

Research Article

Dose-Optimized Evaluation of Lignocellulosic Coagulants and Ferric Chloride for Primary Treatment of Textile and Tannery Wastewaters

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Abstract

This researches the dose–response efficacy of two lignocellulosic coagulants (sawdust and rice husk) in comparison with ferric chloride for textile and tannery wastewaters treatment. The jar tests were conducted using six different doses of the coagulants (0, 2, 4, 6, 8, and 10 grams per 250 milliliters of wastewater) following a completely randomized factorial design, with each test repeated three times to ensure reliable results. The efficiency of the coagulants was evaluated based on several types of key parameters: pH, electrical conductivity (EC), turbidity, total suspended solids (TSS), total dissolved solids (TDS), hardness and extracts concentration into chloride, phosphate and to cadmium had been measured. The data demonstrated the influence of the coagulant type and dose on almost all parameters, as well as multiple wastewater × coagulant interaction effects ($p \leq 0.05$). In general, sawdust proved to be better than rice husk and ferric chloride when applied for all physico-chemical properties and pollutant removal excepting pH adjustment, the turbidity, reduction in solids and cadmium removal^{^^}. The maximum doses, especially 10 g, gave the highest enhancements for both wastewater kinds. The results demonstrate that lignocellulosic coagulants, especially sawdust, are feasible and economical substitutes for the conventional inorganic metal salts as primary treatment agents to textile and tannery industries which are confronted with increasing environmental demand. Importantly, the research indicates possible application of agricultural waste by-products by large water treatment industries.

Keywords

Lignocellulosic Coagulants, Sawdust, Rice husk, Textile Wastewater, Tannery Wastewater, Wastewater Treatment Optimization

1. Introduction

Industrial wastewater from textile and tannery facilities contains a complex mixture of dyes, suspended solids, salts, organic matter, surfactants, and heavy metals, all of which pose significant risks to aquatic ecosystems, soil quality, and

public health [1]. Discharge of untreated or partially treated effluents can lead to eutrophication, reduced light penetration, oxygen depletion, and bioaccumulation of toxic metals within food chains [2]. As environmental regulations tighten glob-

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ally, the need for effective, affordable, and sustainable treatment technologies has become increasingly urgent [3]. Conventional inorganic coagulants such as ferric chloride, alum, and polyaluminum chloride are widely used to remove suspended particulates and destabilize colloids [4]. Although effective, these coagulants often generate large volumes of metal-rich sludge, elevate operational costs, and introduce secondary pollution concerns related to corrosiveness and residual metal ions [5]. For many low- and middle-income regions, such limitations reduce the practicality of long-term reliance on inorganic coagulants [6]. In contrast, natural lignocellulosic materials have emerged as promising alternatives due to their abundance, biodegradability, and low cost [7]. Sawdust and rice husk, in particular, are readily available agricultural by-products that contain cellulose, hemicellulose, and lignin biopolymers rich in carboxyl, hydroxyl, and phenolic functional groups [8]. These functional groups enable mechanisms such as charge neutralization, adsorption, particle bridging, and ion exchange, making them suitable candidates for coagulation and pollutant removal [9]. Previous studies have shown that lignocellulosic materials can effectively remove dyes, heavy metals, and organic matter; however, their performance varies widely depending on wastewater characteristics, particle size, and applied dosage [10]. Despite increasing global interest, systematic dose-response evaluations of lignocellulosic coagulants remain limited, particularly for high-strength industrial effluents like textile and tannery wastewaters [11]. Moreover, comparative assessments against conventional coagulants are necessary to determine practical applicability [12].

This study addresses these gaps by evaluating the coagulation performance of sawdust, rice husk, and ferric chloride across multiple dosage levels for the treatment of tannery and textile wastewaters. The research focuses on their effects on pH, electrical conductivity (EC), turbidity, total suspended solids (TSS), total dissolved solids (TDS), hardness, major ions, and cadmium, providing a comprehensive assessment of their potential as sustainable coagulant alternatives.

2. Materials and Methods

The trial was carried out at the main Laboratory for Research, Lahore, where composite samples of textile and tannery effluent wastewaters were collected in pre-cleaned container, kept on ice during transportation and analysed within 24hrs [13]. Sawdust and rice husk were air-dried, sieved to a uniform particle size, and used without chemical modification [14], while ferric chloride was finely ground to ensure uniform dispersion during jar testing. A completely randomized factorial design with three replicates was employed, applying coagulant doses of 0, 2, 4, 6, 8, and 10 g per 250 mL of wastewater [15]. Jar tests involved rapid mixing at 200 rpm for 2 minutes, followed by slow mixing at 40 rpm for 15 minutes, a settling period of 90 minutes, and final filtration. Analytical procedures included pH and EC measurement using standard probes; turbidity determination via the nephelometric method; TSS and TDS quantification through gravimetric and conductivity-based methods; and analysis of hardness, chloride, and phosphate using APHA standard protocols, while cadmium concentrations were measured using flame atomic absorption spectrometry after sample digestion [16]. Statistical evaluation was performed using two-way and three-way ANOVA to assess the effects of wastewater type, coagulant, and dosage, with Fisher's LSD applied for pairwise comparisons at $p \leq 0.05$.

