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Performance Evaluation of Combined Cactus-derived Bio-Coagulant and Ferric Chloride for Turbidity Removal from Rib River Surface Water

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Abstract

This study examined the mixture of the bio-coagulant derived from cactus and ferric chloride ($FeCl_3$) for removing turbidity from surface water of the Rib River in Debre Tabor, Ethiopia. Mucilage was isolated from the cactus plant, dried, ground to form powder, and analyzed for its functional groups by FTIR spectroscopy. Jar tests were performed at total dosages of 2.5 and 7.5 mg/L using cactus-to-$FeCl_3$ ratios of 2:1, 1:1, and 1:2 at initial pH levels of 6.5, 7.5, and 8.5. The turbidity of the raw water was 496.68 ± 2.36 NTU. The results revealed that turbidity reduction, electrical conductivity, total dissolved solids, and final pH were highly dependent on the coagulant ratio and initial pH. At 7.5 mg/L dosage, the mixture having equal amount of cactus and $FeCl_3$ observes the lowest turbidity of 69 NTU (86.1%) at pH 7.5. This dual mechanism improved destabilization through complementary charge neutralization from cactus mucilage and sweep flocculation mechanism from $FeCl_3$. This combined effect resulted in superior turbidity reduction and improved water quality parameters. Mixture containing high concentration of $FeCl_3$ had higher conductivity and total dissolved solids, whereas high amount of cactus had less dissolved solids and stable pH at the end point.

1. Introduction

Water is the most abundant natural resource on Earth, covering approximately 70% of the planet's surface[1]; however, only about 3% of the total global water resources are freshwater suitable for human consumption, while the vast majority exists as saline water in oceans and sea[2]. This limited availability of usable freshwater is increasingly threatened by water pollution[3]. which has become one of the most critical environmental challenges in the worldwide [4]. Pollution of surface water resources is primarily driven by anthropogenic activities[5], including uncontrolled discharge of domestic wastewater, agricultural runoff containing fertilizers and pesticides, and rapid industrial development[6]. Consequently, the deterioration of surface water quality poses significant risks to public health, aquatic ecosystems, and socio-economic development, particularly in developing regions where surface water sources are commonly used for drinking and domestic purposes without adequate treatment[7].

Turbidity removal is a critical objective in drinking water treatment, as high turbidity reduces aesthetic quality, hinders disinfection, and supports the survival of pathogenic microorganisms [8]. The use of natural coagulants for water purification dates back over 2,000 years, with civilizations in India, China, and Africa employing plant-based materials[9]. Today, reliance on imported chemical coagulants increases costs, limiting access to safe water in low-income and resource-constrained communities[10]. Cactus-based bio coagulants possess coagulation properties comparable to conventional chemical coagulants due to their high content of natural polysaccharides and functional groups (–OH, –COOH)[11]. Ferric chloride, in contrast, is a highly efficient inorganic coagulant commonly used for surface water treatment, operating mainly through sweep coagulation and exhibiting strong performance over a wide turbidity range[12]. However, its use is associated with pH reduction, higher sludge production, and increased operational costs[8].

In response to the growing need for efficient and environmentally sustainable water treatment technologies, this study investigates integrate coagulation approach that combines ferric chloride with a natural cactus-based bio coagulant. Ferric chloride serves as the primary coagulant by effectively destabilizing colloidal particles through charge neutralization and sweep coagulation mechanisms, while the cactus extract, rich in hydroxyl (OH) functional groups, high cellulose content, and low lignin composition, enhances adsorption and particle bridging [13].The combined effect of the two coagulants promotes the formation of larger, denser, and more settleable flocs, thereby improving turbidity removal efficiency. The novelty of this study lies in developing plant-based bio-coagulant derived from cactus mucilage and its application in water treatment in combination with ferric chloride ($FeCl_3$). This dual mechanism would resulted in synergistic water treatment efficiency and meeting water quality standards, thereby promoting sustainability and green chemistry. Accordingly, this research evaluates the performance of the combined coagulant dose for treating turbid surface water from the Rib River, Debre Tabor, Ethiopia, with the aim of contributing to the development of cost-effective and sustainable water treatment solutions applicable to developing regions.

2. Materials and methods

2.1. Description of the Study Area

The research was carried out in the Tach Gayient district of the South Gondar Zone of the Amhara Regional State in northwest Ethiopia, which is situated between latitudes 1129’59.99"- 1115’36" and longitudes 3814’60"- 3837’42". The capital city of Addis Ababa is 766 kilometers away from the Tach Gayient district. It is 100 kilometers from Debre Tabor (a zone town) and 197 kilometers from Bahir Dar (a regional city). The elevation ranges from 750 to 2800 meters above sea level. The district is bordered by the Lay Gayint to the north, North Wollo to the east, Simada to the west, and Lay Gayintthe south. The cactus leaves were collected in five kebeles from the area of Tach Gayient Woreda in South Gondar (Debre Tabor), Ethiopia. And which is transported to Debre Tabor University chemical engineering laboratory for extraction.

