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COD, color, and turbidity reduction from surface water using natural coagulants: Investigation and optimization

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ABSTRACT

Several researchers have established the performance of natural coagulants in treating water via coagulation and flocculation process. This study is aimed at investigating the use of Linseed-based natural coagulant for treating surface water, especially in rural areas where most people cannot afford the high cost of chemically coagulant-treated water. The influence of various experimental parameters such as coagulant dosage, pH, and stirring time on the percentage of color, chemical oxygen demand (COD), and turbidity removal has been studied. The experimental results showed that the use of Linseed has shown high removal of color (97.76 %), turbidity (96.58 %), and COD (90 %) at pH values of 3.03 using a 1.75 g/L coagulant dosage and a stirring time of 37.37 minutes. Upon the numerical optimization of the parameters investigated, the removal of color, turbidity, and COD were found to be 94.0 %, 95.5 %, and 86.35 %, respectively, at pH of 7.0, coagulant dosage of 2.5 g, and stirring time of 40 minutes. The findings showed that Linseed has excellent coagulating competence and is very effective in the removal of impurities from surface water.

1. Introduction

Water is important for human survival and is required by all living organisms. However, surface water is contaminated with the pointed and non-pointed sources due to the population pressure [1]. One of the Africa's fastest-growing populations is found in Ethiopia. In 2015, the number of people living in urban areas was increased to 19 million, and it is predicted to have 37 million in urban residents in the year of 2030 [2]. Growing industrialization, economic activity, and population have not only led to a greater need for freshwater but also to considerable misuse of this natural resource. Untreated wastewater and chemical wastes that are dumped carelessly into rivers have made these bodies of water unable to manage the pollution load [3], and water from surface bodies contains billions of small particles and impurities dissolved in it due to its high solubilizing power. These impurities consist of both organic and inorganic substances, and they change the chemical and physical properties of water [4]. According to recent research on freshwaters around the world, water pollution from organic and inorganic pollutants has gotten significantly worse over the time [5]. The water used for domestic and other purposes accounts for approximately 70 % of the world's freshwater, but this share varies from the country to country, and this significant dependence on freshwater resources indicates the need for water reuse [6]. Therefore, changes to water quality need to be made to reuse turbid water for irrigation and fish reproduction safely and sustainably[7].

There are several methods for treating water, but most of them are environmentally harmful. One of the most efficient methods for treating surface water is coagulation-flocculation process, which has been used for centuries to purify the water [8,9]. Many investigators have removed various organics from water by using improved oxidation methods and activated carbon adsorption process [10]. Other researchers developed economical adsorbent materials made from agricultural wastes such as rice husk[11,12], Moringa oleifera[13], sugarcane bagasse[14], banana pith[15], and wheat straw[16]. In this study, coagulation-flocculation was applied for surface water treatment using linseed (*Linseed*) as a coagulant. This technology is used most often in the treatment of water, and the process of coagulation is used for removing turbidity and color-producing substances, which are

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mainly colloidal particles [17]; and uses a coagulant to destabilize colloid particles [18]. Different studies have supported the effectiveness of this method using natural coagulants to remove impurities from water. Coagulation and flocculation methods are mostly used in water and wastewater treatment to remove suspended particles and organic and inorganic substances [19,20]. The goal of the process is to destabilize the charged solid particles and neutralize the negative charge of particles floating in water by adding coagulants[21].

Many researchers focused on natural coagulants because of the drawbacks of chemical coagulants [22]. As studies have stated, using chemical coagulants for water and wastewater treatment has several disadvantages, including health risks from residual and large sludge production [23]. For an instance, aluminum sulfate treatment can leave residual of Aluminum which can cause Diseases like Alzheimer's which causes progressive Neurological disorders, and memory loss, and is also expensive to use. The second is, ion exchange methods often use chemicals like sodium chloride for regeneration which leads to increased sodium levels in the water [24–27]. Therefore, to present an acceptable replacement for water treatment processes, it needs to search for various, environmentally sound alternative coagulants based on natural resources [28]. It is currently the case that environmental engineers are more focused on lowering coagulant costs and enhancing the resulting sludge's safe-use qualities[29]; the study needed to address the fact that alum has long-lasting or powerful impacts on health and the environment. So, in this study was focused on the use of natural coagulants to remove pollutants from surface water. Therefore, this experiment was developed using *Linseed* at different levels of pH to remove color, COD, and turbidity from surface water. Given its availability, simplicity, and high performance, the commonly used coagulation and flocculation process is a vital step in surface water treatment. In this study, *Linseed* was investigated in detail for its used for water treatment purposes; previously it was mostly known for the purposes of oil, medicine, and food.

The advantages of using natural over the chemical coagulants are that they are abundant, renewable natural resources, more environmentally friendly, healthier, and highly biodegradable in nature. Indigenous people treat turbid water in their homes using plant-based coagulants in many different areas of the world. Ethiopian communities, like those in other countries, use natural coagulants to treat turbid water for drinking and household use [30]. The good news is that Ethiopians will also consume Linseeds for nourishment. Its natural coagulant properties, such as coagulation activities and strong adsorption performance, make it ideal for the filtration of turbid water in the home. As a result, natural coagulants are increasingly being used to treat the wastewater [31].

