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Comparative Analysis of Natural Coagulants Towards Greywater from Mosque in Shah Alam, Selangor

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Greywater is water from non-toilet sources such as sinks, showers, bathrooms, and laundry that does not require harsh chemicals to be pretreated before being discharged into the water bodies. Maintaining high water quality standards is essential, as the treated water will ultimately be distributed back to consumers. Therefore, to address this issue, an innovative solution must be implemented to improve water quality. This research aims to quantify the effectiveness of natural coagulants in treating greywater collected from mosques in Seksyen 18, Shah Alam, Selangor and the key parameters measured include turbidity, temperature, pH, ammonia-nitrogen, chemical oxygen demand (COD), and biochemical oxygen demand (BOD). This study explores the potential of chitosan and *Moringa oleifera* seeds as natural coagulants in pretreatment to reduce pollutants in the sample effluent. A jar test was performed using 5, 10, and 15 g of each natural coagulant mixed separately into the medium sample. The findings demonstrated significant improvements in water quality parameters, underscoring the potential of chitosan and *Moringa oleifera* seeds as sustainable and effective solutions for enhancing pretreatment processes. From the experimental results, chitosan significantly reduced turbidity from 25.21 NTU to 8.36 NTU at an optimum concentration—similarly, *Moringa oleifera* seeds achieved turbidity removal rates of 19.5 NTU. Therefore, from the observation, the lowest turbidity removal was 22.65%, and the maximum was 66.84%. FTIR spectroscopy revealed changes in each coagulant's chemical structure after treatment, particularly in functional groups like hydroxyl (O-H), carbonyl (C=O), and amine (N-H). After treatment, these changes were observed in a scanning electron microscope for both chitosan and *Moringa oleifera* seeds, highlighting their interaction with contaminants in the effluent. Additionally, isotherm analysis for the adsorption capacity of these bio-coagulants was performed, revealing that the Freundlich isotherm provided a better fit for chitosan, suggesting a multilayer adsorption process on heterogeneous surfaces. The results indicate that these natural coagulants can effectively treat the greywater, offering a sustainable alternative to chemical coagulants.

Keywords: Chitosan; greywater; *Moringa oleifera*; pretreatment

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Water is a finite resource vital for sustaining life and ecosystems, making the effective treatment of wastewater a global imperative. As urbanization accelerates and industries flourish, the volume of wastewater increases, underscoring the critical need for efficient treatment methodologies [1]. Coagulants play a pivotal role in this process by inducing the aggregation of suspended particles, organic matter, and pollutants, thereby facilitating their removal from wastewater [2]. Chemical coagulants have always been the industry standard in wastewater treatment plants because their meticulously developed compositions are optimized for maximum efficiency [3]. However, these chemical coagulants can harm the environment by generating large amounts of residue, producing toxic byproducts, and increasing operational costs [4-5]. Amidst these concerns, the quest for sustainable practices and eco-friendly alternatives has gathered momentum, steering attention towards natural coagulants [5]. These alternatives derived from organic sources like plants, microbes, and

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animals offer inherent coagulation properties without the ecological ramifications linked to synthetic chemicals [6].

Wastewater treatment conventionally relies on chemical coagulants, presenting challenges that hinder efficiency and sustainability. Though effective in impurity removal, conventional coagulants often contain harmful elements that threaten aquatic life and human health [7]. Their discharge disrupts ecosystems and contaminates water sources [8]. The production, transportation, and disposal of chemical coagulants are energy-intensive, contributing to environmental degradation and climate change [9]. Economically, procurement costs, safe disposal, and environmental cleanup strain treatment facilities and local communities [10]. Furthermore, conventional coagulants are inefficient in treating diverse pollutants and varying wastewater compositions, complicating the treatment process in achieving consistent results [11, 12, 13]. Thus, exploring effective, eco-friendly, cost-efficient, and adaptable alternatives is essential to enhance wastewater treatment efficiency and sustainability, ensuring environmental protection and community well-being.

Therefore, this research encompasses the evaluation of chitosan and *Moringa oleifera* seeds as natural coagulants for greywater treatment, focusing on key water quality parameters such as turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen. The study aims to comprehensively analyze the effectiveness, optimal concentrations, and pH levels of these coagulants. Additionally, it includes an assessment of the changes in chemical structure and functional groups through Fourier Transform Infrared (FTIR) Spectroscopy and an isotherm analysis utilizing the Freundlich and Langmuir models to understand adsorption capacities, together with the morphology characteristics of both bio-coagulants in a scanning electron microscope. This analysis can later be applied to their use in various water treatment contexts. Ultimately, the findings support the adoption of biodegradable and non-toxic coagulants, aligning with global sustainability efforts and potentially influencing policymaking to improve water treatment practices.

MATERIALS AND METHODS

Sample Collection

The samples have been collected from the ablution water in Masjid An-Nadhah, Shah Alam, Selangor which is stored and preserved in a bottle container prior to further testing [14]. In situ analysis of the water quality parameters was conducted using a portable multi-parameter probe, Model LAQUAact-DO110 (HORIBA, Japan) [15]. This instrument was utilized to measure key environmental indicators, including temperature, pH, and dissolved oxygen (DO), directly at the sampling location, ensuring real-time and accurate data acquisition without sample alteration or degradation [15]. For laboratory testing, the experiment was conducted in the Environmental Laboratory in the Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor.

Laboratory Testing

The laboratory testing in this research involved jar tests to evaluate chitosan and *Moringa oleifera* seeds as natural coagulants for greywater treatment [12,13]. Coagulants (5, 10, and 15 g) were individually added to greywater samples and mixed rapidly at 140 rpm for 2 minutes to ensure even distribution, simulating water treatment processes. Anionic or cationic polymers often assist coagulation. Key water quality parameters—turbidity, BOD, COD, TSS, ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen—were measured in triplicate before and after treatment to assess the pollutant reduction in the samples [14].

Moringa Oleifera Coagulant Preparation

The extraction of coagulant from *Moringa oleifera* seeds involves several steps [12]. Mature seeds are harvested and dried to reduce moisture content. Once dried, the seeds are ground into a fine powder using a mortar and pestle [12]. This powder is then mixed with water to extract the coagulant proteins (see Figure 1). The resulting solution, enriched with the natural coagulating properties of *Moringa oleifera*, serves as an effective bio-coagulant in wastewater treatment. Its active compounds, primarily cationic proteins, work by neutralizing the negatively charged particles in the water, facilitating flocculation and sedimentation. This eco-friendly alternative to chemical coagulants not only enhances the clarity of treated water but also reduces sludge volume and minimizes secondary pollution.

Chitosan Coagulant Preparation

Crustacean exoskeletons are the source of chitin, which is carefully extracted and prepared [13]. Crustacean shells are first purchased from suppliers or seafood processing facilities and are thoroughly cleaned to remove leftover meat, protein, and mineral residue. The chitin material is removed from these shells during demineralisation by treating them with acidic liquids like hydrochloric acid, which dissolves calcium carbonate [13]. The next step, deacetylation, is treating the chitin with an alkaline solution (often sodium hydroxide) to eliminate the acetyl groups and convert them to chitosan [13]. This complex series of procedures later produced a substance called chitosan (see Figure 2), a useful natural coagulant that can be used in various wastewater treatment applications.

Figure 1. Process of extracting *Moringa* seeds.

Figure 2. Process of grinding shrimp shell.