3. Results and Discussion

3.1. pH

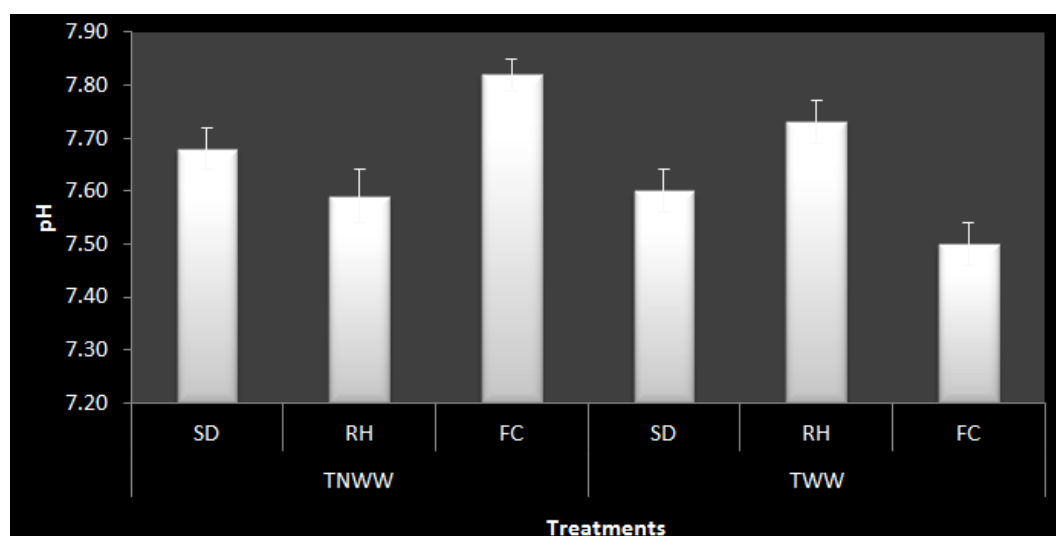
Coagulant type and dose significantly influenced pH. Increasing dosage resulted in a progressive pH reduction from alkaline toward neutral values. Sawdust at 10 g produced the largest pH reduction. Tannery wastewater exhibited slightly higher average pH than textile wastewater. Interactions indicated that coagulants behaved differently depending on wastewater matrix, suggesting matrix-dependent functional group interactions Table 1, Figures 1, 2 [17].

Table 1. Impact of different organic and inorganic coagulants at varying concentrations on the pH levels of wastewater.

Factors	pH
Wastewater (WW)	
Tannery Wastewater	7.70 a
Textile Wastewater	7.61 b
Coagulants (C)	
Sawdust	7.64
Rice Husk	7.66
Ferric Chloride	7.66

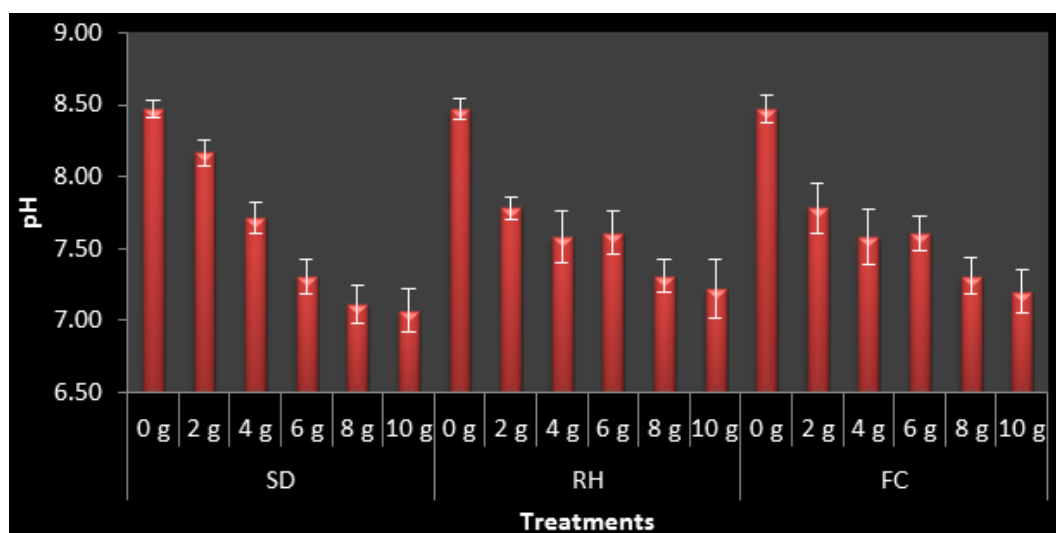
Factors	pH
Levels (l)	
0 g	8.47 a
2 g	7.91 b
4 g	7.62 c
6 g	7.51 c
8 g	7.25 d
10 g	7.16 d
LSD (WW) ($p \leq 0.05$)	0.08
LSD (C) ($p \leq 0.05$)	0.10
LSD (L) ($p \leq 0.05$)	0.15
LSD WW $\times$ C ($p \leq 0.05$)	0.15
LSD WW $\times$ L ($p \leq 0.05$)	0.21
LSD C $\times$ L ($p \leq 0.05$)	0.26
LSD WW $\times$ C $\times$ L ($p \leq 0.05$)	0.37
F- value (WW)	4.06*
F- value (C)	0.08 ^{NS}
F- value (L)	77.27**
F- value WW $\times$ C	8.81**
F- value WW $\times$ L	0.00 ^{NS}
F- value C $\times$ L	2.37*
F- value WW $\times$ C $\times$ L	0.83 ^{NS}

Any two values within a column that are followed by the same letters are considered not significantly different at $p \leq 0.05$. A double asterisk (**) indicates significance at $p \leq 0.01$, a single asterisk (*) indicates significance at $p \leq 0.05$, and "NS" stands for non-significant differences. The data is based on three replicates ($n = 3$).



