body (ZDHC, 2016).

2. *Materials and methods*

2.1. Materials

2.1.1. Water Hyacinth (WH) (Eichhornia crassipes)

The water ponds in the neighboring village areas of Lahore are the sources of WH (*Eichhornia crassipes*). To remove dust, it was cleaned and dried after collection. Separately crushed, the stem and leaves were sieved to a 20-mesh size as shown in the Figure 2–5.

2.1.2. Wastewater

Wastewater was obtained from the outlet drain of the dyeing unit of Kohinoor Mills Limited.

2.1.3. Testing material

- COD testing vials, Range (0 to 15000 ppm) were provided by HACH LANGE, Germany.
- COD testing vials, Range (0 to 1500 ppm) were supplied by HACH LANGE, Germany.
- Distilled water prepared at an in-house lab of Kohinoor Mills Limited, Pakistan.



Figure 2. Harvested Water Hyacinth.

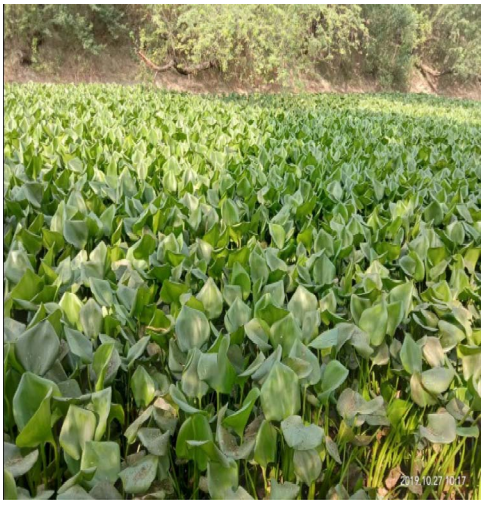


Figure 3. Water Hyacinth plant in water.

- Calibration solution for "HI 98194 EC/DO Multiparameter" sourced from HANNA instruments Italy/USA (Abdul Majid, 2020).
- FTIR of both WHSP and WHLP was obtained from Workhorse Benchtop (USA) FTIRs 200-X with standard measurement range 400–7000 cm^{-1}.
- TGA was obtained from Shimadzu TGA-50/51 Thermogravimetric analysis. This instrument was procured from Shimadzu corporation Japan.
- Optical compound Microscope (Leica) with magnification 10 × (eyepiece) × 10× (objective) = 100× was used to analyse the microscopic structures of WHSP and WHLP. The compound microscope used was sourced from Leica Microsystems, Germany.



Figure 4. Ground WH Stem Powder (WHSP).



Figure 5. Ground WH Leaves Powder (WHLP).

2.1.4. Chemicals

Potassium dichromate (Reagent Grade, ≥99.5%) and sulfuric acid (ACS Grade, 95–98%) were purchased from Sigma-Aldrich (Merck KGaA, Darmstadt, Germany).

2.2. Methods

The bioflocculant's efficacy was assessed by treating Wastewater using the jar test approach. In jar testing, samples of crude Wastewater stored in jars were mixed with a predetermined amount of bioflocculant [19, 20]. After that, the sample was agitated to allow for floc formation, development, and settlement in a manner like that of a full-scale treatment plant.

2.2.1. Collection of Wastewater sample

The Wastewater sample was taken after every eight hours from the common exit drain of the dyeing unit of Kohinoor Mills Limited. Ultimately, all of the individual

samples were combined to create a composite sample. The 100-liter plastic drums were used to collect the Wastewater. The Wastewater had a dark brown colour. A sample of collected Wastewater was kept at 200 °C in Kohinoor Mills Limited's Wastewater testing lab. The goal of controlled storage was to preserve the Wastewater's characteristics over an extended period of time [15, 21, 22].

2.2.2. Testing parameters

The collected Wastewater underwent basic parameter testing, including COD, EC, DO, TSS, and TDS. Prior to testing, the Wastewater was well mixed.

2.2.2.1. COD The sealed-tube colorimetric approach was used to measure the COD of the Wastewater sample. A pre-dosed mixture of sulfuric acid and potassium dichromate was placed in a Hach Lange COD reagent vial, and 2 ml volume of the collected Wastewater was carefully added. To oxidize all organic and inorganic particles, this mixture was subsequently digested for 2 h at 150 °C in a dedicated COD reactor. A spectrophotometer, which measures the colour change proportionate to the oxygen needed for oxidation, was used to assess the COD content after digestion and chilling.

2.2.2.2. EC EC was measured using a calibrated EC meter to determine the total concentration of dissolved salts and ions. The probe was submerged directly into the Wastewater sample, and the instrument's reading, corrected for temperature, provided a precise value in μS/cm.

2.2.2.3. DO DO concentration was determined using a calibrated DO meter with an electrochemical probe. The probe was carefully immersed into the Wastewater sample to prevent aeration, and the meter provided a direct reading in mg/L.

2.2.2.4. TSS The conventional gravimetric method was used to quantify TSS. A glass fiber filter which was previously weighed was used to vacuum filter a 100 ml Wastewater sample. The filter, with the captured solids, was subsequently dried at 105 °C to a constant weight. The weight difference was then used to determine the final mass of the solids, giving a precise measurement of the non-filterable residue.

2.2.2.5. TDS The gravimetric evaporation method was used to analyze the total dissolved solids (TDS). To evaporate the liquid, a measured volume of the filtered Wastewater sample was moved to an evaporating dish which was previously weighed and heated to 180 °C. After cooling, the resultant residue was weighed, and the mass difference was used to calculate the concentration of TDS in milligrams per liter.

2.2.3. Mixing of bioflocculant in the Wastewater

After weighing the powdered Hyacinth leaves and stem using a balance, one liter of Wastewater was added to a glass beaker containing the bioflocculant. At 450 rpm

and 25 °C, the glass beaker was then set on a magnetic stirrer plate. After 30 min of mixing, the mixture was left for 20 min to allow the suspended components to settle in the Wastewater [4, 23].