Jar Test Experiments

Jar tests were performed with a standard apparatus that included three 1-L beakers [2]. This experiment was done to obtain the appropriate coagulant concentration for coagulation processes. The water samples, each containing 1 L, were rapidly agitated at 140 rpm for 2 minutes. During the testing, varied coagulant concentrations were introduced to the beakers for effective coagulant dispersion. The coagulant concentrations of 5, 10, and 15 g were administered in the 1 L sample of the jar test. The mixing speed dropped to 70 rpm for 10 minutes at the flocculation stage. The suspension was left undisturbed for 30 minutes to facilitate the settlement processes [6]. The extended sedimentation time was chosen to evaluate the process's effectiveness [2]. A final treated water sample (10 mL) was collected from the top surface of the water in the beakers with a syringe. Treated samples were then checked in triplicate following the parameters for laboratory testing [6].

Fourier Transform Infrared (FTIR)

Fourier Transform Infrared (FTIR) Spectroscopy was employed to investigate the structural and chemical modifications of the coagulant materials before and after the coagulation-flocculation process. The analysis was performed using a Perkin Elmer FTIR Spectrometer (SDTA 851, USA) within the spectral range of 4000 to 650 cm^{-1}. This technique enabled the identification of functional groups and molecular bonds present in the coagulant samples by detecting their characteristic absorption bands.

Samples of the coagulant were collected before and after the jar test experiments to assess changes induced by interactions with contaminants in the wastewater. FTIR analysis provided insights into the chemical structure of the coagulant, highlighting any shifts in peak positions, intensity variations, or the emergence/disappearance of specific functional group signals. These changes are indicative of chemical reactions or molecular interactions that occur during the treatment process.

The results from the FTIR spectra allowed for the identification of key functional groups involved in the coagulation mechanism, such as hydroxyl (-OH), carboxyl (-COOH), and amine ($-NH_2$) groups. Shifts in these functional group peaks provided evidence of binding or complexation with pollutant molecules, supporting the proposed mechanism of pollutant removal through adsorption, charge neutralisation, and bridging effects. This comprehensive analysis confirmed the active participation of specific functional groups in the removal of suspended particles and organic matter from the wastewater, thereby validating the coagulant's effectiveness at the molecular level [10].

Isotherm Analysis

Isotherm analysis using the Freundlich and Langmuir models determined the adsorption capacities of the coagulants in the water samples [7]. These tests comprehensively evaluated the effectiveness and mechanisms of chitosan and *Moringa oleifera* seeds in greywater treatment after the adsorption process. The Freundlich model for linear equations is as follows:

$$\text{Log } q_e = \log K_f + 1/n\,(\log C_e) \qquad \text{(Equation 1)}$$

Where C_e is the equilibrium concentration of solution (mg/L), q_e is the amount of pollutants adsorbed per unit weight of coagulant, K_f is the adsorption constant, and n is the adsorption intensity. By analysing the intercept and slope, respectively, from the linear plot of log q_e vs log C_e, it is possible to calculate the values of K_f and n.

The linear form of the Langmuir isotherm can be expressed as:

$$\frac{1}{q_e} = \frac{1}{Q_m K_L} \times \frac{1}{C_e} + \frac{1}{Q_m} \qquad \text{(Equation 2)}$$

Where C_e is the equilibrium concentration of the solute in solution (mg/L), q_e is the amount of solute adsorbed per unit mass of adsorbent at equilibrium (mg/g), Q_m is the maximum adsorption capacity (mg/g), K_L is the Langmuir adsorption constant (L/mg), which reflects the affinity of the binding sites.

Scanning Electron Microscope

Scanning Electron Microscopy (SEM) was employed to investigate the surface morphology and structural changes of the bio-coagulants—chitosan and *Moringa oleifera*—before and after their application in the coagulation-flocculation process using the jar test method [8]. This analysis was performed to observe the interaction between the bio-coagulants and the pollutants present in the treated water and to evaluate the physical impact of the coagulation process on the bio-coagulant surfaces. Samples of the bio-coagulants were collected at two stages, which included before treatment (raw chitosan and moringa oleifera powder) and after treatment (residual flocs collected post-jar test). The solid samples were first air-dried at room temperature for 24–48 hours to remove moisture content. Once dry, fine particles were mounted onto aluminium stubs using double-sided carbon adhesive tape. To enhance conductivity and minimise charging during imaging, the mounted samples were coated with a thin layer (approximately 10 nm) of gold or platinum using a sputter coater (Quorum Q150R S) [8]. The SEM observations were performed using a field emission scanning electron microscope (FESEM). Imaging was carried out under the following parameters;

Accelerating Voltage: 5–15 kV
Magnification Range: 500× to 50,000×
Working Distance: 8–10 mm
Detector Type: Secondary Electron Detector (SE) for surface topography
Chamber Pressure: High vacuum mode (10^{-4} Pa or lower)
Spot Size: 3–5 nm resolution for high-detail surface observation

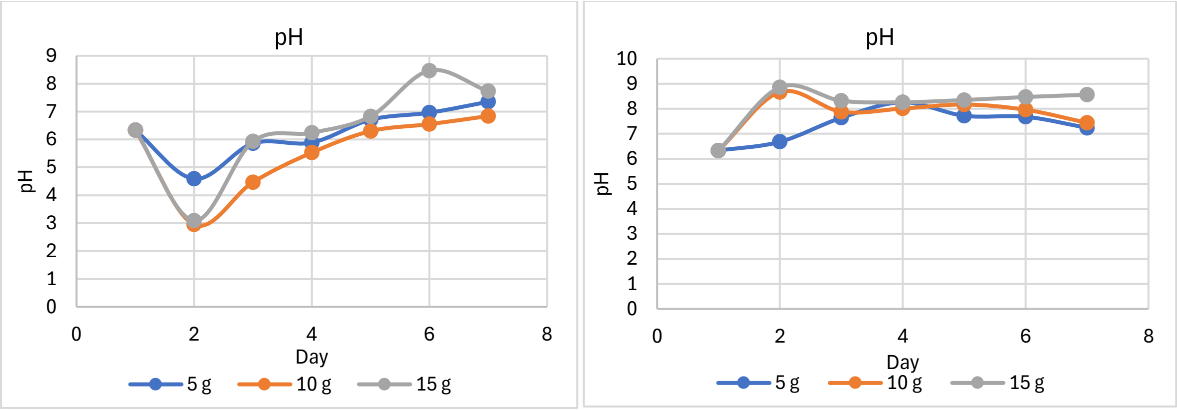
Anova: Two-Factor Without Replication

A One-Way ANOVA was used to assess differences in pollutant removal efficiency between two bio-coagulants: chitosan and *Moringa oleifera*. This method determines if there are significant differences between the means of independent groups. It is often applied in water treatment studies to compare conditions like coagulant type, dosage, or contact time.