TNWW = Tannery wastewater; TWW = Textile waste water; SD = Sawdust; RH = Rice husk; FC = Ferric chloride

Figure 1. Interactive effect of wastewaters and various coagulants on the pH.



TNWW = Tannery wastewater; TWW = Textile waste water; SD = Sawdust; RH = Rice husk; FC = Ferric Chloride

Figure 2. Interactive effect of various levels of organic and inorganic coagulants on the pH of wastewaters.

3.2. Electrical Conductivity (EC)

EC declined with increasing dosage for all coagulants. Sawdust produced the greatest overall reduction, indicating more effective removal of dissolved ion-rich particulates.

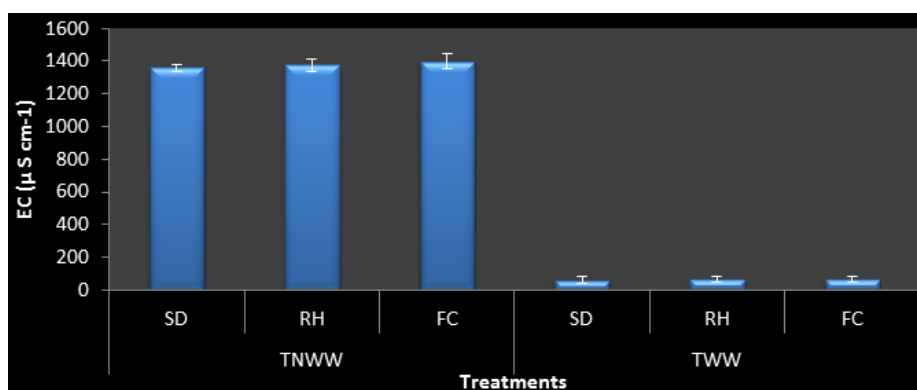
Tannery wastewater exhibited much higher EC than textile wastewater due to higher salt loads. Observed reductions reflect sorption-mediated ion removal and particle destabilization. Ferric chloride showed smaller EC reductions, likely due to chloride ion contribution Table 2, Figures 3, 4 [18].

Table 2. Effect of various organic and inorganic coagulants at various concentrations on the EC ($\mu\text{S cm}^{-1}$) of wastewaters.

Factors	EC ($\mu\text{S cm}^{-1}$)
Wastewater (WW)	
Tannery Wastewater	1376.90 a
Textile Wastewater	63.40 b
Coagulants (C)	
Sawdust	709.13 c
Rice Husk	720.04 b
Ferric Chloride	731.30 a
Levels (L)	
0 g	775.83 a
2 g	764.81 a
4 g	737.29 b
6 g	711.56 c
8 g	690.18 d
10 g	641.27 e
LSD (WW) ($p \leq 0.05$)	7.01
LSD (C) ($p \leq 0.05$)	8.59
LSD (L) ($p \leq 0.05$)	12.15

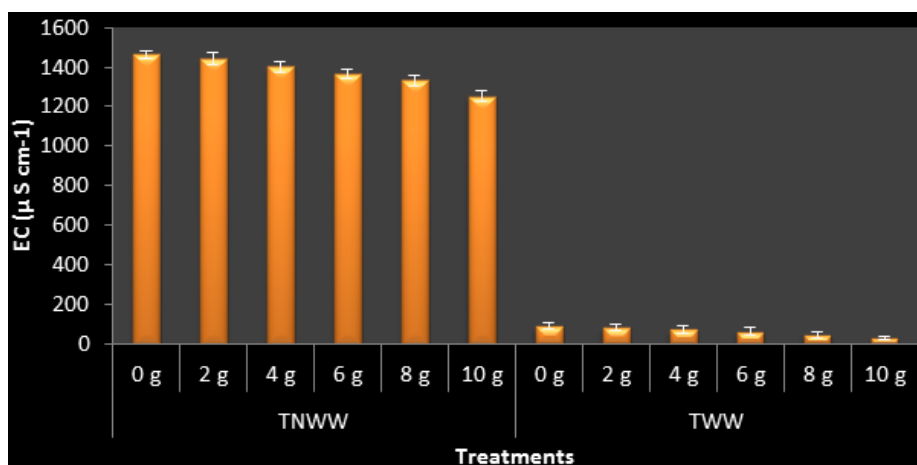
Factors	EC ($\mu\text{S cm}^{-1}$)
LSD WW $\times$ C ($p \leq 0.05$)	12.15
LSD WW $\times$ L ($p \leq 0.05$)	17.19
LSD C $\times$ L ($p \leq 0.05$)	21.05
LSD WW $\times$ C $\times$ L ($p \leq 0.05$)	29.77
F- value (WW)	139181**
F- value (C)	13.22**
F- value (L)	135.35**
F- value WW $\times$ C	8.72*
F- value WW $\times$ L	42.65**
F- value C $\times$ L	0.58 ^{NS}
F- value WW $\times$ C $\times$ L	0.39 ^{NS}

Any two values within a column that are followed by the same letters are considered not significantly different at $p \leq 0.05$. A double asterisk (**) indicates significance at $p \leq 0.01$, a single asterisk (*) indicates significance at $p \leq 0.05$, and "NS" stands for non-significant differences. The data is based on three replicates ($n = 3$).