3. Results and discussion

The initial treatment of textile Wastewater was done using WHSP and WHLP. The principal aim was to investigate the adsorption characteristics and efficacy of the two biomasses derived from the same plant for the initial Wastewater treatment process. This study also investigated the sustainability of this solution for Wastewater treatment. This study examined how different biomass concentrations affected Wastewater's COD, TSS, TDS, and EC. By varying the dosage of each biomass, a comparison was made to determine the effective quantity of biomass for treating Wastewater initially.

3.1. Water Hyacinth stem powder (WHSP)

3.1.1. Effect of WHSP concentration on COD of Wastewater

WHSP reduced the Wastewater's COD as shown in Figure 6. There was a maximum reduction at 5 g/L WHSP concentration, as shown in Table 1 (see supplementary data). Further increase in concentration of WHSP had the opposite effect. A 5.5% COD reduction was observed while using WHSP, depicting a sustainable solution for Wastewater treatment. Although, the reduction efficiency is lower than that of conventional chemicals and few other biomasses, its sustainability and cost efficiency make it a suitable option for Wastewater treatment.

3.1.2. Effect of WHSP concentration on TSS of Wastewater

The quantity of suspended solids in the Wastewater was successfully decreased by the increase in WHSP concentration as shown in Figure 6. The 5 g/L concentration of WHSP has decreased the TSS up to 42.5% as shown in Table 2 (see supplementary data). Further increases in the concentration of WHSP had an adverse effect and caused suspensions that began floating on the Wastewater's surface. Therefore, the TSS contents increased after a certain value of concentration.

3.1.3. Effect of WHSP concentration on TDS of Wastewater

The addition of WHSP biomass resulted in a decrease in the quantity of soluble solids in the Wastewater indicating that WHSP absorbed the soluble particles in the Wastewater. The 5 g/L concentration had reduced the TDS by 9.5% in the Wastewater as shown in Figure 6 and Table 3 (see supplementary data). Increasing the concentration any further hardly had any impact. The porous structure of stem powder as shown in Figure 6 had contributed to the adsorption of TDS from



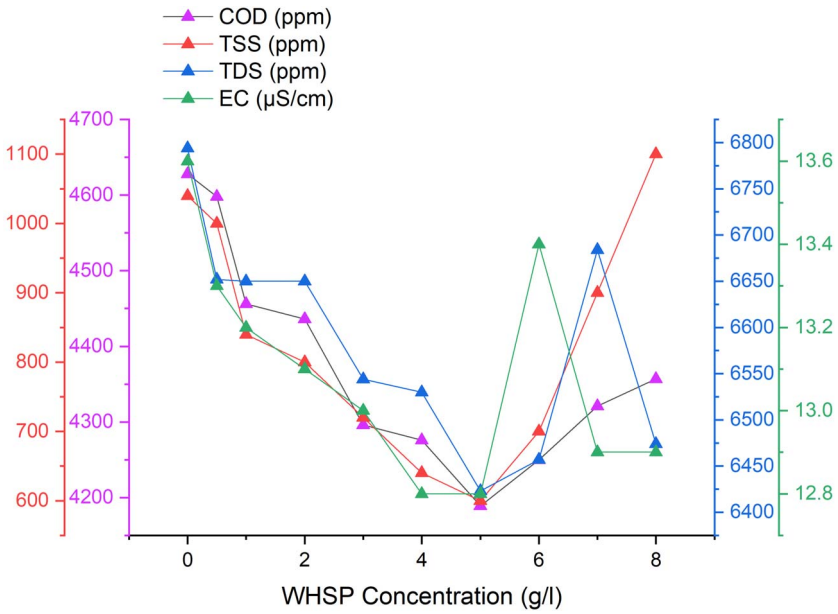


Figure 6. Effect of Water Hyacinth Stem Powder (WHSP) concentration on Wastewater parameters, including Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and Electrical Conductivity (EC).

Wastewater. Moreover, the presence of hydroxyl group as shown in the FTIR analysis interacted with the TDS contents.

3.1.4. Effect of WHSP concentration on EC of Wastewater

A 5.5% reduction in the electrical conductivity was observed at 5 g/L concentration of WHSP as shown in Figure 6 and Table 4 (see supplementary data). Further increase in the concentration of biomass hindered the flow of charged particles and had no beneficial effect on the EC of Wastewater. There is a saturation point beyond which higher biomass concentrations do not result in proportionately better conductivity reductions, as the positive effects of additional adsorbent on EC became insignificant.

3.2. Water Hyacinth leaves powder (WHLP)

3.2.1. Effect of WHLP concentration on COD of Wastewater

The increase in the concentration of WHLP reduced the chemical oxygen demand (COD) of Wastewater up to 16.4%. A concentration of 0.8 mg/L had shown significant results as shown in Figure 7 and Table 1 (see supplementary data). Since the biomass was suspended in the Wastewater, further concentration increases had negative effects. Therefore, appropriate concentration of WHLP is recommended for maximum COD removal from Wastewater. Moreover, WHLP has higher efficiency as compared to WHSP.

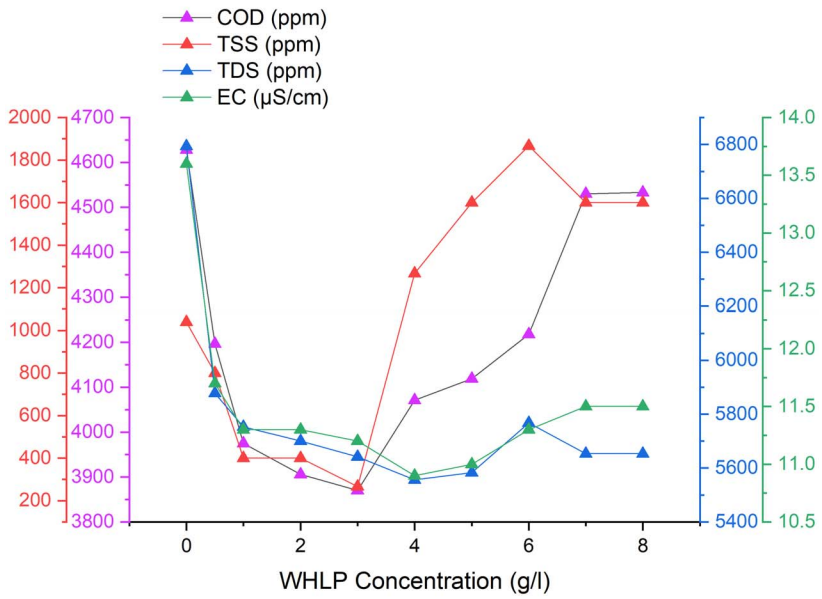


Figure 7. Effect of Water Hyacinth Leaf Powder (WHLP) concentration on Wastewater parameters, including Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and Electrical Conductivity (EC).