RESULTS AND DISCUSSION

Effect of Coagulation-Flocculation on pH

From Figure 3, *Moringa oleifera* seeds slightly decreased the initial pH of 6.33 due to natural organic acids present in the seeds, but the pH remained within the acceptable limits [11]. In contrast, chitosan maintained a stable pH, starting at 6.33, due to its weakly basic nature, ensuring the treated water remained within safe ranges for various uses [16]. This stability makes chitosan more advantageous for applications requiring consistent pH levels, while *Moringa* seeds are still effective but may require additional pH adjustment. Research by [17] supports this observation, noting that chitosan does not significantly alter the pH of treated water, making it an attractive option for water treatment applications where pH consistency is crucial.



a) b)

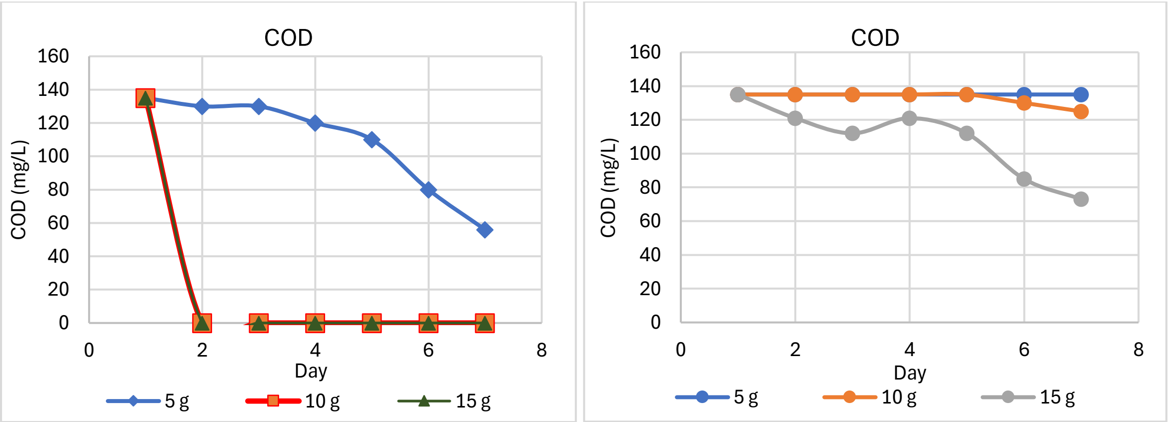
Figure 3. Comparison between different types of coagulants for pH level: a) *Moringa oleifera*, b) chitosan.

Effect of Coagulation-Flocculation on the Reduction of Chemical Oxygen Demand

This study analysed the effectiveness of *Moringa oleifera* seeds and chitosan in reducing chemical oxygen demand (COD) in greywater. *Moringa oleifera* seeds proved highly effective, especially at higher concentrations, maintaining zero COD levels with 10 g and 15 g treatments throughout the seven days. It indicates that the cationic proteins in *Moringa* seeds efficiently neutralise and aggregate organic pollutants, leading to significant COD reduction [10]. On the other hand, chitosan exhibited consistent COD reduction across all tested concentrations. For instance, in the 5 g treatment, COD levels decreased from 132 mg/L to 56 mg/L over seven days. Despite initial fluctuations at higher concentrations, chitosan's performance stabilised, showcasing its strong adsorption capacity and network-forming ability to trap organic pollutants [17]. While both coagulants effectively reduce COD, *Moringa oleifera* seeds demonstrated superior performance at higher dosages, whereas chitosan provided steady and reliable COD reduction across varying concentrations.

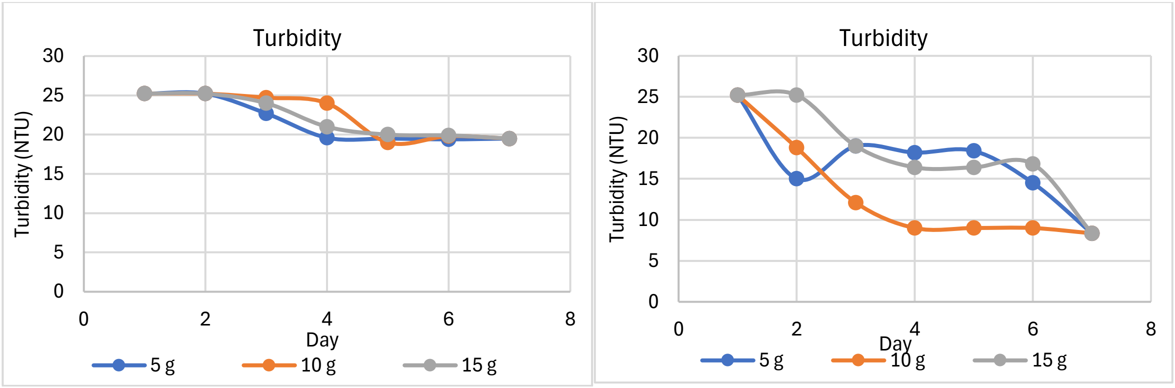
Effect of Coagulation-Flocculation on Turbidity Removal

Figure 5 compares the effectiveness of *Moringa* oleifera seeds and chitosan in reducing turbidity in greywater. *Moringa oleifera* seeds reduced the initial turbidity of 25.21 NTU to 19.5 NTU, achieving a 22.65% reduction. This reduction is attributed to the cationic proteins in *Moringa* seeds, which neutralise negatively charged particles, causing them to aggregate and settle [7]. Conversely, chitosan demonstrated a higher turbidity reduction efficiency by lowering the turbidity from 25.21 NTU to 8.36 NTU, achieving a 66.84% reduction. Chitosan's superior performance is due to its ability to form a network that traps and flocculates suspended particles, enhancing sedimentation [13]. While both coagulants effectively improve water clarity, chitosan's higher reduction rate indicates greater efficacy in removing suspended particles and significantly enhancing water quality.



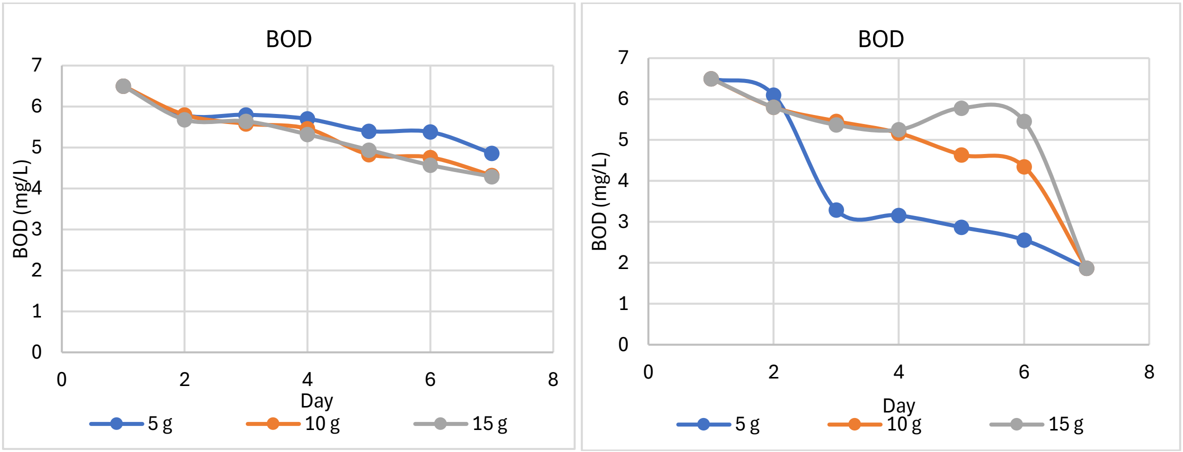
a) b)

Figure 4. Comparison between different types of coagulants for chemical oxygen demand: a) *Moringa oleifera*, b) chitosan.



a) b)

Figure 5. Comparison between different types of coagulants for turbidity removal a) *Moringa oleifera*, b) chitosan.



a) b)

Figure 6. Comparison between different types of coagulants for biochemical oxygen demand: a) *Moringa oleifera*, b) chitosan.