TNWW = Tannery wastewater; TWW = Textile waste water

Figure 3. Interactive effect of wastewaters and various coagulants on the EC ($\mu\text{S cm}^{-1}$) of wastewaters.



TNWW = Tannery wastewater; TWW = Textile waste water

Figure 4. Interactive effect of different levels of coagulants on the EC ($\mu\text{S cm}^{-1}$) of wastewater.

3.3. Turbidity

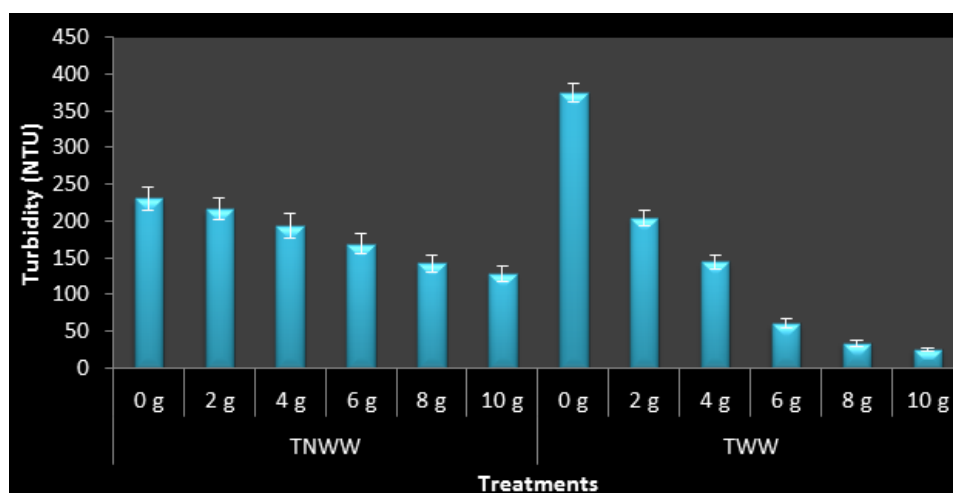
Turbidity removal increased sharply with dose. Sawdust provided the most pronounced turbidity reduction, followed

by rice husk. At 10 g, residual turbidity dropped to <80 NTU on average. These results indicate that lignocellulosic surface functional groups enhance particle bridging, sweep flocculation, and sedimentation in Table 3, Figures 5, 6 [19].

Table 3. Effect of various organic and inorganic coagulants at various concentrations on the turbidity (NTU) of wastewaters.

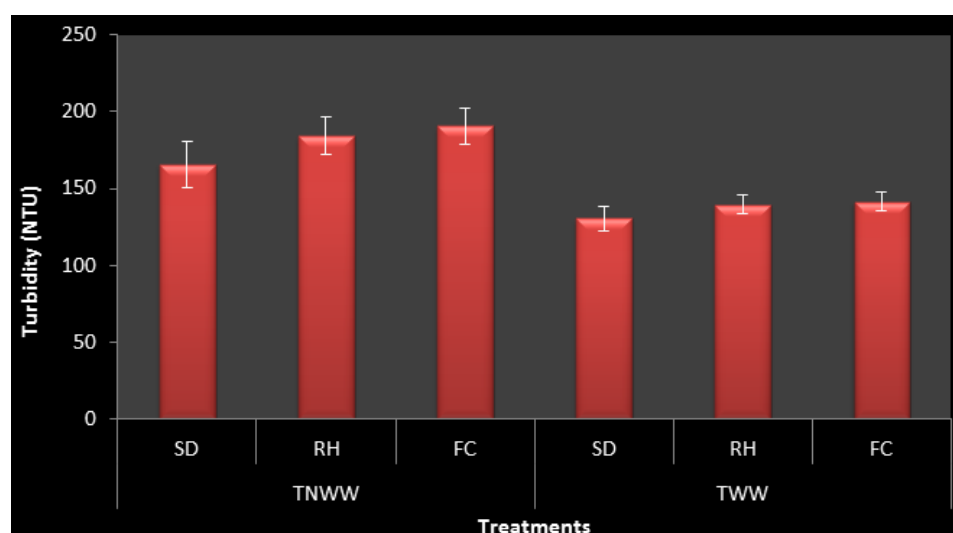
Factors	Turbidity (NTU)
Wastewater (WW)	
Tannery Wastewater	180.15 a
Textile Wastewater	135.67 b
Coagulants (C)	
Sawdust	147.99 b
Rice Husk	161.86 a
Ferric Chloride	163.88 a
Levels (L)	
0 g	302.50 a
2 g	210.50 b
4 g	154.17 c
6 g	114.98 d
8 g	88.14 e
10 g	77.16 f
LSD (WW) ($p \leq 0.05$)	4.05
LSD (C) ($p \leq 0.05$)	4.96
LSD (L) ($p \leq 0.05$)	7.01
LSD WW $\times$ C ($p \leq 0.05$)	7.02
LSD WW $\times$ L ($p \leq 0.05$)	9.92
LSD C $\times$ L ($p \leq 0.05$)	12.15
LSD WW $\times$ C $\times$ L ($p \leq 0.05$)	17.18
F- value (WW)	478.97**
F- value (C)	24.15**
F- value (L)	1191.66**
F- value WW $\times$ C	6.87*
F- value WW $\times$ L	397.40**
F- value C $\times$ L	1.60 ^{NS}
F- value WW $\times$ C $\times$ L	1.46 ^{NS}

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TNWW = Tannery wastewater; TWW = Textile waste water

Figure 5. Interactive effect of different levels of coagulants on turbidity of wastewater.