Wild cactus pad was collected from naturally growing uncultivated public land of Tach Gayient woreda, South Gondar Zone, Amhara Regional State, Ethiopia. In this location, the uncultivated wild cactus plant is freely accessible for non-commercial and academic research activities with no regulatory restrictions. Cactus Plant identification was performed by Mr. Habtamu Agmas Tarekegn (Department of Natural and Resource Management, Debre Tabor University). Following the collection, the samples were subsequently undergone to the laboratory of chemical engineering, Debre Tabor University for bio-coagulant preparation and further experimental investigations. For the turbidity removal jar test, surface water sample were collected from publicly accessible water body of Erub river with no requirements of a specific access permission.

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Figure 1 Map of Tach Gayient, indicating the study kebeles (highlighted in red)

2.2. Preparation of Cactus Bio coagulant and ferric chloride coagulant

Fresh cactus pads were washed with tap water to remove dirt and impurities. The areoles, glochids, and spines were removed using a knife, and the thin outer skin was peeled off. The inner cactus tissue was washed with filtered water and cut into small pieces. Similar washing, peeling, cutting, and crushing procedures have been reported for preparing *Opuntia ficus-indica* mucilage as a coagulant [13]. The cactus tissue was pressed to extract the mucilage, sun-dried for four days, and further oven-dried overnight at 50°C[14]. The dried material was milled into a fine powder and stored in a clean, dry container until use. Oven-drying followed by grinding is a commonly reported method for producing powdered cactus coagulants (nima model BL-A)[2]. To prepare ferric chloride solution an analytical-grade ferric chloride ($FeCl_3$; ≥98% purity, Sigma-Aldrich, USA) was used as the chemical coagulant. A 10 g/L stock $FeCl_3$ solution was prepared by dissolving 10 g of anhydrous $FeCl_3$ powder in distilled water and diluting to 1 L[15]. The solution was stored in a sealed glass container at room temperature and freshly prepared weekly[16]. Adding the coagulant during rapid mixing ensures uniform dispersion, which is an essential step in jar-test coagulation.

Raw cactus (1)

Figure 2 Overall bio coagulant preparation procedure

2.3. Bio-coagulant characterization

The infrared spectrum of cactus was obtained using a Fourier transform infrared spectrometer (SHIMADZU Code: HI 98713, Cluj Napoca, Romania), Spectra were recorded over the range of 4000–500 cm^{-} [11]. The moisture content in the cactus bio-coagulant was determined following standard method. Briefly, approximately 5 g of cactus powder was placed in a pre-weighed ceramic crucible and heated at 105°C for 30 min. The sample was cooled in a desiccator and weighed. Moisture content was calculated using Eq. (1)

$$\text{Moisture content } (\%) = \frac{W2 - W3}{W2 - W1}$$

1

Where; W_1 is the weight of the empty crucible, W_2 is the weight of the crucible plus fresh sample, and W3 is the weight of the crucible plus dried sample.

To determine the ash content, 2.5 g of dried cactus powder was placed in a pre-weighed ceramic crucible. The sample was pyrolyzed in a muffle furnace for approximately at 750 ^{o}C for 3 h. After cooling in a desiccator, the ash was weighed. Ash content was calculated using Eq. (2).

$$Ash\ content\ (\%) = \frac{M3 - m1}{M2 - m1}$$

2

2.4. Coagulation Experiment via jar test

Surface water samples were collected from Erib river, a major watercourse crossing wider geographical locations and public communities around Debre Tabor, Ethiopia. The water body crosses various villages and freely accessible for the agricultural, domestic and non-commercial purposes to the surrounding publics. We collected the water samples explicitly for physicochemical characterization and coagulation experiment and no formal permission was required during the time of sample collection.

The collected water samples were transferred to the laboratory and stored in a cool place for further analysis. Before treatment, the raw water was assessed for its pH, turbidity, alkalinity, electrical conductivity (EC), and total dissolved solids (TDS) and triplicate measurement of the sample performed at three location of the river using established water-quality analysis techniques. The coagulation experiments were conducted using a six-paddle jar test apparatus (Phipps & Bird Model 7791, USA). Briefly, 1 L of water was introduced into each beaker and mixed with the coagulants at a rapid speed of 150 rpm for five minutes, then reduced the speed to 40 rpm for fifteen minutes, and finally allowed the mixture to settle for ten minutes [17]. The pH levels were adjusted to 6.5, 7.5, or 8.5 by adding 1 M HCl or NaOH. Finally, the performance of mixed coagulant was evaluated for different mixing ratios (Bio-coagulant: FeCl3). The combined coagulant concentrations were varied as 2.5mg/l, and 7.5 mg/ L to determine the optimal treatment quantity.

2.5. Analytical methods and statistical analysis

For pH analysis, a portable, waterproof pH meter ((Hanna HI 9124) with laboratory-calibrated accuracy was employed. A portable Turbidimeter (Hach 2100Q) was employed for precise water turbidity readings in outdoor investigations [17]. A conductivity meter (Milwaukee MW301 Pro Conductivity Meter) was used to measure the electrical conductivity (EC) of water, which gives a reading of the concentration of ions and the general quality of the water. It is appropriate for a range of water testing applications because to its broad measuring range [18].