Effect of Coagulation-Flocculation on the Reduction of Biochemical Oxygen Demand

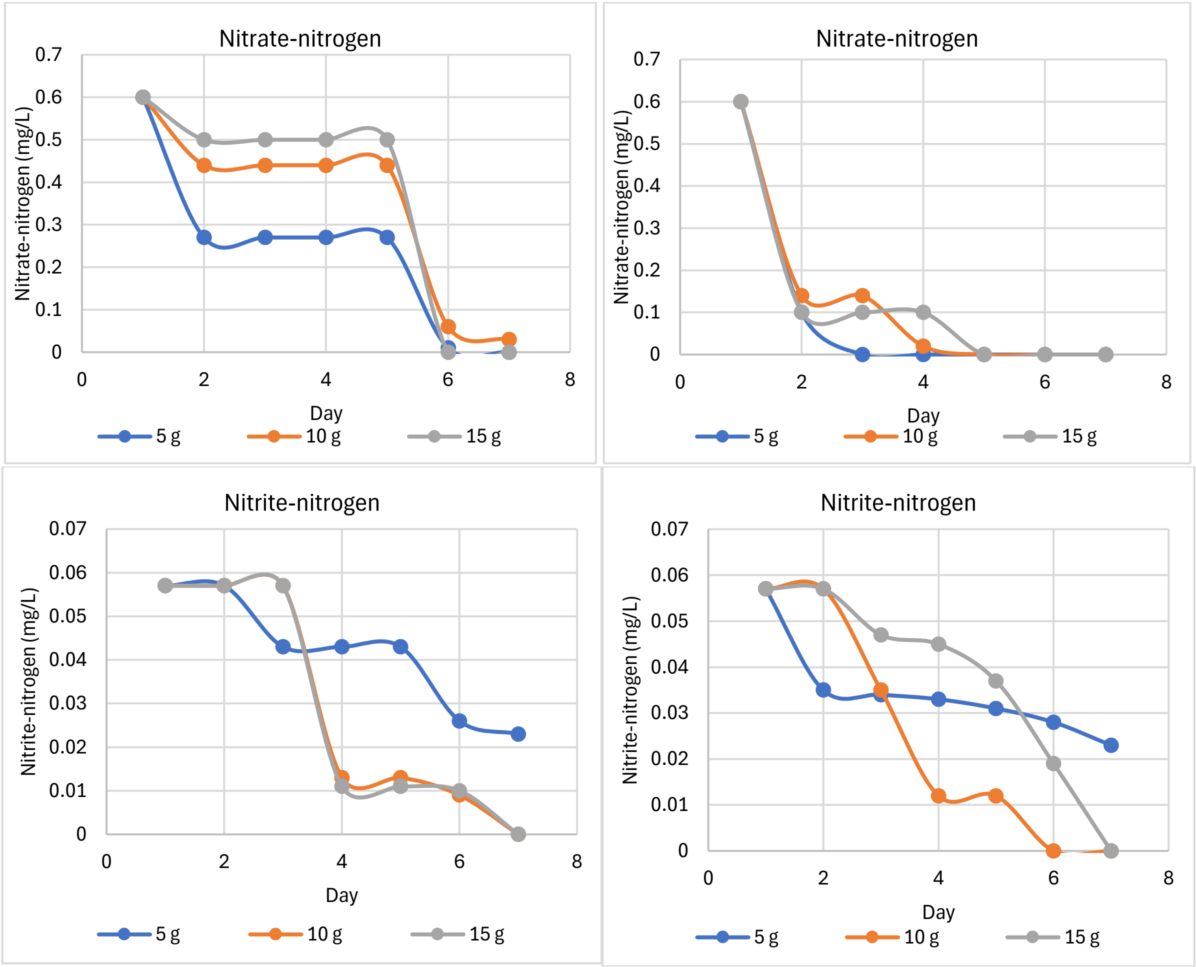
The effectiveness of *Moringa oleifera* seeds and chitosan in reducing biological oxygen demand (BOD) in greywater was compared after the jar test experiment. *Moringa oleifera* seeds reduced the initial BOD from 6.5 mg/L to 4.29 mg/L by Day 7. This reduction is attributed to the cationic proteins in *Moringa* seeds that neutralise and aggregate organic matter, facilitating its removal. In contrast, chitosan demonstrated a more consistent and substantial BOD reduction, decreasing the initial BOD from 6.5 mg/L to 1.87 mg/L by Day 7 [6]. Chitosan's polymer structure forms a network that traps and flocculates organic pollutants, leading to more effective sedimentation and removal [3]. While both coagulants effectively lower BOD levels, chitosan's greater reduction indicates its superior ability to remove organic contaminants, resulting in enhanced water quality and reduced demand for oxygen in the treated water.

Effect of Coagulation-Flocculation on the Reduction of Nitrate-nitrogen and Nitrite-nitrogen

Based on Figure 7, the effectiveness of *Moringa oleifera* a seeds and chitosan in reducing nitrate-nitrogen and nitrite-nitrogen levels in greywater was analysed. Despite slight fluctuations, *Moringa oleifera* seeds effectively reduced nitrate-nitrogen levels, with the initial concentration of 0.6 mg/L decreasing to zero by the end of the treatment period. Similarly, nitrite-nitrogen levels were reduced from 0.057 mg/L to zero by Day 7, attributed to the cationic proteins in *Moringa* seeds that neutralise and aggregate nitrate-nitrogen and nitrite-nitrogen ions. Chitosan also showed strong adsorption properties, reducing nitrate-nitrogen levels from 0.6 mg/L to zero by Day 6 and nitrite-nitrogen levels from 0.057 mg/L to zero by Day 7, with minor initial fluctuations. The amine groups in chitosan facilitate the adsorption of nitrate-nitrogen and nitrite-nitrogen ions, forming a network that traps these contaminants [18]. While both coagulants demonstrated high efficacy in reducing nitrate-nitrogen and nitrite-nitrogen levels, chitosan's rapid and consistent reduction highlights its robust adsorption capabilities, making it slightly more effective in achieving and maintaining low levels of these nitrogenous pollutants [19].

Effect of Coagulation-Flocculation on Ammonia-Nitrogen Reduction

The analysis of *Moringa oleifera* seeds and chitosan in reducing ammonia-nitrogen levels is shown in Figure 8. *Moringa oleifera* seeds consistently decreased ammonia-nitrogen, reducing the starting level from 0.04 mg/L to 0.012 mg/L by Day 7. The decrease is caused by the positively charged proteins in *Moringa* seeds, which efficiently bind and deactivate ammonia-nitrogen molecules, creating clusters taken out of the water [20]. Chitosan performed better than its counterpart by showing a stronger decrease, starting at 0.04 mg/L and dropping to 0.0172 mg/L by Day 7 with a 5 g dosage. Numerous amine groups in chitosan's structure enable strong electrostatic interactions with ammonia-nitrogen, greatly improving its adsorption and elimination [21]. Although both natural coagulants worked well, chitosan's excellent adsorption capabilities and reliable efficiency make it a top choice for enhancing ammonia-nitrogen reduction in greywater, demonstrating its potential as a valuable resource in eco-friendly water treatment.



a) b)

Figure 7. Comparison between different types of coagulants for nitrate-nitrogen and nitrite-nitrogen reduction: a) *Moringa oleifera*, b) chitosan.