TNWW = Tannery wastewater; TWW = Textile waste water; SD = Sawdust; RH = Rice husk; FC = Ferric chloride

Figure 6. Interactive effect of organic and inorganic coagulants on turbidity of various wastewaters.

3.4. Total Suspended Solids (TSS)

All coagulants significantly lowered TSS, with sawdust removing the greatest amount. Tannery wastewater initially

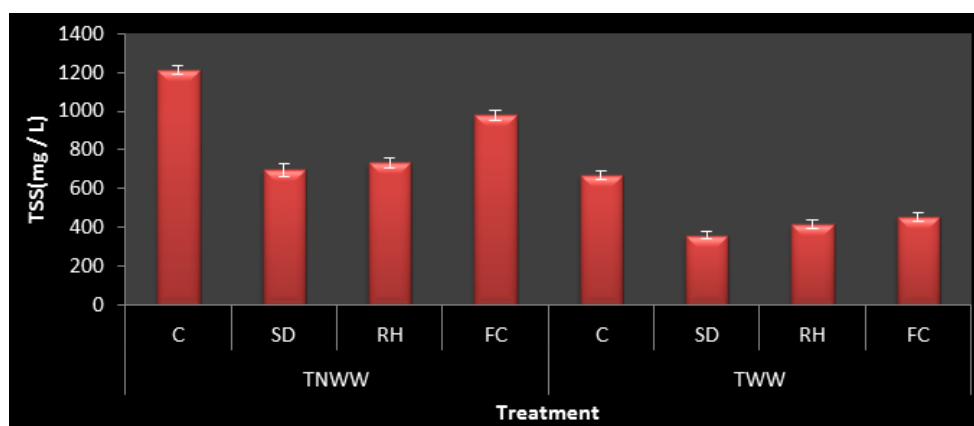
contained higher TSS than textile wastewater due to its higher organic load. Sawdust's superior performance may reflect higher surface area and stronger bridging interactions [Table 4](#), [Figure 7](#), [20].

Table 4. Effect of various organic and inorganic coagulants on the total suspended solids (mg/L) of waste waters.

Factors	TSS (mg/L)
Wastewater (WW)	
Tannery Wastewater	906.42 a
Textile Wastewater	474.58 b
Coagulants (C)	

Control	940.50 a
Sawdust (10 g)	528.67 d
Rice Husk (10 g)	574.83 c
Ferric Chloride (10 g)	718.00 b
LSD (WW) ($p \leq 0.05$)	21.81
LSD (C) ($p \leq 0.05$)	30.85
LSD WW $\times$ C ($p \leq 0.05$)	43.63
F- value (WW)	1760.40**
F- value (C)	323.56**
F- value WW $\times$ C	34.39**

Any two values within a column that are followed by the same letters are considered not significantly different at $p \leq 0.05$. A double asterisk (**) indicates significance at $p \leq 0.01$, a single asterisk (*) indicates significance at $p \leq 0.05$, and "NS" stands for non-significant differences. The data is based on three replicates ($n = 3$).



TNWW = Tannery wastewater; TWW = Textile waste water; C = Control; SD = Sawdust; RH = Rice husk; FC = Ferric chloride

Figure 7. Interactive effect of organic and inorganic coagulants on total suspended solids (mg/L) of various wastewaters.

3.5. Total Dissolved Solids (TDS)

TDS decreased significantly across all coagulants, with sawdust showing the highest removal efficiency. The greater

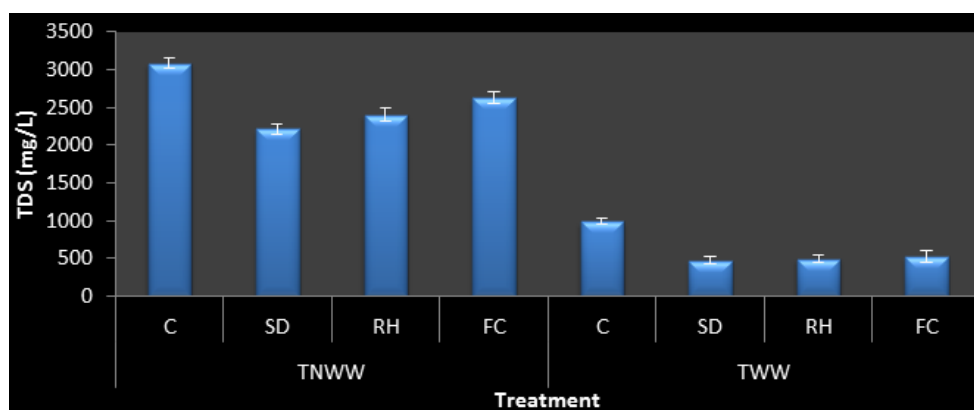
reduction suggests enhanced sorption of dissolved organic and inorganic constituents. Ferric chloride, although effective for some parameters, showed lower removal of dissolved-phase contaminants in Table 5, Figure 8 [20].