To measure the quality of surface water, pH, turbidity, electrical conductivity (EC), and total dissolved solid (TDS) were measured for raw and treated water. Turbidity removal efficiency was calculated using Eq. (3)

$$\text{Turbidity Removal efficency}\ (\backslash\%) = \frac{To - Tf}{To} \times\ 100$$

3

Where, T_0 is the initial turbidity of raw water (NTU) and T_f is the turbidity of treated water after settling (NTU).

All experiments were conducted in triplicate to ensure the reliability of the data and test the effect of treatments, the data was analyzed using SPSS software version 20. Thus, the data are reported as standard deviation of the average mean of triplicates and represented by an error bars (mean ± SD).

3. Results and Discussion

3.1. Characterization of synthesized cactus-derived bio coagulant

The physicochemical properties of the cactus powder were determined by moisture and ash content analysis and Fourier-transform infrared (FTIR) spectroscopy to identify functional groups that could participate in the coagulation process. The obtained moisture and ash content were 2.4 ± 0% and 25.58 ± 0.9%, correspondingly. The moisture properties of the mucilage' were done based on the method described elsewhere [14].Whereas, FTIR analysis was carried out to determine the functional groups present in the powder. Jar tests were performed to determine the optimal dose of the coagulant and coagulant aid with ferric chloride (FeCl3). They were carried out using both cactus powder and FeCl3 alone and in mixture. The preserved water's quality was evaluated using the pH, electrical conductivity (EC), total dissolved solids (TDS), and alkalinity, and which were compared to the applicable limits for drinking-water.

Figure 3 illustrates the FTIR spectrum of cactus-derived bio-coagulant, reflecting the active functional groups responsible to coagulation process. The broad spectra adsorption band observed around 3751 and 3669 cm^{-1} indicates the presence of hydroxyl stretching (OH^-) group within the mucilage matrix relevant to hydrogen bond formation and interaction with suspended particles to facilitate flocculation [2]. The band spectrum at 2932 and 2634 cm^{-1} confirms the presence of aliphatic C-H stretching groups such as organic polysaccharides and lipids inherent to cactus mucilage. Moreover, the peaks at 1613 and 1527 represents the C = O stretching and indicate carbonyl containing groups in the cactus matrix. Additionally, the bands around 1293, 1147 and 1015 shows C-O and C-O-C stretching groups associated with polysaccharides in the bio-coagulant [19].

Table 1
Physicochemical characteristics of Rib river water sample and WHO guideline

Parameter	Raw Water (Mean ± SD)	WHO Guideline Value
pH	7.83 ± 0.35	6.5–8.5
Turbidity (NTU)	496. 68 ± 2.36	< 5
TDS (ppm)	60.37 ± 1.52	< 1000
EC (µS/cm)	113.33 ± 1.80	< 1000
Alkalinity	69.94 ± 1.16	< 50

As can be seen in Table 1, most of the water quality parameters exceed the WHO drinking water limit, indicating the need for appropriate water treatment practices.

3.2. Water treatment using combined bio-coagulant and ferric chloride

The water treatment experiments were conducted using rib river surface water and a combined coagulant with different mixing ratio of a natural coagulant (cactus-derived) and chemical coagulant (ferric chloride). Under the investigation, the effect of initial pH, combined dose on turbidity, electrical conductivity and total dissolved solid were examined.

1. Effect of Bio-Coagulant–Ferric Chloride Mixture Ratio and Initial pH on Water Quality at a Total Coagulant Dose of 2.5 mg/L

The consequence of initial pH on turbidity differ with the cactus-to-$FeCl_3$ ratio (Fig. 4). The equal- amount of the mixture (cactus 1.25 + $FeCl_3$ 1.25) indicated that decreasing residual turbidity as the initial pH range from 6.5 to 8.5. Conversely, the cactus dominated mixture (1.75 + 0.75) shows an increasing trend, whereas the $FeCl_3$-rich mixture (0.75 + 1.75) showed a decrease at pH 8.5 and the higher values indicated at pH 6.5 and 7.5. These differences propose that the effect of pH depended on coagulant composition. Cactus mucilage can encourage particle adsorption and polymer bridging, while ferric chloride helps colloidal destabilization through iron hydrolysis products. The balance between these mechanisms can affect the floc formation and clarification. Previous research on cactus-based coagulants and $FeCl_3$ has similarly described that treatment performance depends on coagulant composition and operating conditions ([11]. Conversely, the optimum condition must be established using removal efficiency and statistical analysis.

Electrical conductivity increased with increasing $FeCl_3$ percentage and reducing cactus amount at all examined pH values (Fig. 4C). The lowest conductivity almost 22 µS/cm) ensued with cactus 1.75 + $FeCl_3$ 0.75 at pH 6.5, however the maximum (approximately 128 µS/cm) occurred with (cactus 0.75 + $FeCl_3$ 1.75) at pH 8.5. Nevertheless, the pH-dependent trend varied among mixtures. The higher

conductivity of $FeCl_3$-rich mixtures may be recognized to the introduction of dissolved ions, consistent with the conductivity increase with ferric chloride dosage reported by [20]. Although pH affects ferric-salt hydrolysis and precipitation [21]. As shown in Fig. (4B), the residual total dissolved solids (TDS) remained highly influenced on the coagulant blend ratio and initial pH. Throughout all pH values, increasing the ferric chloride ($FeCl_3$) fraction while decreasing the cactus dose substantially raised TDS, peaking at 96 ppm corresponding to pH of 7.5. However, maximizing the ratio of cactus bio coagulant (Cactus 1.75 + FeCl3 0.75) significantly minimized TDS, reaching its lowest value (10 ppm) at pH of 6.5.