3.2.2. Effect of WHLP concentration on TSS of Wastewater

The quantity of suspended solids in the Wastewater had remarkably decreased due to WHLP biomass concentration as shown in Figure 7 and Table 2 (see supplementary data). A concentration of 0.8 g/L had shown a 74.4% TSS reduction, which is comparable to conventional chemicals and other biomass used for the same purpose. Increase in concentrations had a detrimental effect and caused suspensions to float on the Wastewater's surface indicating that the TSS quantity had increased considerably.

3.2.3. Effect of WHLP concentration on TDS of Wastewater

The addition of biomass WHLP resulted in a decrease in the quantity of soluble solids in the Wastewater as shown in Figure 7. This indicates that WHLP had absorbed the soluble particles in the Wastewater. A concentration of 1 g/L reduced 18.2% of TDS from Wastewater, which is comparable to other biomasses. However, increasing the concentration any further had negligible impact on TDS as shown in Table 3 (see supplementary data).

3.2.4. Effect of WHLP concentration on EC (µS/cm) of Wastewater

The rise in WHLP biomass concentration was accompanied by a slight decrease in electrical conductivity of Wastewater. The EC was minimum at 1 g/L concentration,

however, following this the EC stabilized as shown in Figure 7 and Table 4 (see supplementary data).

3.3. Comparison of adsorption performance of $FeCl_3$ alum, calcium carbonate, poly aluminum chloride, sawdust and rice husk with WH

The adsorption performance of WH was compared with conventional chemical ($FeCl_3$, Alum, Calcium Carbonate, Poly Aluminum Chloride), biomass (sawdust and rice husk) [14, 24, 25] as shown in Table 3. A primary goal of this study is the promotion of sustainability in Wastewater treatment. The removal efficiency of WHLP for removing TDS, TSS and COD is better than sawdust as shown in Table 3. However, the higher removal efficiency of conventional chemicals is at the cost of environmental degradation.

Table 3. Comparison of adsorption performance of $FeCl_3$, Sawdust and Rice Husk with WH.

Parameter	Reduction efficiency (%) of WHLP	Reduction efficiency (%) of WHSP	Reduction efficiency (%) of $FeCl_3$	Reduction efficiency (%) of alum	Reduction efficiency (%) of calcium carbonate	Reduction efficiency (%) of poly aluminum chloride	Reduction efficiency (%) of sawdust	Reduction efficiency (%) of Rice Husk
TDS	18.2	9.5	50–80	10–20	5–10	15–25	18	22
TSS	74.4	42.3	70–90	70–90	40–60	80–95	40	60
COD	16.4	5.5	40–50	50–70	30–40	60–80	10	35

This study also promotes sustainable practices in Wastewater treatment. Notably, WHLP demonstrated superior removal efficiency for TDS, TSS, and COD when compared to sawdust, as delineated in Table 3. While conventional chemical methods may exhibit higher removal efficiencies, their widespread application poses significant concerns regarding environmental degradation, underscoring the imperative for more eco-friendly alternatives like WH [14, 26, 27].

3.4. FTIR analysis

The WHSP spectrum displayed a prominent broad hydroxyl (O–H) stretching band at 3 300–3400 cm^{-1}, indicative of cellulose, hemicellulose, and lignin as shown in the Figure 8. Aliphatic C–H stretching vibrations were evident near 2900 cm^{-1}, characteristic of carbohydrate components. The strong absorption in the fingerprint region, especially around 1016 cm^{-1}, confirmed the presence of C–O stretching from the dominant polysaccharide backbone of the stem. Less pronounced carbonyl (C=O) peaks suggested the presence of hemicellulose or lignin-related structures [28–30].

The WHLP spectrum showed a strong, broad O–H stretching band at 3300–3400 cm^{-1}, highlighting its lignocellulosic nature as shown in the Figure 9.

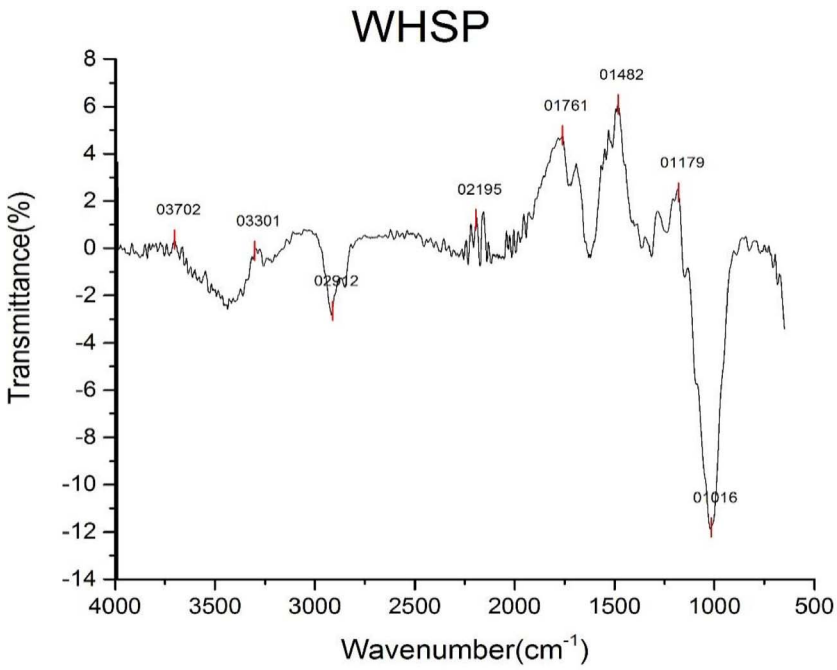


Figure 8. FTIR spectrum of Water Hyacinth Stem Powder (WHSP), showing its characteristic absorbance peaks and functional groups across the wavenumber range of 500 to 4000 cm^{-1}.