Table 5. Effect of various organic and inorganic coagulants on the total dissolved solids (mg/L) of waste waters.

Factors	TDS (mg/L)
Wastewater (WW)	
Tannery Wastewater	2580.90 a
Textile Wastewater	621.70 b
Coagulants (C)	
Control	2037.30 a
Sawdust (10 g)	1344.20 d

Rice Husk (10 g)	1450.00 c
Ferric Chloride (10 g)	1573.80 b
LSD (WW) ($p \leq 0.05$)	32.03
LSD (C) ($p \leq 0.05$)	45.30
LSD WW $\times$ C ($p \leq 0.05$)	64.06
F- value (WW)	16810.20**
F- value (C)	408.60**
F- value WW $\times$ C	32.61**

Any two values within a column that are followed by the same letters are considered not significantly different at $p \leq 0.05$. A double asterisk (**) indicates significance at $p \leq 0.01$, a single asterisk (*) indicates significance at $p \leq 0.05$, and "NS" stands for non-significant differences. The data is based on three replicates ($n = 3$).



TNWW = Tannery wastewater; TWW = Textile waste water; C = Control; SD = Sawdust; RH = Rice husk; FC = Ferric chloride

Figure 8. Interactive effect of organic and inorganic coagulants on total dissolved solids (mg/L) of various wastewaters.

3.6. Total Hardness

Hardness was significantly reduced by all coagulants.

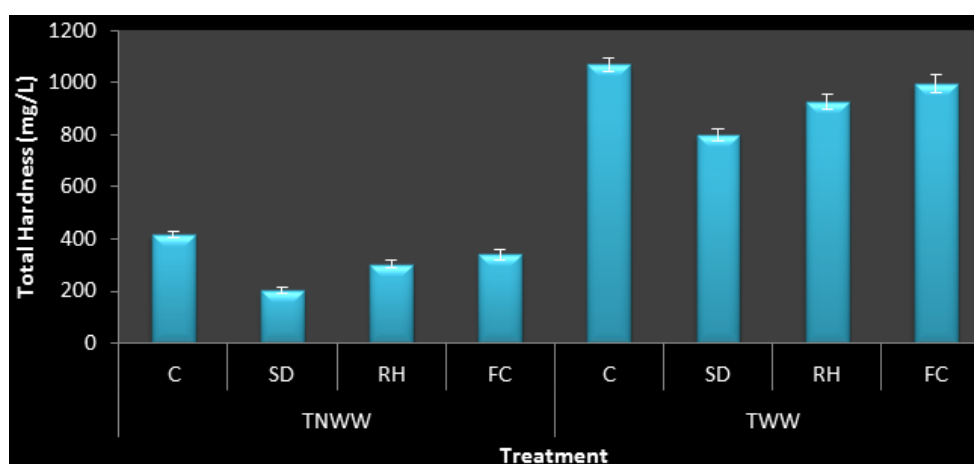
Sawdust again showed the most effective softening, reducing hardness to nearly half of the control level. Lignocellulosic materials likely remove Ca^{2+} and Mg^{2+} through ion exchange and complexation in Table 6, Figure 9 [21].

Table 6. Effect of various organic and inorganic coagulants on the total hardness (mg/L) of waste waters.

Factors	TH (mg/L)
Wastewater (WW)	
Tannery Wastewater	315.67 b
Textile Wastewater	948.08 a
Coagulants (C)	
Control	742.67 a
Sawdust (10 g)	501.67 d
Rice Husk (10 g)	615.00 c
Ferric Chloride (10 g)	668.17 b

Factors	TH (mg/L)
LSD (WW) ($p \leq 0.05$)	18.12
LSD (C) ($p \leq 0.05$)	25.63
LSD WW $\times$ C ($p \leq 0.05$)	36.24
F- value (WW)	5472.53**
F- value (C)	140.62**
F- value WW $\times$ C	2.54 ^{NS}

Any two values within a column that are followed by the same letters are considered not significantly different at $p \leq 0.05$. A double asterisk (**) indicates significance at $p \leq 0.01$, a single asterisk (*) indicates significance at $p \leq 0.05$, and "NS" stands for non-significant differences. The data is based on three replicates ($n = 3$).



TNWW = Tannery wastewater; TWW = Textile waste water; C = Control; SD = Sawdust; RH = Rice husk; FC = Ferric chloride

Figure 9. Interactive effect of organic and inorganic coagulants on total hardness (mg/L) of various wastewaters.