The high TDS in chemical-dominated blends is attributed to the quick hydrolysis of FeCl3, which releases highly soluble Fe^{3+} and Cl^- ions that remain dissolved in the effluent [22]. the use of cactus bio coagulants consume macromolecular polymers that aggregate particles via bridging and adsorption without introducing excessive inorganic ions, thereby preserving post-treatment ionic stability [23]. Better performance at pH 6.5 indicates that slightly acidic conditions favor the protonation and conformation of cactus polymers for efficient flocculation. At higher pH levels (7.5 and 8.5), altered ferric hydroxide solubility and polymer charge changes reduced effectiveness, increasing unconfined dissolved species. These dynamics establish that optimized bio-chemical originations can attain illumination marks without causing secondary water quality degradation.

The response pH was affected by both the initial pH and the quantity of cactus related to the FeCl3 used[24]. When the starting pH was 6.5, all the treatments made the pH rising. But when the initial pH was 7.5 or 8.5, the pH deceased down. The treatment with more FeCl3 caused the leading drop in pH when starting at 8.5, which matches what happens during ferric ion hydrolysis and when hydrogen ions are released during coagulation [21]. Besides, using more cactus facilitated keep the final pH steadier under the tested conditions. These findings show how important it is to adjust the coagulant amount and starting pH to get the best treatment results, along with removing turbidity. The pH value of treated water sample after coagulation process were in the range between 6.5–8.5, meeting the WHO standards.

1. **Effect of Cactus Bio-Coagulant–Ferric Chloride Mixture Ratio and Initial pH on Water Quality at a Total Coagulant Dose of 7.5 mg/L**

Figure 5 illustrates the effect of mixing ratio of bio-coagulant and ferric chloride chemical coagulant on different water quality parameters. As shown in Fig. 5A, equal amount mixture coagulant dose (cactus 3.75 + $FeCl_3$ 3.75) showed that the lowest residual turbidity across all pH values, reaching nearly 69 NTU at pH of 7.5. The dominated cactus mixture (5 + 2.5) formed middle values, however the $FeCl_3$-rich mixture (2.5 + 5) exhibited higher residual turbidity. The relatively low turbidity found with the equal-ratio mixture may indicate a favorable balance between polymer-assisted particle aggregation and chemical coagulation. Similar studies have highlighted the importance of optimizing natural and chemical coagulant combinations to improve clarification performance [23]. However, the results indicate the lowest practical residual turbidity rather than a statistically established optimum; initial turbidity and removal efficiency should also be considered.

The analysis of TDS results reveals that the mixture which contains a higher proportion of the cactus (cactus 5 + FeCl3 2.5) has lower values of TDS. As the pH varied between 6.5 and 8.5, the TDS values decreased from 64 ppm to 53 ppm. Equal ratio mixture (3.75 + 3.75) had relatively minor fluctuations, while the $FeCl_3$ rich mixture (2.5 + 5) had an insignificant increase in the TDS. It can be noted that the effect of treatment on the water quality parameters was different. In particular, as TDS is the measurement of dissolved materials and not suspended, it can give a different reaction compared to the turbidity. The impact of dissolved ions due to the coagulant or dissolved ions of the cactus solution can affect the results. Hence, the minimum value of TDS for the cactus solution at pH 8.5 should be considered separately from turbidity.

Conductivity Electrical conductivity (EC) differ with initial pH and coagulant ratio in (Fig. 5C). The cactus-rich mixture (5:2.5) displayed a reduction in EC from 127 to 118 µS/cm as the initial pH increased from 6.5 to 8.5, although the $FeCl_3$- dominated mixture showed an increase EC, getting approximately 152 µS/cm. The high EC value may be associated with dissolved ionic compounds present or used in chemical coagulation process. The variations in conductivity due to the use of bio-coagulant have been noted by [25]. The above results indicate the importance of considering the EC in the choice of appropriate coagulant ratio at a Total Dose of 7.5 mg/L. The ultimate pH persisted moderately stable across the initial pH values and cactus–$FeCl_3$ ratios, representing that the mixture of the coagulants retained near to the neutral conditions under the experimental conditions. The slight reduction shows in the $FeCl_3$-dominated mixture at an initial pH of 8.5 might be related with ferric ion hydrolysis and the use of water alkalinity during coagulation process. The same investigation on pH-related effects have been demonstrated by [26]. This study investigate that the final pH depended on the type of coagulant used, with plant-based coagulants generally causing less prominent pH changes than alum.

El Bouaidi et al. (2022), highlighted that coagulation performance of cactus bio coagulant greatly influenced by operating pH and coagulant characteristics. These outcomes propose that the combined dose of the two coagulants influenced pH stability, while further statistical analysis is needed to establish whether the observed differences are significant.