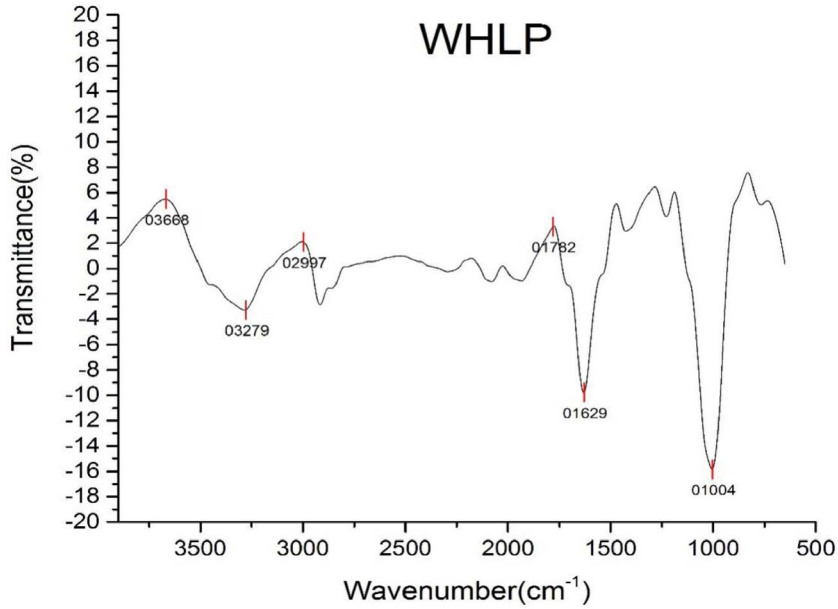


Figure 9. FTIR spectrum of Water Hyacinth Leaves Powder (WHLP), illustrating the unique vibrational modes and chemical composition of the leaf material across the wavenumber range of 500 to 4000 cm^{-1}.

C–H stretching vibrations were observed around 2997 cm^{-1}, consistent with the organic framework. A distinct peak at 1782 cm^{-1} suggested more pronounced C=O stretching, possibly indicating a higher content of specific hemicellulose components or extractives in the leaves compared to the stem. The intense C–O stretching band around 1004 cm^{-1} further confirmed the rich polysaccharide composition of the leaf material [31–33].

FTIR analysis was conducted to get to determine the presence of functional groups in biomass water Hyacinth. Figures 8–9 presents the FTIR analysis of WHSP and WHLP, respectively. The presence of hydroxyl group (O–H) is indicated at wavenumber 3666 cm^{-1} and 3702 cm^{-1} in WHLP and WHSP, respectively. Similarly, carboxylic acid (C=O) is identified at wavenumber around 1700 cm^{-1} in WH. A high peak intensity near 1000 cm^{-1} suggests the presence of proteins (N–H).

3.5. TGA analysis

Figures 10–11 describe the TGA analysis of WHSP and WHLP, respectively. It provides valuable insights into the thermal stability and composition of WHSP and WHLP. In the case of WHSP, the TGA curve shows an initial weight loss around 30–120 °C, corresponding to the evaporation of moisture and light volatile components. A significant weight loss occurred between 250 °C and 350 °C, which can be attributed to the decomposition of hemicellulose and cellulose. This is followed by a slower, more gradual weight loss from 350 °C to about 600 °C, which is attributed to the breakdown of lignin and other thermally stable organic materials. Beyond 600 °C, the weight stabilized, leaving a final residue of approximately 15%, which represents the formation of a carbonaceous char or mineral ash. This pattern suggests that WHSP has relatively high thermal stability, maintaining structural integrity over a broader temperature range [30, 34, 35].

An endothermic peak at 100 °C indicates that some amount of adsorbed water in the samples has evaporated. Moreover, a significant weight loss was observed at 220 °C, which is attributed to the decomposition of cellulose, hemicellulose and lignin. The rate of decomposition of WHLP is slightly lower suggesting its slightly high thermal stability.

Although there are few significant variations, a similar pattern is seen for WHLP. A harsher decline that started a little sooner than WHSP, at 230–250 °C, following the initial moisture loss, which occurred between 30–120 °C. The more noticeable weight loss between 250 °C and 350 °C suggests that there may be a greater amount of thermally labile substances, including hemicellulose. The material still degrades, albeit more slowly, when the temperature increased from 350 °C to 600 °C. In comparison to WHSP, WHLP exhibited a lower degree of thermal stability, as seen by the somewhat lower residual mass of 13–14% left over after analysis [31, 36, 37].