3.7. Chloride

Chloride concentrations decreased significantly with sawdust and rice husk, with sawdust being most effective. Ferric

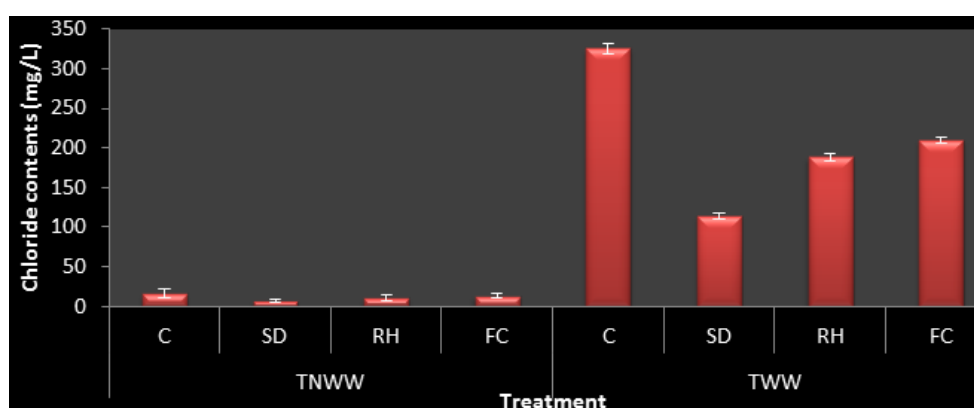
chloride showed smaller reductions due to its inherent chloride content. Biosorption mechanisms and surface complexation explain the improved performance of organic coagulants in Table 7, Figure 10 [22].

Table 7. Effect of various organic and inorganic coagulants on the chloride contents (mg/L) of waste waters.

Factors	Cl ⁻¹ (mg/L)
Wastewater (WW)	
Tannery Wastewater	11.67 b
Textile Wastewater	209.42 a
Coagulants (C)	
Control	170.81 a
Sawdust (10 g)	60.46 c
Rice Husk (10 g)	99.38 b

Ferric Chloride (10 g)	111.51 b
LSD (WW) ($p \leq 0.05$)	8.83
LSD (C) ($p \leq 0.05$)	12.50
LSD WW $\times$ C ($p \leq 0.05$)	17.67
F- value (WW)	2249.04**
F- value (C)	120.13**
F- value WW $\times$ C	100.66**

Any two values within a column that are followed by the same letters are considered not significantly different at $p \leq 0.05$. A double asterisk (**) indicates significance at $p \leq 0.01$, a single asterisk (*) indicates significance at $p \leq 0.05$, and "NS" stands for non-significant differences. The data is based on three replicates ($n = 3$).



TNWW = Tannery wastewater; TWW = Textile waste water; C = Control; SD = Sawdust; RH = Rice husk; FC = Ferric chloride

Figure 10. Interactive effect of organic and inorganic coagulants on chloride contents (mg/L) of various wastewaters.

3.8. Phosphate

Phosphate removal was significant for all coagulants.

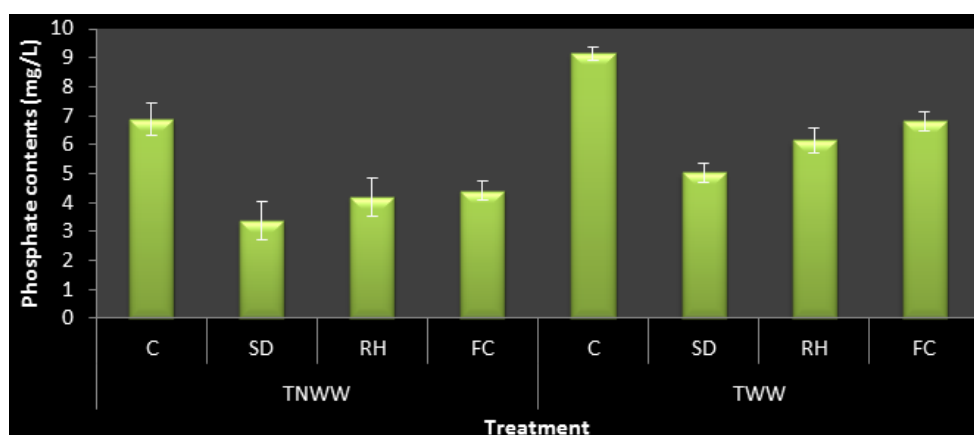
Sawdust achieved the lowest residual phosphate concentration. Its performance may be attributed to functional group affinity for phosphate ions and enhanced floc formation in Table 8, Figure 11 [23].

Table 8. Effect of various organic and inorganic coagulants on the phosphate contents (mg/L) of waste waters.

Factors	PO_4^{3-} (mg/L)
Wastewater (WW)	
Tannery Wastewater	6.78 a
Textile Wastewater	4.70 b
Coagulants (C)	
Control	8.01 a
Sawdust (10 g)	4.19 d
Rice Husk (10 g)	5.17 c
Ferric Chloride (10 g)	5.61 b
LSD (WW) ($p \leq 0.05$)	0.05
LSD (C) ($p \leq 0.05$)	0.08

LSD WW $\times$ C ($p \leq 0.05$)	0.11
F- value (WW)	6032.00**
F- value (C)	3670.25**
F- value WW $\times$ C	37.53**

Any two values within a column that are followed by the same letters are considered not significantly different at $p \leq 0.05$. A double asterisk (**) indicates significance at $p \leq 0.01$, a single asterisk (*) indicates significance at $p \leq 0.05$, and "NS" stands for non-significant differences. The data is based on three replicates ($n = 3$).



TNWW = Tannery wastewater; TWW = Textile waste water; C = Control; SD = Sawdust; RH = Rice husk; FC = Ferric chloride

Figure 11. Interactive effect of organic and inorganic coagulants on phosphate contents (mg/L) of various wastewaters.