4. Conclusion

This study investigates the combined performance of cactus-derived *Opuntia ficus-indica* bio-coagulant and ferric chloride for turbidity removal from Rib River surface water. The raw water was extremely turbid, with an initial turbidity of 496.68 ± 2.36 NTU, requiring effective treatment before drinking. These findings established that turbidity removal was affected by the cactus-to-$FeCl_3$ ratio, initial pH, and total coagulant dose. At a total coagulant dose of 7.5 mg/L, the equal mixture of cactus bio-coagulant and $FeCl_3$ (3.75 mg/L each) observed the lowest residual turbidity, approximately 69 NTU at pH 7.5. This proposes that the equal-ratio combination provided an effective balance between the adsorption and polymer-bridging mechanisms of cactus mucilage and the charge-neutralization and sweep-flocculation mechanisms of ferric chloride.

Cactus-rich mixtures typically produced lower electrical conductivity and total dissolved solids, whereas $FeCl_3$-rich mixtures increased these parameters because of the release of dissolved iron and chloride ions during coagulation process. The cactus bio-coagulant also facilitated to maintain a more stable final pH, while higher $FeCl_3$ concentrations caused a higher pH reduction, particularly under alkaline initial conditions. Most treated-water pH values near within the WHO standard (6.5–8.5). Overall, the combined use of cactus-derived bio-coagulant and ferric chloride demonstrated significant potential to maintain sustainable and cost-effective coagulation approach for treating turbid surface water. This framework can reduce chemical-coagulant consumption, minimize adverse effects of chemical coagulants and support the development of locally available water-treatment solutions in developing regions. Future studies should consider optimizing the mixing ratio of bio-coagulant and ferric chloride chemical coagulant to identify the effective and economical coagulation conditions. Biological analysis of the surface water should also be considered to investigate its effect on the removal of pathogens.

Authors contribution

Melkamu Bantie Ayicheh: Conceptualization, methodology, data curation, writing original draft, investigation, formal analysis; **Gashaw Tsegaw Tiruneh**: writing-review & editing; **Beyene Kindu Tibebu**: writing review & editing; **Yeshiwas Ayew Teka**: writing review & editing; **Habtamu Agmas Tarekegn**: writing review & editing; **Meriko Ewnetu Sahlie**: writing review & editing, visualization; **Getu Maru Demelash**: Conceptualization, Writing-review & editing, formal analysis, Supervision

Competing interest statement

We declare that there are no financial or other interests that could have resulted in affecting the outcomes of this study.

Declarations

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Author Contribution

Melkamu Bantie Ayicheh: Conceptualization, methodology, data curation, writing original draft, investigation, formal analysis; Gashaw Tsegaw Tiruneh: writing-review & editing; Beyene Kindu Tibebu: writing review & editing; Yeshiwas Ayew Teka: writing review & editing; Habtamu Agmas Tarekegn: writing review & editing; Meriko Ewnetu Sahlie: writing review & editing, visualization; Getu Maru Demelash: Conceptualization, Writing-review & editing, formal analysis, Supervision

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Data Availability

Data will be available from the corresponding author upon request

References

1. Mishra, R. K. Fresh Water availability and It's Global challenge. *J. Mar. Sci. Res.* **2**, 01–03 (2023).
2. Nigussie, Z. & Habtu, N. G. Performance evaluation of biocoagulant for the effective removal of turbidity and microbial pathogens from drinking water. *J. Water Health*. **21**, 1158–1176 (2023).
3. Ingrao, C., Strippoli, R., Lagioia, G. & Huisingh, D. Heliyon Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. *Heliyon* **9**, e18507 (2023).
4. Ostel, S. A. L. P. Entering an era of water scarcity: the challenges ahead. **10**, 941–948 (2025).
5. Akhtar, N., Izzuddin, M., Ishak, S., Bhawani, S. A. & Umar, K. Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review. (2021).
6. Shahzadi, F., Haydar, S. & Tabraiz, S. Optimization of Coagulation to Remove Turbidity from Surface Water Using Novel Nature-Based Plant Coagulant and Response Surface Methodology. (2024).
7. Assegide, E., Alamirew, T., Bayabil, H. & Dile, Y. T. Impacts of Surface Water Quality in the Awash River Basin, Ethiopia : A Systematic Review. 3, (2022).
8. Rasheed, F. A. Removal of Coagulants Water Turbidity Using Different. 2, 115–126 (2017).
9. Amin, N. K., Abdelwahab, O. & El-ashtoukhy, E. Z. & Abdel-aziz, M. H. Comparative analysis of new natural coagulant extracts for turbidity removal in water systems. **91**, 797–810 (2025).
10. Soros, A., Amburgey, J. E., Stauber, C. E., Sobsey, M. D. & Casanova, L. M. *Uncorrected Proof Uncorrected Proof* 1–15 doi:10.2166/wh.2019.114. (2019).
11. Benalia, A., Baatache, O., Derbal, K., Khalfaoui, A. & Atime, L. The Effect of a Cactus -Based Natural Coagulant on the Physical – Chemical and Bacteriological Quality of Drinking Water: Batch and Continuous Mode Studies. 1–23 (2026).
12. Ravele, M. P. et al. Recent advances in coagulants in wastewater treatment. *Sustain. Chem. One World*. **11**, 100280 (2026).
13. Worku, G. D. & Abate, S. N. Heliyon Efficiency comparison of natural coagulants (Cactus pads and Moringa seeds) for treating textile wastewater (in the case of Kombolcha textile industry). *Heliyon* **11**, e42379 (2025).
14. Luna-Sosa, B. et al. Extraction and characterization of mucilage from Opuntia ficus-indica cultivated on hydroponic system. *Not Bot. Horti Agrobot Cluj-Napoca*. **50**, 1–16 (2022).
15. Inam, M. A., Khan, R., Lee, K. H. & Wie, Y. M. Removal of Arsenic Oxyanions from Water by Ferric Chloride-Optimization of Process Conditions and Implications for Improving Coagulation