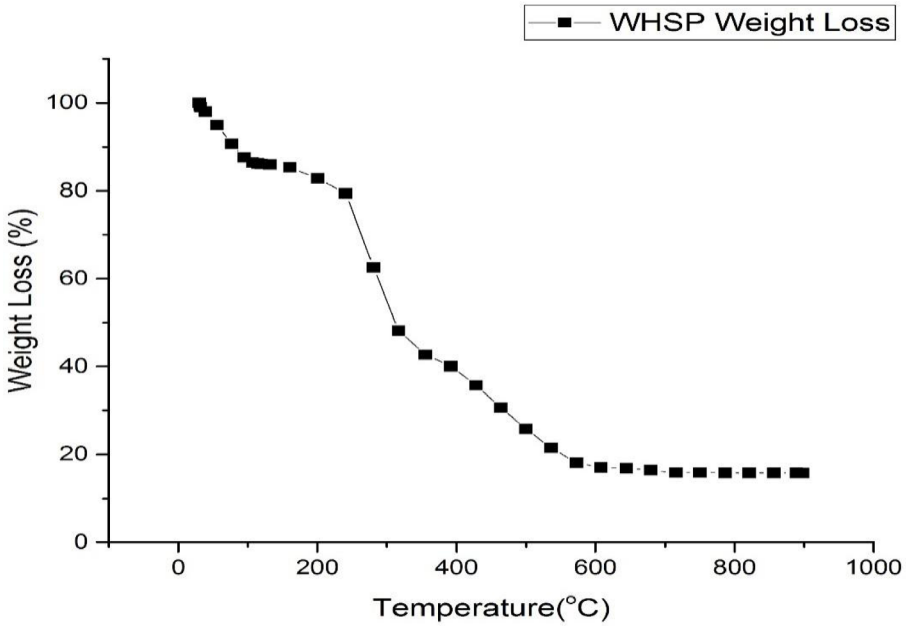


Figure 10. Thermogravimetric analysis of Water Hyacinth Stem Powder (WHSP) shows a major weight loss between 250–600 °C due to the decomposition of hemicellulose, cellulose, and lignin, with approximately 15% residue remaining at 900 °C, indicating higher thermal stability.

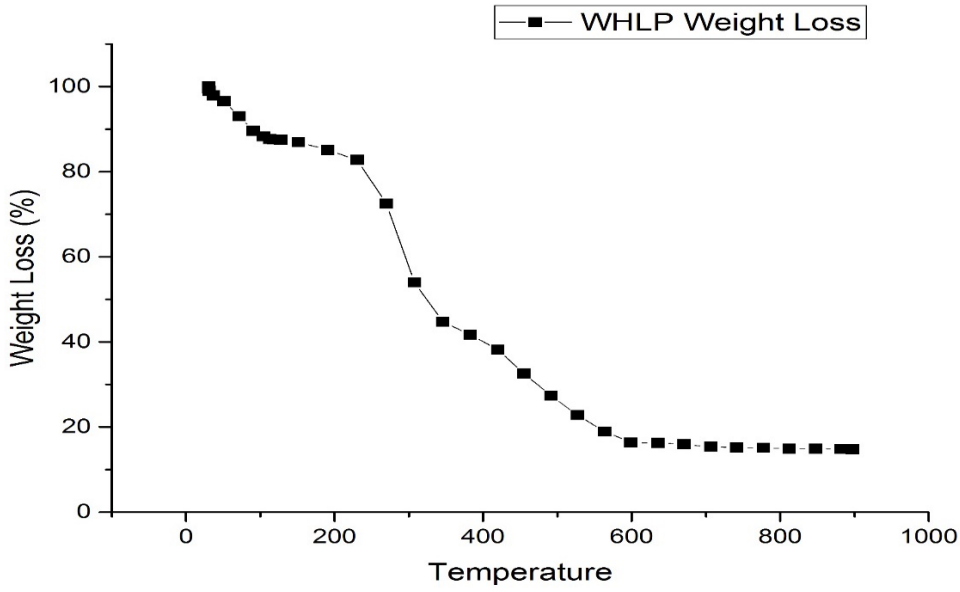


Figure 11. Thermogravimetric analysis of Water Hyacinth Leaf Powder (WHLP) revealing significant degradation starting slightly earlier (230–600 °C), with a final residue of 13–14%, suggesting a relatively lower thermal stability than WHSP.

Comparing the two materials, WHLP demonstrated superior thermal stability. The stem-based powder began decomposing at a slightly higher temperature and retained a greater percentage of mass at the end of the heating cycle.

3.6. Microscopic analysis

The microscopic analysis of WHSP and WHLP are shown in Figures 12–13, respectively. Compound microscope with magnification 100x was used. Surface morphology and physical structure of WHSP and WHLP, the structural differences were observed in the microscopic analysis—particularly in terms of granularity and fiber orientation—to explain the higher adsorption capacity of WHLP compared to WHSP.

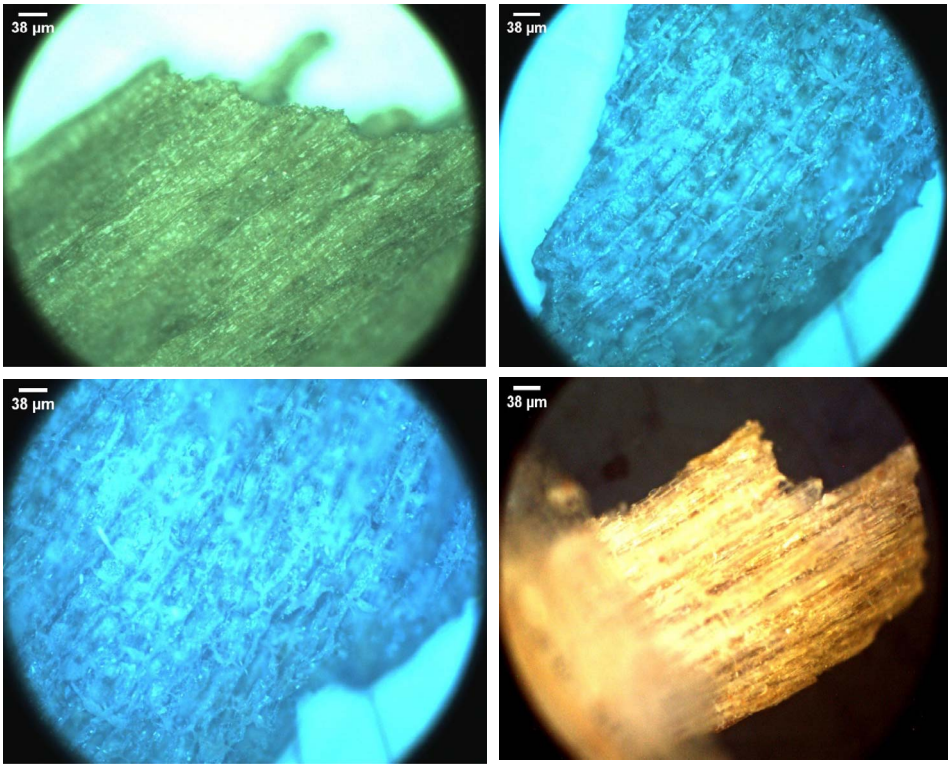


Figure 12. Optical micrograph illustrating the microscopic structure of Water Hyacinth Stem Powder (WHSP) at 38 µm magnification, captured with a Leica optical microscope with magnification of 100x. This view depicts the more elongated and less irregular morphology typical of stem components.