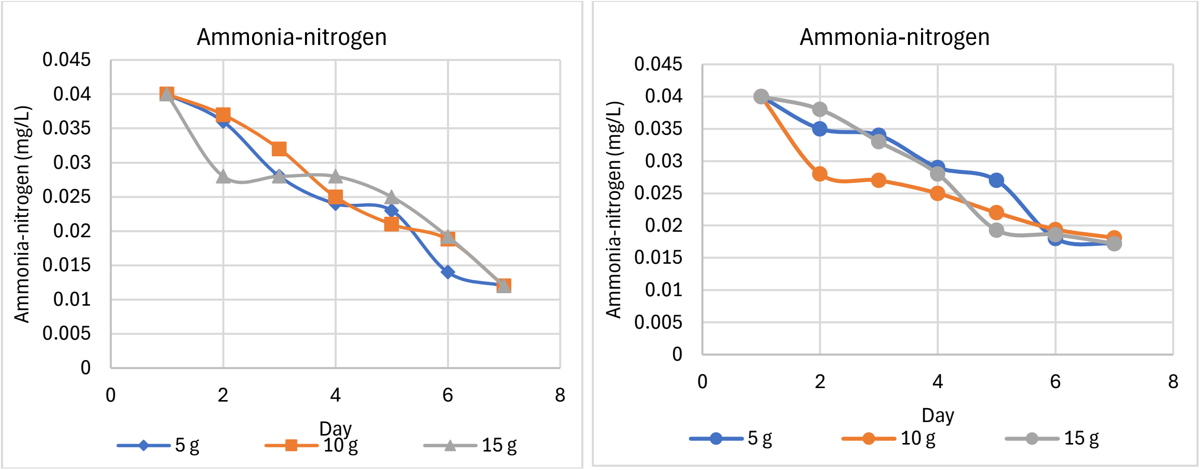


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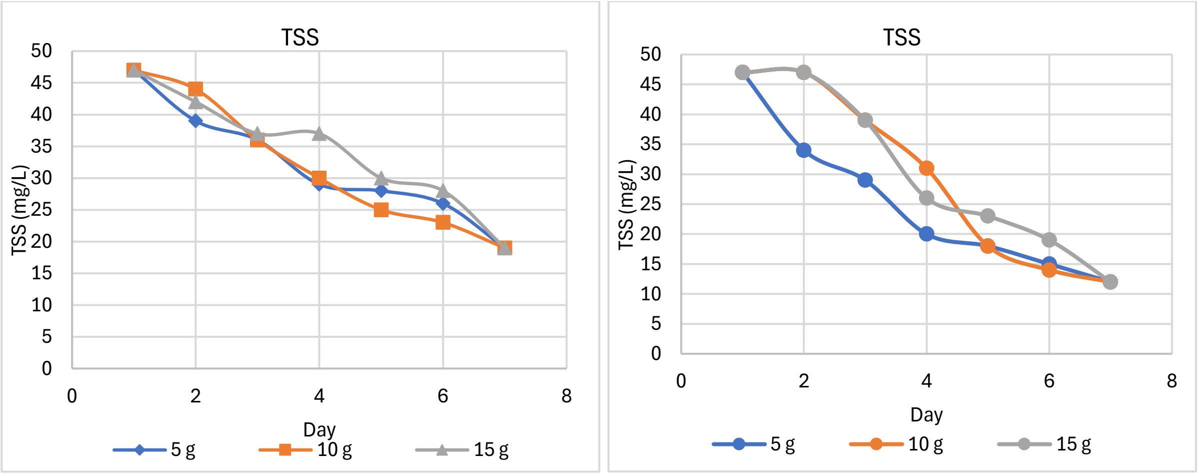
Figure 8. Comparison between different types of coagulants for ammonia-nitrogen reduction: a) *Moringa oleifera*, b) chitosan.



a) b)

Figure 9 Comparison between different types of coagulants for total suspended solid reduction: a) *Moringa oleifera*, b) chitosan.

Effect of Coagulation-Flocculation on Total Suspended Solid Reduction

Figure 9 evaluated the effectiveness of *Moringa oleifera* seeds and chitosan in reducing total suspended solids (TSS) in greywater. *Moringa oleifera* seeds demonstrated significant efficacy, reducing TSS from an initial concentration of 47 mg/L to 19 mg/L by Day 7 at the 5 g dosage. This reduction is attributed to the cationic proteins in the seeds, which neutralise and aggregate suspended particles, facilitating their removal [2]. Chitosan, however, showed even greater effectiveness, decreasing TSS levels from 47 mg/L to 12 mg/L over the same period at the same dosage. Chitosan's polymeric structure forms a network that efficiently traps and flocculates suspended particles, enhancing sedimentation [3]. While both coagulants effectively reduced TSS, chitosan's superior performance underscores its higher capability in aggregating and removing suspended solids, making it a more efficient option for improving water clarity and quality in greywater treatment processes.

Table 1. The percentage removal of suspended solids using coagulants.

Type of Coagulant	***Parameters***	**Before treatment (mg/L) C_0**	**After treatment (mg/L) C_e**	**Percentages removal (%)**
Moringa oleifera	Suspended solids	47	19	60
Chitosan		47	12	74
Moringa oleifera	COD	132	56	58
Chitosan		132	0	100
Moringa oleifera	Turbidity	25.21	19.5	22
Chitosan		25.21	8.36	67
Moringa oleifera	BOD	6.5	4.29	34
Chitosan		6.5	1.87	71

Table 2. The adsorption data were fitted to both the Langmuir and the Freundlich isotherm models.

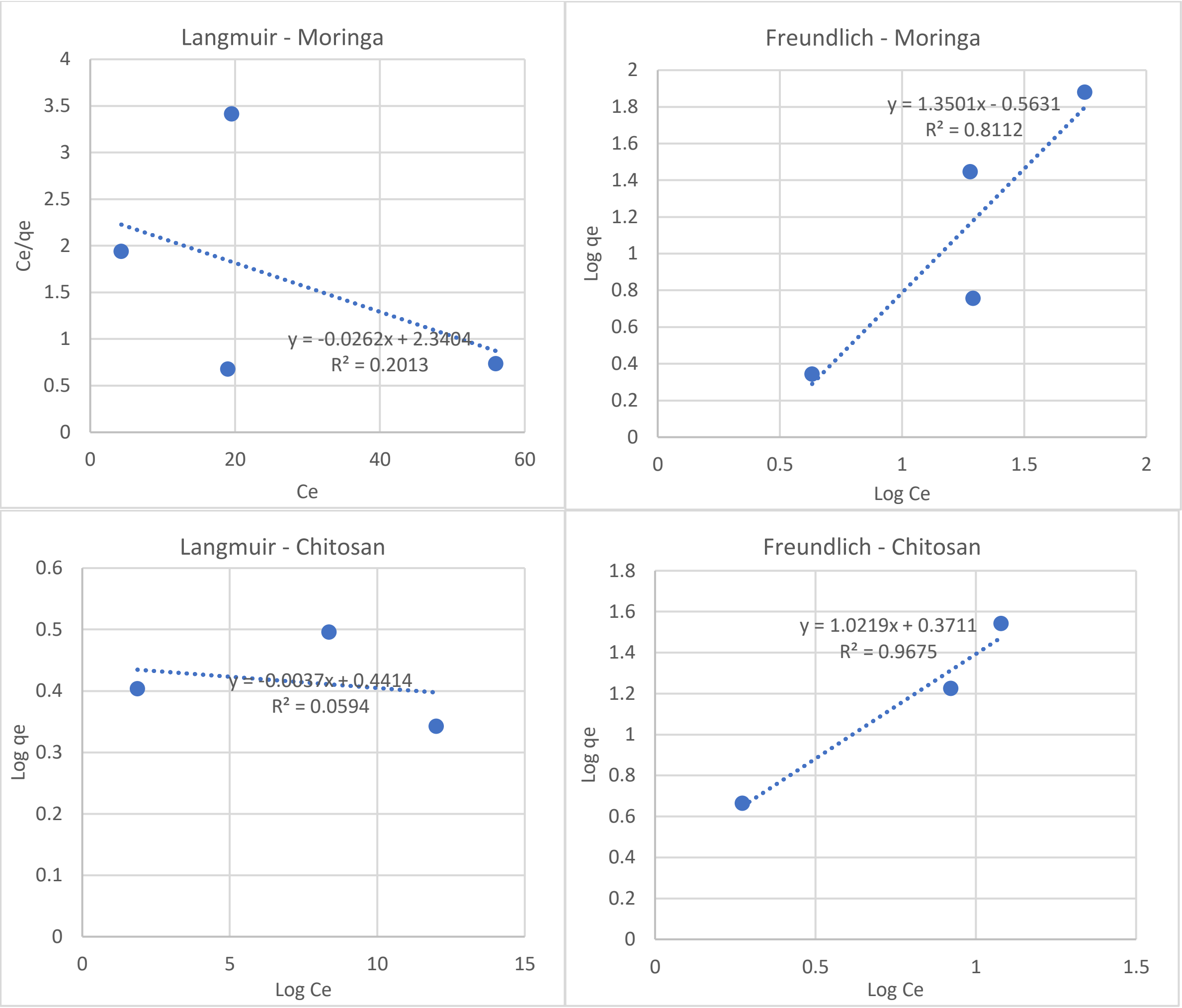
Type of Coagulant	**Parameters**	$\frac{C_e}{q_e}$	C_e	q_e	$\log C_e$	$\log q_e$
Moringa oleifera	Suspended solids	0.679	19	28	1.279	1.447
	COD	0.737	56	76	1.748	1.881
	Turbidity	3.415	19.5	5.71	1.290	0.757
	BOD	1.941	4.29	2.21	0.632	0.344
Chitosan	Suspended solids	0.343	12	35	1.079	1.544
	Turbidity	0.496	8.36	16.85	0.922	1.226
	BOD	0.404	1.87	4.63	0.272	0.666