Performance. *Int J. Environ. Res. Public. Health* **18**, (2021).

16. Matijević, E. & Scheiner, P. Ferric hydrous oxide sols: III. Preparation of uniform particles by hydrolysis of Fe(III)-chloride, -nitrate, and -perchlorate solutions. *J. Colloid Interface Sci.* **63**, 509–524 (1978).
17. Husen, A. K. et al. Color, COD, and turbidity removal from surface water by using linseed and alum coagulants: optimization through response surface methodology. *Appl. Water Sci.* **14**, 1–16 (2024).
18. Kalibbala, H. M., Olupot, P. W. & Ambani, O. M. Synthesis and efficacy of cactus-banana peels composite as a natural coagulant for water treatment. *Results Eng.* **17**, 100945 (2023).
19. Arris, S., Ayat, A., Bencheikh-lehocine, M. & Meniai, A. Removal of turbidity and chemical oxygen demand using an eco-friendly coagulant / flocculent (optimization and modeling through the response surface methodology). *Desalin. Water Treat.* **211**, 338–348 (2021).
20. Islam, S. & Shang, J. Q. Coagulation enhanced electrokinetic settling of mature fine oil sands tailings. *Int. J. Min. Sci. Technol.* **29**, 199–208 (2019).
21. Duan, J. & Gregory, J. Coagulation by hydrolysing metal salts. *Adv. Colloid Interface Sci.* **100–102**, 475–502 (2003).
22. Worku, G. D. & Abate, S. N. Efficiency comparison of natural coagulants (Cactus pads and Moringa seeds) for treating textile wastewater (in the case of Kombolcha textile industry). *Heliyon*11, e42379 (2025).
23. Ali, S. K., Abdou, M. M., Emara, M. M., Farag, R. S. & Mubarak, M. F. Eco-friendly solutions: a comprehensive review of natural coagulants for sustainable water treatment. *Environ. Geochem. Health*. **47**, 1–26 (2025).
24. Vishali, S. & Karthikeyan, R. Cactus opuntia (ficus-indica): an eco-friendly alternative coagulant in the treatment of paint effluent. *Desalin. Water Treat.* **56**, 1489–1497 (2015).
25. Raj, A., Dash, S., Landa, B. & Vara, S. Efficacy of Natural Coagulants in Treating Selected Industrial Wastewaters. *Nat Environ. Pollut Technol* **24**, (2025).
26. Diver, D., Nhapi, I. & Ruziwa, W. R. The potential and constraints of replacing conventional chemical coagulants with natural plant extracts in water and wastewater treatment. *Environ. Adv.* **13**, 100421 (2023).
27. El Bouaidi, W. et al. Nature-based coagulants for drinking water treatment: An ecotoxicological overview. *Water Environ. Res.* **94**, e10782 (2022).