WHLP has a more broken particle structure and finer granulation, indicating a greater surface area is available for adsorption. Increased porosity from this finer structure provides more adsorbate interaction sites.

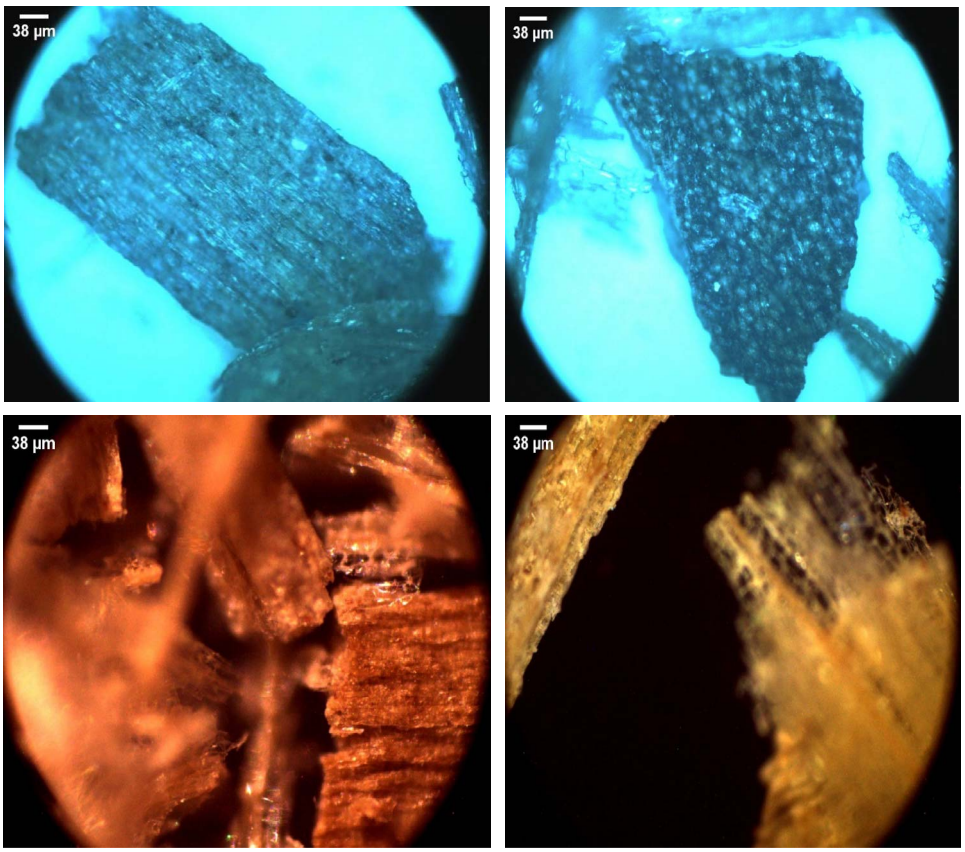


Figure 13. Optical micrograph revealing the intricate microscopic structure of Water Hyacinth Leaf Powder (WHLP) at 38 µm magnification, as observed using a Leica optical microscope of magnification 100x. The image highlights the rough, fibrous texture characteristic of leaf material.

Additionally, micropores, which are essential for adsorbing smaller molecules like ions or tiny chemical compounds, are predominant [33, 38, 39].

On the other hand, WHSP shows fewer accessible pores or surface area than WHLP due to its larger fibers and more compact structure. Its lower porosity restricts the total adsorption capacity, especially for tiny molecules that need fine-scale surface area for successful binding, even though its fibrous structure still gives it adsorbent qualities [36, 37, 40].

The presence of pores, cracks and other features influence the adsorption capacity of biomass. These structural features help enhance the adsorption capacity by facilitating the movement and retention of molecules within the biomass structure [39, 41]. The tubular structure of WHSP is due to presence of capillaries and accounts for the adsorption behaviour. The pores are evident in the microscopic structure of WHLP, as depicted in the Figure 13. These pores are responsible for the high adsorption capacity of WHLP.

4. Conclusions and recommendations

This study investigated the efficacy of using water Hyacinth, an inexpensive and environmentally benign bioflocculant, instead of chemical coagulants such as calcium carbonate, $FeCl_3$, alum and poly aluminum chloride for the primary treatment of textile Wastewater. During the first treatment, water Hyacinth showed extraction of the suspensions from the textile Wastewater. Compared to chemical treatment, the sludge produced by the water Hyacinth stem & leaves treatment process was less in amount and biodegradable that depicts its contribution to sustainability. It is a promising method for initial treatment of textile Wastewater. When used to remediate textile Wastewater, water Hyacinth plants pose no risks and are readily managed. This plant is frequently utilized to treat Wastewater using the wetland method. Water Hyacinth stem's structure is porous, much like a sponge. It may absorb the heavy metals found in textile Wastewater, as shown by lower TDS levels in this study. For the purpose of removing suspended particulates from textile Wastewater, water Hyacinth leaf powder is more effective than water Hyacinth stem powder. Water Hyacinth plant is a bioflocculant that has several benefits, including affordability, availability, and the strength of the flocs that are formed. Although batch experiments were utilized to calculate the research's results, findings can be used to create continuous flow systems for industrial applications. Similarly, mathematical modeling is necessary for the efficient use of this biomass in Wastewater treatment. There is a need to scale-up treatment systems mimicking industrial Wastewater treatment processes. Furthermore, techno-economic analysis is recommended in future to evaluate the cost benefits and feasibility of water Hyacinth-based treatment.

Author's contribution

Ahmad, Shoaib: Writing - orignal draft, Investigation, Formal analysis & Data curation, Writing - review & editing; **Majid, Abdul**: Conceptualization, Data curation, Methodology; **Haider, Bilal**: Supervision, Validation, Resources. All correspondence regarding this manuscript should be addressed to Bilal Haider.