Isotherm Analysis

Based on Figure 10, a comparative analysis of isotherm models was conducted to evaluate the adsorption capacities of *Moringa oleifera* seeds and chitosan used as natural coagulants in greywater treatment. The adsorption data were fitted to both the Langmuir and the Freundlich isotherm models. For *Moringa oleifera* seeds, the Freundlich isotherm provided a better fit, suggesting that adsorption occurs on a heterogeneous surface with multiple layers. It indicates that *Moringa* seeds have varying affinities for different contaminants, making them versatile in treating diverse pollutants [22]. On the other hand, chitosan also demonstrated a better fit with the Freundlich isotherm, highlighting its ability to adsorb contaminants on heterogeneous surfaces with multiple adsorption sites. However, chitosan exhibited a higher adsorption capacity than *Moringa* seeds, as indicated by the Freundlich constants. This superior performance can be attributed to chitosan's abundant amine groups and polymeric structure, which provide more effective contaminant binding sites [21]. While both coagulants follow the Freundlich isotherm model, chitosan's higher adsorption capacity makes it a more efficient choice for greywater treatment.

Anova: Two-Factor Without Replication

Two-way ANOVA without replication was performed to evaluate the effects of coagulant type and parameter type on percentage removal. The results indicated a significant main effect of coagulant type ($p = 0.016$), suggesting that chitosan outperformed *Moringa* overall (see Table 3). No significant difference in removal performance across the four water quality parameters was found ($p > 0.05$). This suggests that the bio-coagulants exhibited comparable removal efficiencies regardless of the parameter being treated.



a) b)

Figure 10. Isotherm Analysis a) Langmuir b) Freundlich.

Table 3. Anova: Two-Factor Without Replication.

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Moringa oleifera	4	174	43.5	345
Chitosan	4	312	78	223.3333
Suspended Solids	2	134	67	98
COD	2	158	79	882
Turbidity	2	89	44.5	1012.5
BOD	2	105	52.5	684.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2380.5	1	2380.5	24.086	0.016197	10.12796
Columns	1408.5	3	469.5	4.750422	0.116475	9.276628
Error	296.5	3	98.83333			
Total	4085.5	7				

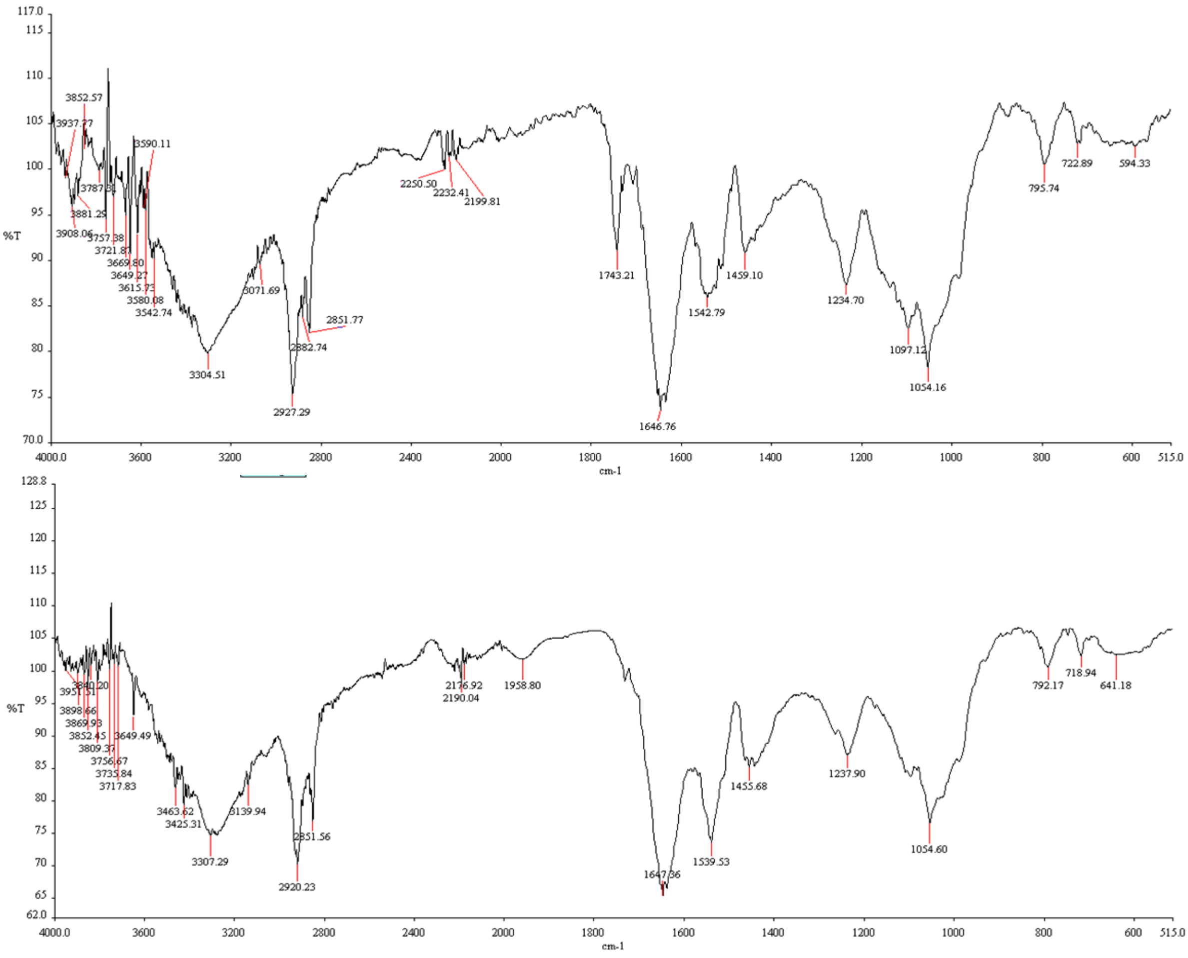


Figure 11. FTIR analysis of *Moringa oleifera* seeds.

Table 4. Functional group of *Moringa oleifera* seeds before and after treatment.