Figures

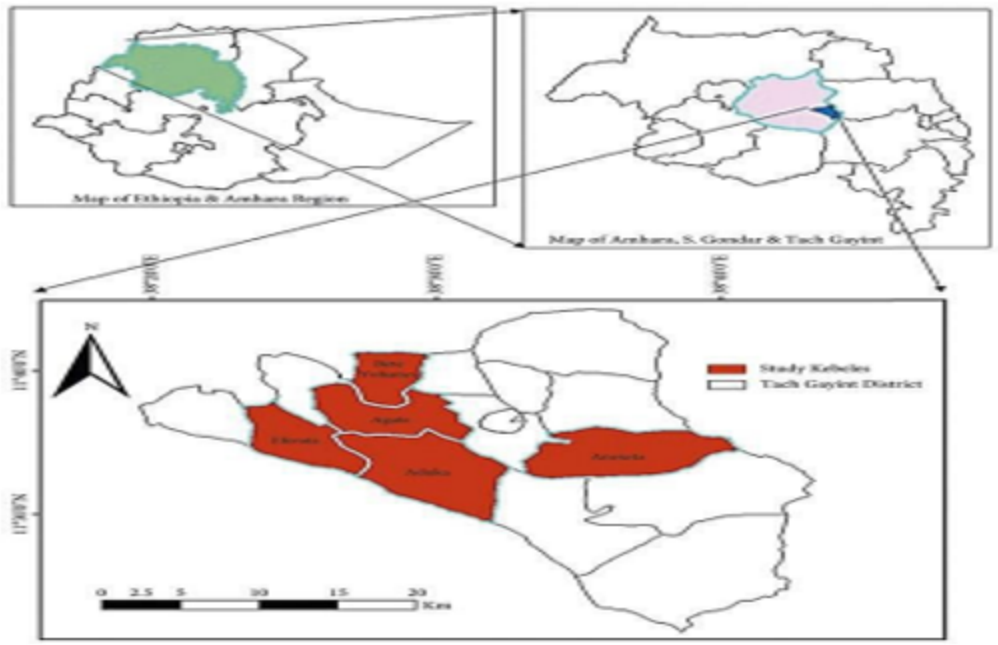

Figure 1

Map of Tach Gayient, indicating the study kebeles (highlighted in red)