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Conflict of interest

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Source data

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References

1 Uddin Ahmed Siddiqui B, Ahmed K. Mini review on textile effluent treatment. *Sci Int (Lahore) [Internet]*. 2015;**27**(6):6177–6181. Available from: www.pburch.net.

2 Abdul M. *Primary treatment of textile wastewater using natural flocculant "water Hyacinth - Eichhornia crassipes" biomass*. Lahore: Institute of Chemical Engineering and Technology University of the Punjab; 2020.

3 Achak M, Hafidi A, Ouazzani N, Sayadi S, Mandi L. Low cost biosorbent "banana peel" for the removal of phenolic compounds from olive mill Wastewater: Kinetic and equilibrium studies. *J Hazard Mater*. 2009;**166**(1):117–125. doi:10.1016/J.JHAZMAT.2008.11.036.

4 Haider B, Ahmad S, Hussain SN. Adsorption of crystal violet dye onto anionic polyacrylamide-modified graphite: equilibrium, kinetics, and mechanism. *ASEAN J. Chem Eng*. 2024;**24**(2):174–185.

5 Ali EN, Muyibi SA, Salleh HM, Alam Z, Ramlan M, Salleh M. Production of natural coagulant from moringa oleifera seed for application in treatment of low turbidity water. *J Water Resource Prot*. 2010;**2010**(03):259–266. doi:10.4236/JWARP.2010.23030.

6 Arslan-Alaton I, Tanik A, Ovez S, Iskender G, Gurel M, Orhon D. Reuse potential of urban Wastewater treatment plant effluents in Turkey: a case study on selected plants. *Desalination*. 2007;**215**(1–3):159–165. doi:10.1016/J.DESAL.2006.11.019.

7 Arulmathi P, Jeyaprabha C, Sivasankar P, Rajkumar V. Treatment of textile wastewater by coagulation–flocculation process using gossypium herbaceum and polyaniline coagulants. *Clean - Soil Air Water*. 2019;**47**(7):1800464. doi:10.1002/CLEN.201800464.

8 Baatache O, Derbal K, Benalia A, Aberkane I, Guizah QE, Khalfaoui A, Pizzi A. Valorization of pine cones (*Pinus nigras*) for industrial wastewater treatment and crystal violet removal: a sustainable approach based on bio-coagulants and a bio-adsorbent. *Water*. 2024;**16**(2):260. doi:10.3390/W16020260.

9 Bahrodin MB, Zaidi NS, Hussein N, Sillanpää M, Prasetyo DD, Syafiuddin A. Recent advances on coagulation-based treatment of wastewater: transition from chemical to natural coagulant. *Curr Pollut Rep [Internet]*. 2021;**7**(3):379–391. Available from: https://link.springer.com/article/10.1007/s40726-021-00191-7.

10 Carmen Z, Daniela S. Textile organic dyes—characteristics, polluting effects and separation/elimination procedures from industrial effluents—a critical overview. In: *Organic pollutants ten years after the Stockholm convention—environmental and analytical update*. Rijeka: InTech; 2012. doi:10.5772/32373.

11 Farooq U, Kozinski JA, Khan MA, Athar M. Biosorption of heavy metal ions using wheat based biosorbents—a review of the recent literature. *Bioresour Technol*. 2010;**101**(14):5043–5053. doi:10.1016/J.BIORTECH.2010.02.030.

12 Febrianto J, Kosasih AN, Sunarso J, Ju YH, Indraswati N, Ismadji S. Equilibrium and kinetic studies in adsorption of heavy metals using biosorbent: a summary of recent studies. *J Hazard Mater*. 2009;**162**(2–3):616–645. doi:10.1016/J.JHAZMAT.2008.06.042.

13 Hutagalung SS, Muchlis I, Khotimah K. Textile wastewater treatment using advanced oxidation process (AOP). *IOP Conf Ser Mater Sci Eng*. 2020;**722**(1):012032. doi:10.1088/1757-899X/722/1/012032.

14 Jayathunga GK, Amarasinghe BMWPK. Rice husk based adsorbents for textile effluent treatment. *Eng J Inst Eng Sri Lanka*. 2009;**42**(4):122–127. doi:10.4038/ENGINEER.V42I4.7041.

15 Karam A, Bakhoum ES, Zaher K. Coagulation/flocculation process for textile mill effluent treatment: experimental and numerical perspectives. *Int J Sustain Eng*. 2021;**14**(5):983–995. doi:10.1080/19397038.2020.1842547.

16 Khatmode NP, Thakare SB. Removal of pH, TDS, TSS & color from textile effluent by using sawdust as adsorbent. *Int J Sci Basic Appl Res*. 2015;**24**(2):158–163.

17 Koul B, Bhat N, Abubakar M, Mishra M, Arukha AP, Yadav D. Application of natural coagulants in water treatment: a sustainable alternative to chemicals. *Water*. 2022;**14**(22):3751. doi:10.3390/W14223751.

18 Ahmad S, Haider B, Ahmad HB, Shafeeq A. Comparative removal of chromium Cr(VI) from Wastewater by sawdust and activated charcoal derived from Acacia and Sheesham wood. *Chem Eng J S*. 2024;**4**(6):857–879.

19 Ramirez-Muñoz A, Forgionny A, Muñoz-Saldaña J, Flórez E, Acelas N. Pharmaceuticals removal from aqueous solution by water Hyacinth (*Eichhornia crassipes*): a comprehensive investigation of kinetics, equilibrium, and thermodynamics. *Environ Sci Pollut Res*. 2025;**32**(7):4239–4256. doi:10.1007/s11356-024-35665-w.

20 Mohan D, Rajput S, Singh VK, Steele PH, Pittman CU. Modeling and evaluation of chromium remediation from water using low cost bio-char, a green adsorbent. *J Hazard Mater*. 2011;**188**(1–3):319–333. doi:10.1016/J.JHAZMAT.2011.01.127.