Coagulant	**Condition**	**Wavenumber (cm^{-1})**	**Functional group**	**Changes**
Moringa oleifera	Before	3400-3600	O-H	Presence
		2850-2950	C-H	Presence
		1743	C=O	Presence
	After	3400-3600	O-H	Presence
		2850-2950	C-H	Presence
		2005-2181	C=O	Absence

Fourier Transform Infrared (FTIR)

The Fourier Transform Infrared (FTIR) analysis was conducted to understand the chemical interactions and structural changes in *Moringa oleifera* seeds and chitosan before and after their application as coagulants in greywater treatment. *Moringa oleifera* seeds exhibited minor changes in their FTIR spectra, particularly in the functional groups responsible for coagulation [23]. Before treatment, prominent peaks were observed for hydroxyl (O-H) stretching, aliphatic C-H stretching, and carbonyl (C=O) stretching. After treatment, these peaks shifted, indicating interactions between the bioactive compounds in *Moringa* seeds and the contaminants in greywater. For instance, the shift in the carbonyl peak suggests the formation of new complexes, highlighting the seeds' active role in pollutant removal [24].

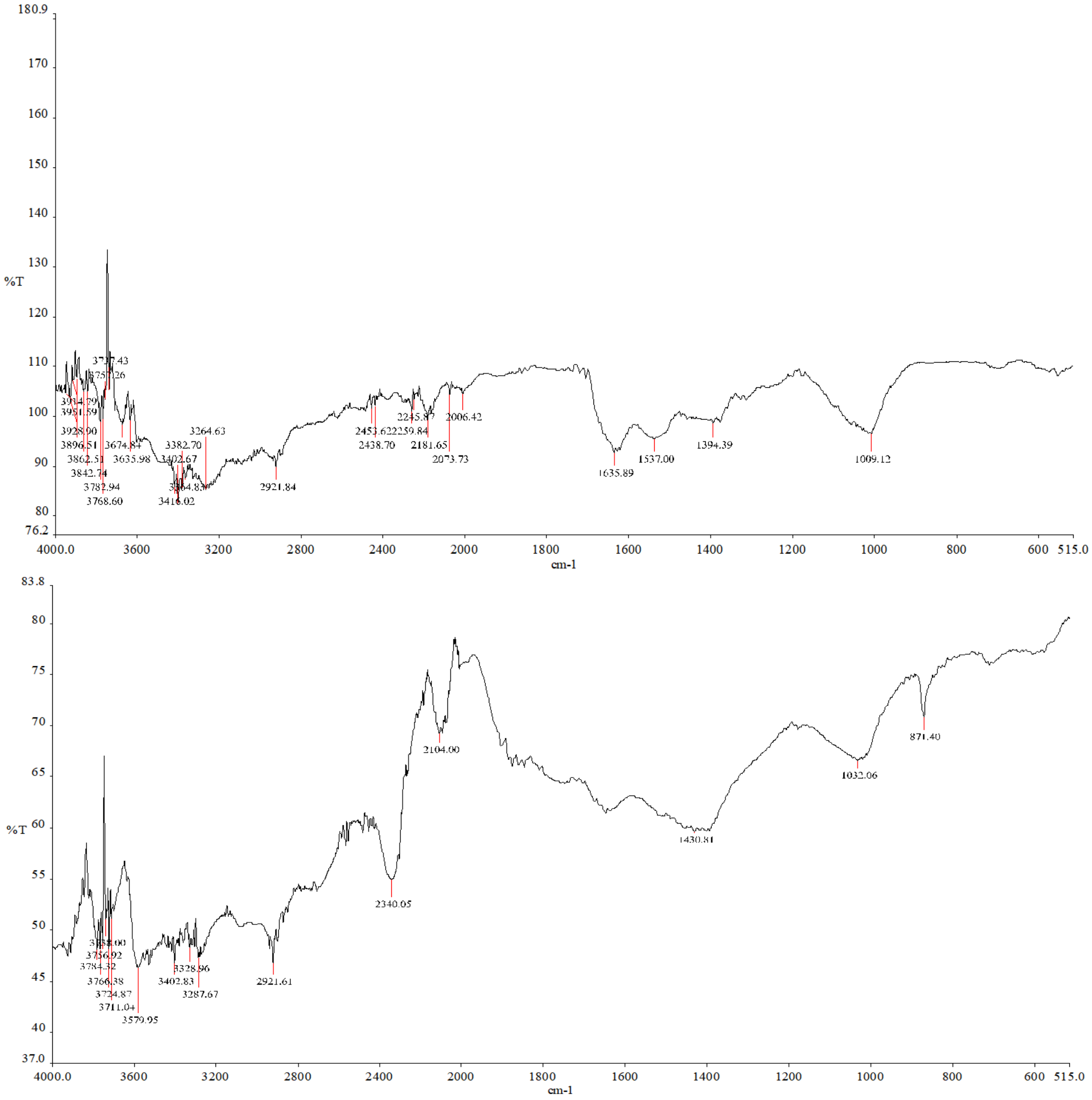


Figure 12. FTIR analysis of chitosan.

Table 5. Functional group of chitosan before and after treatment.

Coagulant	**Condition**	**Wavenumber (cm^{-1})**	**Functional group**	**Changes**
Chitosan	Before	3400-3600	O-H	Presence
		2850-2950	C-H	Presence
		1009	C-O-C	Presence
	After	3400-3600	O-H	Presence
		2850-2950	C-H	Presence
		871-1008	C-O-C	Slight shift from 1009 cm^{-1}

In the case of chitosan, the FTIR spectra revealed the presence of key functional groups such as hydroxyl (O- H), amine (N-H), and carbonyl (C=O) stretching before treatment. After treatment, shifts and changes in peak intensities were observed, particularly in the amine and hydroxyl groups [21]. These shifts indicate strong interactions between chitosan's functional groups and the contaminants, facilitating coagulation and adsorption processes [8]. The reduction in peak intensities and the appearance of new peaks suggest the formation of new bonds, underscoring chitosan's effectiveness in binding and removing pollutants from greywater. Overall, the FTIR analysis provided valuable insights into both coagulants' molecular mechanisms of pollutant removal. *Moringa oleifera* seeds and chitosan both demonstrated significant chemical interactions with contaminants, but chitosan exhibited more pronounced structural changes, highlighting its superior coagulation and adsorption capabilities [7]. This analysis confirms the effectiveness of both natural coagulants in greywater treatment, with chitosan showing a stronger interaction profile.

Analysis of Scanning Electron Microscope

From the observations, the SEM image of untreated chitosan in Figure 13 reveals a rough and irregular surface texture, characterised by noticeable patterns and microcracks, indicative of its natural biopolymer structure. Small particles and debris scattered across the surface suggest possible impurities or residues from sample preparation [25]. The porous nature of the chitosan surface is beneficial for its application as a natural coagulant, as it increases the surface area available for adsorption. The image, taken at 200x magnification with a scale bar of 200 µm, highlights the detailed micro-scale features.

After treatment using chitosan, the SEM image in Figure 14 shows a rough, textured surface characterised by numerous cracks, crevices, and irregular shapes. The material's grainy appearance and the pronounced unevenness suggest that the treatment process induces significant changes, likely enhancing the surface area or altering the physical attributes to improve its efficacy as a coagulant. This morphological evolution could be indicative of physical or chemical modifications intended to enhance chitosan's performance in its application [26].