Figure 2

Overall bio coagulant preparation procedure

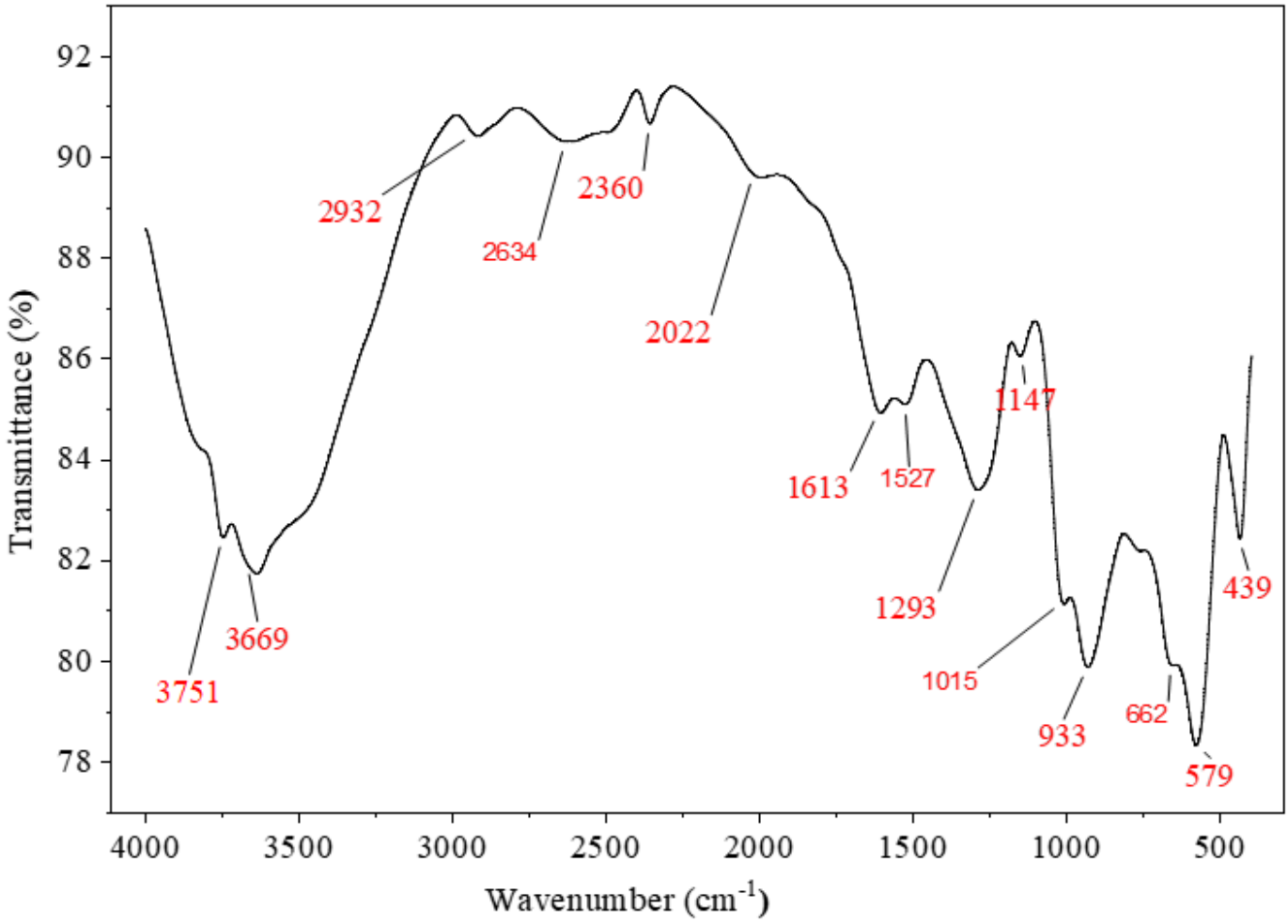

Figure 3

FTIR spectrum of cactus-derived bio coagulant

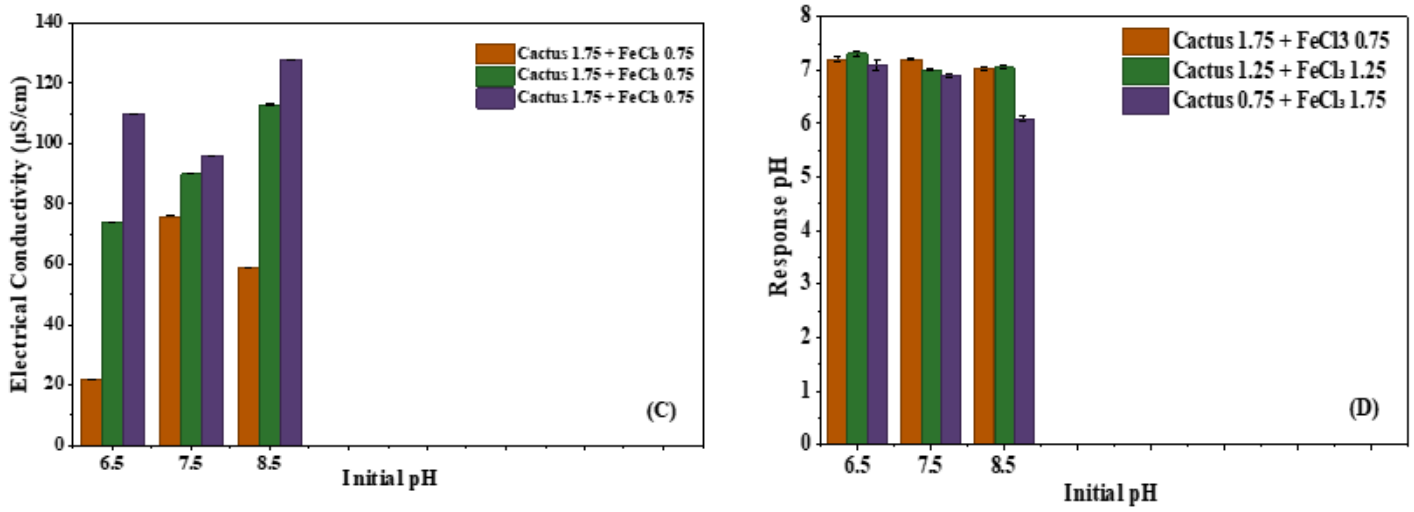

Figure 4

Effect of cactus bio-coagulant–ferric chloride mixing ratio and initial pH on water quality at a combined dose of 2.5 mg/L; (A) Turbidity, (B) TDS, (C) Electrical conductivity and (D) response pH

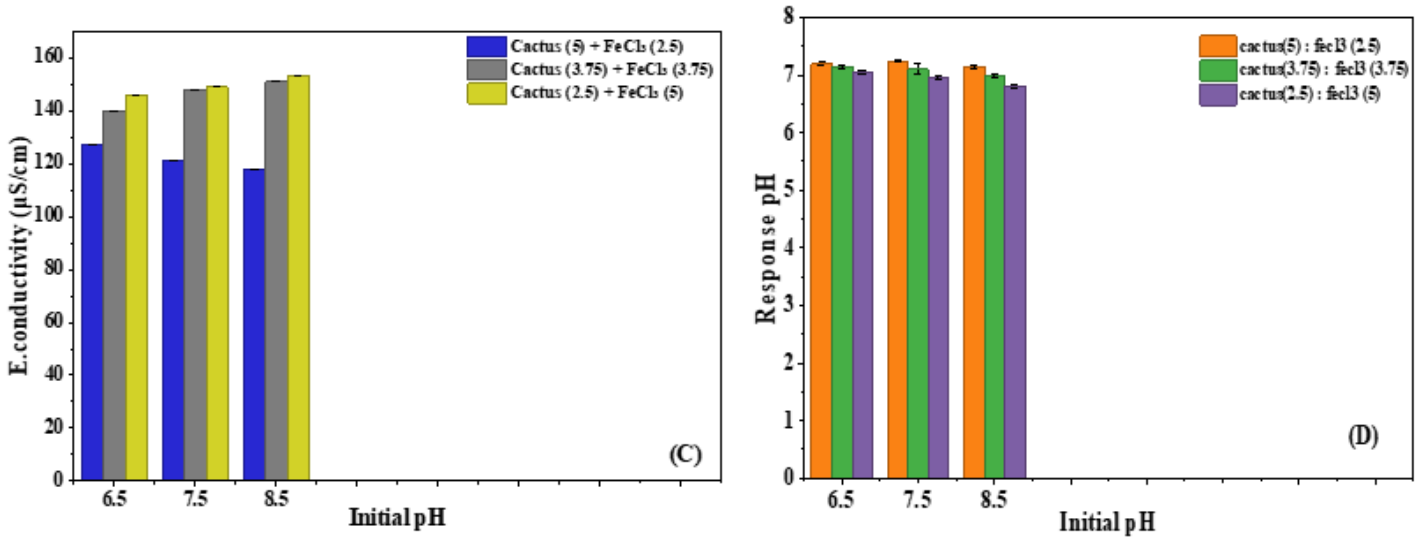

Figure 5

Effect of cactus bio-coagulant–ferric chloride mixing ratio and initial pH on water quality at a combined dose of 7.5 mg/L; (A) Turbidity, (B) TDS, (C) Electrical conductivity and (D) response pH.