21 Patel H. Charcoal as an adsorbent for textile Wastewater treatment. *Sep Sci Technol (Philadelphia)*. 2018;**53**(17):2797–2812. doi:10.1080/01496395.2018.1473880.

22 Sahunin C, Kaewboran J, Hunsom M. Treatment of textile dyeing Wastewater by photo oxidation using UV/H_2O_2/Fe^{2+} reagents. *ScienceAsia*. 2006;**32**(2):181–186. doi:10.2306/SCIENCEASIA1513-1874.2006.32.181.

23 Sevimli MF, Sarikaya HZ. Ozone treatment of textile effluents and dyes: effect of applied ozone dose, pH and dye concentration. *J Chem Technol Biotechnol*. 2002;**77**(7):842–850. doi:10.1002/JCTB.644.

24 Ghusoon JS, Wael SHA-J, Hala MS, Abdulaziz A, Mohanad MK, Ahmed A. Plant-based coagulants for water treatment. *IOP Conf Ser Mater Sci Eng*. 2021;**1058**(1):012001. doi:10.1088/1757-899X/1058/1/012001.

25 Yang L, Chen JP. Biosorption of hexavalent chromium onto raw and chemically modified Sargassum sp. *Bioresour Technol*. 2008;**99**(2):297–307. doi:10.1016/J.BIORTECH.2006.12.021.

26 Abd Aziz MA, Hairunnaja MA, Bashari NAF, Md Isa K. Recent advances in processed water Hyacinth (*Eichhornia crassipes*) for the removal of organic contaminants from water. In: *Controlling Environmental Pollution*. Singapore: Springer; 2025. p. 269–283. doi:10.1007/978-981-97-8931-3_15.

27 Al-Hermizy SMM, Awadh HA, Abbas MN. Biosorption technique using water Hyacinth plant as an effective and sustainable approach for treating oil refinery waste: Vanadium element as a case study. *J Ecol Eng*. 2025;**26**(6):251–272. doi:10.12911/22998993/202658.

28 Moheba M, El-Wakil AM, Awad FS. Highly porous activated carbon derived from the papaya plant (stems and leaves) for superior adsorption of alizarin red s and methylene blue dyes from Wastewater. *RSC Adv*. 2025;**15**(1):674–687. doi:10.1039/D4RA07957D.

29 Gul S, Afsar S, Raza N, Gul H, Khezami L, Almufarij R, Hussain SN. Efficient adsorptive removal of textile dye neutral red in environmental samples using white clover stem powder. *Biomass Convers Biorefin*. 2024;**14**(7):31079–31092. doi:10.1007/s13399-023-04770-0.

30 Rajaa N, Kadhim FJ, Abbas MN, Banyhussan QS. The improvement of concrete strength through the addition of sustainable materials (agrowaste loaded with copper ions). In: *3rd International Conference for Civil Engineering Science (ICCES 2023), IOP Conf. Series: Earth and Environmental Science*. vol. 1232, Bristol: IOP Publishing; 2023. 012038. doi:10.1088/1755-1315/1232/1/012038.

31 Ahmad S, Asrar Z, Haider B, Hussain SN. Tailored polyether sulfone/cellulose acetate based mixed matrix membranes for enhanced crude glycerin purification. *J Pakistan Inst Chem Eng*. 2024;**52**(1):41–51.

32 Priya ES, Selvan PS. Water Hyacinth (*Eichhornia crassipes*)—an efficient and economic adsorbent for textile effluent treatment—a review. *Arab J Chem*. 2017;**10**(Supplement 2):S3548–S3558. doi:10.1016/j.arabjc.2014.03.002.

33 Nahar K, Sunny SA. Co-benefits of *Eichhornia crassipes* (water Hyacinth) as sustainable biomass for biofuel production and aquatic ecosystem phytoremediation. *Fuels*. 2024;**5**(3):317–333. doi:10.3390/fuels5030018.

34 Shadhan ZJ, Alhamd S, Abbas MN. Recovery of vanadium element from wastewater of petroleum refineries using effective adsorbent: Mathematical approach via isothermal, kinetics and thermodynamic simulation. *Al-Qadisiyah J Eng Sci*. 2024;**17**(3):211–219. doi:10.30772/qjes.2024.145441.1069.

35 Alhamd SJ, Abbas MN, Al-Fatlawy HJJ, Ibrahim TA, Abbas ZN. Removal of phenol from oilfield produced water using non-conventional adsorbent medium by an eco-friendly approach. *Karbala Int J Mod Sci*. 2024a;**10**(2):191–210. doi:10.33640/2405-609X.3350.

36 Alsarayreh AA, Ibrahim SA, Alhamd SJ, Ibrahim TA, Abbas MN. Removal of selenium ions from contaminated aqueous solutions by adsorption using lemon peels as a non-conventional medium. *Karbala Int J Mod Sci*. 2024;**10**(4):511–531. doi:10.33640/2405-609X.3375.

37 Hamdi GM, Abbas MN, Ali SAK. Bioethanol production from agricultural waste: a review. *J Eng Sustain Dev*. 2024;**28**(2):233–252. doi:10.31272/jeasd.28.2.7.

38 Hameed WA, Abbas MN. Dyes adsorption from contaminated aqueous solution using SiO2 nanoparticles prepared from extracted tree leaves. *J Ecol Eng*. 2024;**25**(7):41–57. doi:10.12911/22998993/187921.

39 Khudair SY, Alsarayreh AA, Abbas MN. Adsorption of vanadium from Iraqi crude oil on nano zeolite and alum sludge. *J Eng Sustain Dev*. 2024;**28**(6):762–769. doi:10.31272/jeasd.28.6.9.

40 Abdullah WR, Alhamadani YAJ, Abass IK, Abbas MN. Study of chemical and physical parameters affected on purification of water from inorganic contaminants. *Period Eng Nat Sci*. 2023;**11**(2):166–175. doi:10.21533/pen.v11.i2.109.

41 Nega TD, Ramayya VA, Afessa MM, Manenti F. *Invasive water Hyacinth challenges, opportunities, mitigation, and policy implications: The case of the Nile Basin*. IntechOpen; 2023. doi:10.5772/intechopen.106779.