3.9. Cadmium

All coagulants significantly reduced cadmium concentrations, with sawdust performing best. Tannery wastewater

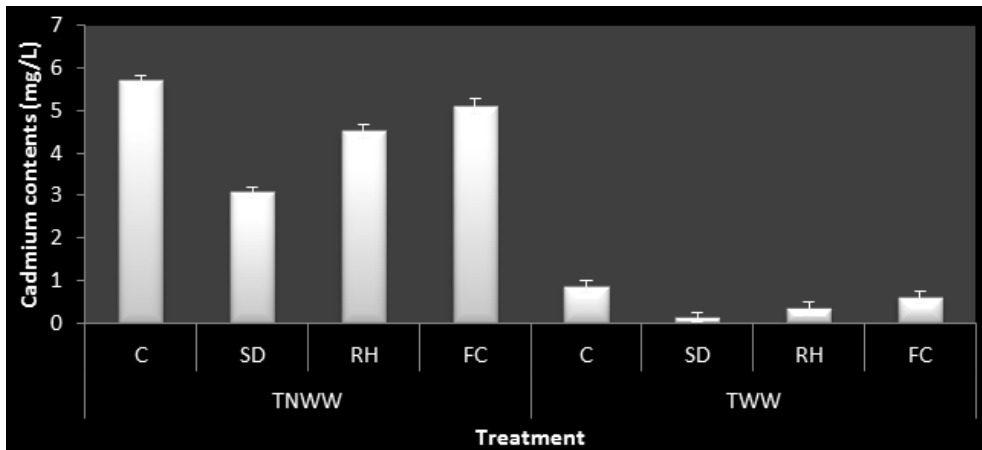
exhibited substantially higher initial cadmium levels. Organic coagulants likely bind cadmium via carboxyl and phenolic groups, consistent with previous biosorption research [Table 9](#), [Figure 12](#) [24].

Table 9. Effect of various organic and inorganic coagulants on the cadmium contents (mg/L) of waste waters.

Factors	Cd (mg/L)
Wastewater (WW)	
Tannery Wastewater	4.59 a
Textile Wastewater	0.46 b
Coagulants (C)	
Control	3.29 a
Sawdust (10 g)	1.55 c
Rice Husk (10 g)	2.43 a
Ferric Chloride (10 g)	2.85 ab
LSD (WW) ($p \leq 0.05$)	0.45
LSD (C) ($p \leq 0.05$)	0.63
LSD WW $\times$ C ($p \leq 0.05$)	0.90

F- value (WW)	375.72**
F- value (C)	12.05**
F- value WW × C	3.34*

Any two values within a column that are followed by the same letters are considered not significantly different at $p \leq 0.05$. A double asterisk (**) indicates significance at $p \leq 0.01$, a single asterisk (*) indicates significance at $p \leq 0.05$, and "NS" stands for non-significant differences. The data is based on three replicates ($n = 3$).



TNWW = Tannery wastewater; TWW = Textile waste water; C = Control; SD = Sawdust; RH = Rice husk; FC = Ferric chloride

Figure 12. Interactive effect of organic and inorganic coagulants on cadmium contents (mg/L) of various wastewaters.

4. Conclusions

This study demonstrates that lignocellulosic coagulants particularly sawdust are highly effective for primary treatment of textile and tannery wastewaters. Increasing dosage improved removal efficiency across all measured parameters. The 10 g dose delivered the most consistent and significant improvements, suggesting an optimal range under the tested conditions. Sawdust outperformed rice husk and ferric chloride across pH moderation, EC reduction, turbidity removal, solids reduction, hardness, ion removal, phosphate lowering, and cadmium adsorption. These results indicate strong potential for integrating lignocellulosic coagulants into low-cost, sustainable wastewater treatment strategies.

5. Limitations

Despite the promising results, this study has several limitations that should be acknowledged. First, only two lignocellulosic coagulants sawdust and rice husk were evaluated, and both were used in their raw, unmodified forms. Chemical or thermal activation, which may significantly enhance performance, was not explored. Second, the study focused on primary treatment and did not assess downstream impacts on biological treatment efficiency or sludge characteristics. Additionally,

wastewater samples were collected from specific textile and tannery facilities, and variability across industries, seasons, and operational conditions may influence contaminant profiles and treatment response. The jar test conditions applied in the laboratory may not fully replicate hydrodynamic conditions in full-scale treatment systems. Finally, the study applied a maximum dosage of 10 g per 250 mL; higher or finer-tuned dosing ranges may further refine the dose–response relationship. These limitations suggest avenues for future research, including modified adsorbent forms, pilot-scale validation, cost–benefit analysis, and life-cycle environmental assessments.

Abbreviations

ANOVA	Analysis of Variance
EC	Electrical Conductivity
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
LSD	Least Significant Difference
pH	Potential of Hydrogen
G	Gram (Unit of Measurement)
$\mu\text{S cm}^{-1}$	Micro-Siemens per Centimeter (Unit of Electrical Conductivity)
NTU	Nephelometric Turbidity Units
mg/L	Milligrams per Liter
FC	Ferric Chloride

SD	Sawdust
RH	Rice Husk
LSD	($p \leq 0.05$): Least Significant Difference at 5% Significance Level

Data Availability Statement

Available upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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