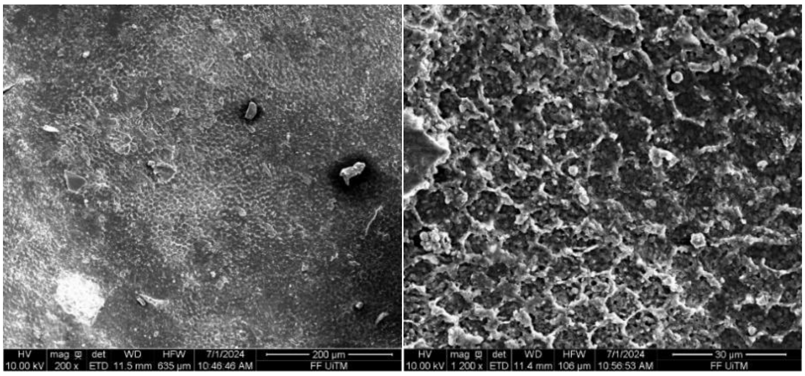


Figure 13. SEM image of chitosan coagulant before treatment.

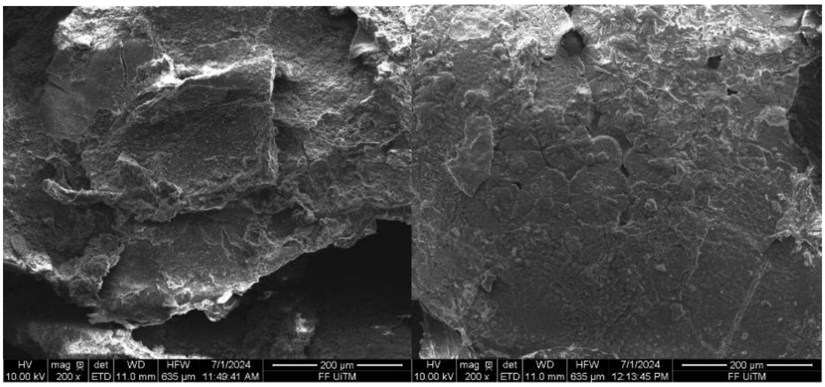


Figure 14 SEM image of chitosan coagulant after treatment

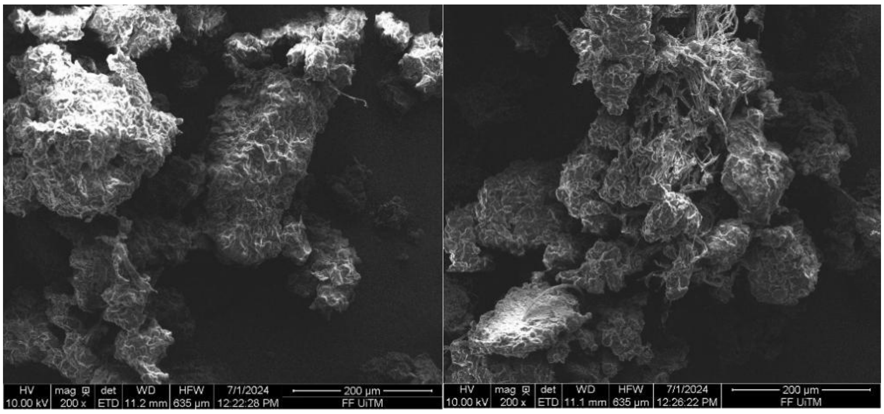


Figure 15. SEM image of *Moringa oleifera* coagulant before treatment.

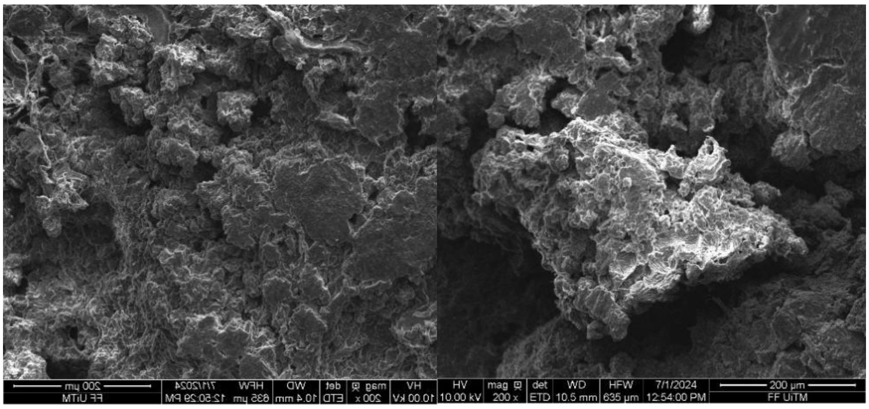


Figure 16. SEM image of *Moringa oleifera* coagulant after treatment.

Figure 15 shows the image before the treatment of *Moringa oleifera* as a complex, highly textured surface with many creases and folds, suggesting a porous or fibrous material. This untouched aspect demonstrates a natural state without any signs of the material undergoing surface modification or coating processes. The detailed SEM visualisation emphasises the raw structure of the sample at a microscopic level, providing a benchmark for assessing the impact of the treatment [25].

Post-treatment, the SEM image in Figure 16 reveals a substantial transformation in the surface characteristics. The treatment with the *Moringa* coagulant has created a rough, uneven surface riddled with pores. These pores, varying in shape and size, form an interconnected network throughout the material, indicating that the coagulant has altered the surface morphology dramatically. This granular appearance and porous structure are likely outcomes of either the formation of new phases, the removal of substances, or the deposition of new layers onto the sample surface due to the coagulation process. The comparison underscores the efficacy of the *Moringa* coagulant in treating the sample, evident in the stark contrast in surface texture and structure before and after the treatment [27]. This transformation can be attributed to the coagulating properties of *Moringa*, which facilitate the aggregation of particles, leading to a more porous and granular material structure.

The SEM images provided a high-resolution visualisation of the surface morphology of the bio-coagulants. Prior to treatment, the chitosan and *Moringa oleifera* samples exhibited relatively smooth and porous structures, characteristic of natural polymeric materials. After the treatment, noticeable morphological changes such as surface roughness, floc formation, and particulate aggregation were observed. These changes are indicative of pollutant adsorption or entrapment on the surface of the bio-coagulants, thereby confirming their active role in the coagulation-flocculation process. The comparative analysis of SEM images before and after treatment enabled the assessment of the physical interaction between the bio-coagulants and pollutants, supporting the proposed mechanisms of coagulation—such as bridging, charge neutralisation, and entrapment.

CONCLUSION

This research evaluated the effectiveness of *Moringa oleifera* seeds and chitosan as natural coagulants in treating greywater from a mosque. Initial water quality parameters included a turbidity of 25.21 NTU, pH of 6.33, ammonia-nitrogen concentration of 0.04 mg/L, COD of 132 mg/L, and BOD of 6.5 mg/L. *Moringa* seeds reduced turbidity by 22.65%, whereas chitosan achieved a 66.84% reduction. *Moringa* seeds effectively maintained zero levels at higher concentrations for COD, while chitosan consistently reduced COD across all the dosages. For BOD reduction, the use of *Moringa* seeds went from 6.5 mg/L to 4.29 mg/L, while chitosan reduced it more effectively to 1.87 mg/L. Both coagulants decreased ammonia-nitrogen levels, with chitosan showing more stable performance. Chitosan also excelled in reducing nitrate-nitrogen and nitrite-nitrogen levels to zero by Day 6 and Day 7, respectively, while *Moringa* seeds showed effective but slightly less consistent results. In reducing suspended solids, chitosan outperformed *Moringa*, lowering levels from 47 mg/L to 12 mg/L compared to *Moringa*'s reduction to 19 mg/L. FTIR analysis confirmed robust interactions of both coagulants with impurities via functional groups like hydroxyl, carbonyl, and amine. While both coagulants were effective, chitosan demonstrated superior performance, particularly in turbidity, COD, and suspended solids reduction, making it a more efficient and sustainable option for greywater treatment.

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