A large number of previous studies have focused on removing pollutants using synthetic treatments; very few have examined the removal of contaminants from actual industrial wastewater [32], and numerous researchers have worked to optimize this process[33]. The process was optimized using central composite design (CCD) implementing response surface methodology (RSM)[34]. This is essential to lowering overdosing or under-dosing issues and ensuring financial safety. Hence, the specific objectives of this study were to characterize the surface water, investigate the removal efficiency of color, COD, and turbidity, use *Linseed* as a coagulant, by varying the coagulant dosage, surface water pH, and stirring time, and the optimization of the process.

Determining the optimum value for the removal degree of pollutants under different parameters is the main advantage of RSM using CCD [35]. Optimization of coagulation is determined by several parameters [17]. Based on the CCD, the results were optimized using the RSM (Design Expert 13.0.5.0). A test of the model's suitability showed a good degree of agreement between experimental and predicted values under optimum parameters. The study proved that the application of RSM can successfully optimize the coagulation and flocculation processes in the purification of surface water[36]

Table 1
presents the physiochemical characteristics of the sample.

Parameters	Before treatment	After treatment
pH	8.6	3.03–7.0
COD (mg/L)	340.0	34 – 46.41
Turbidity (NTU)	47.80	1.635 – 2.151
Color	Reddish-brown	Clear

2. Materials and methods

2.1. Wastewater characterization

A sample of real surface water was collected from the Awetu River in Jimma town, Ethiopia, and stored in glass sample containers that were properly cleaned. The sample was then transported immediately to the laboratory, where it would be appropriately stored for future experiments. As [28], the sample was assessed for pH, COD, color, and turbidity using the standard methodology to investigate the physiochemical characteristics of surface water (Table1).

The NaOH and H_2SO_4 were obtained from the environmental engineering lab analytics resources of Jimma University, Jimma Institute of Technology (JiT) in Ethiopia. All chemicals used were of analytical quality, readily available from stores, and needed no additional purification. To achieve the goal of the study, a variety of materials were also used in the investigation, including jar test apparatus, etc. The *Linseed* was bought from the market and preserved in the Laboratory before use.

2.2. Sample and sampling techniques

The sample for this investigation was collected using standard protocols, following the American Public Health Association (1998). The grab sampling technique was applied to collect the sample at a precise moment when the surface water was distributed equally, both horizontally and vertically, in the center of the flow channel to avoid settled solids and floating scum. The sample was transported in less than 15 minutes and stored in a refrigerator at 4°C for three days to minimize the chances of their characteristics until the use was completed.

2.3. Methods

In the current investigation, *Linseed* coagulants were prepared in aid of the experimental setup. The coagulation-flocculation processing (jar tests) in removing contaminants using *Linseed* coagulants was investigated. The Fig. 1 showed that the experimental setup for the coagulation-flocculation process.

The volume of the sample water was 2 L, and the pH of the sample was measured and adjusted using a pH meter (model: pH 3310) with using NaOH and H_2SO_4solution to determine the hydrogen and hydroxide ion concentrations (pH). The pH meter's electrode was rinsed with distilled water and dried before being fully submerged, and the pH readings were recorded when the display on the meter was stable.

A digital turbidity meter (model: HI-93703) was used to determine the samples' turbidity before and after the treatment operations. Turbidity is a measurement of the rate at which light is absorbed or scattered by suspended particles in water. The samples of surface water were added to the each beaker. The turbidity meter was calibrated and introduced into the sample, and the values were recorded when the display was stable at NTU. The color of the untreated and treated surface water was measured using a UV/Vis-spectrophotometer with a maximum wavelength of 450 nm. The COD reactor (HACH type) was used to determine the chemical oxygen demand of before and after treatment of surface water. Based on these methods COD, color, and turbidity removal percentages were calculated.

Linseed dosage at 150 rpm for 2 minutes

Linseed dosage coagulation and flocculation at 40 r/min for 15 minutes

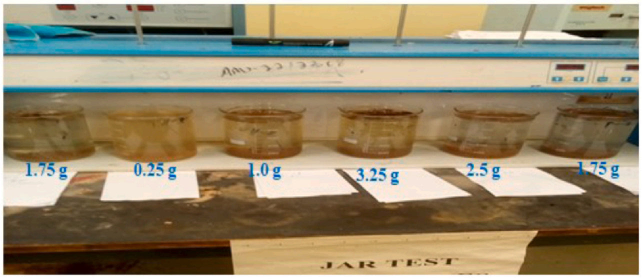

Fig. 1. Experimental setup for the coagulation-flocculation process.

2.4. *Coagulant preparation*

The *Linseed* was purchased from a local market in Merketo (Bishishe) and manually cleaned to eliminate stones and dust. Cleaning was done by hand sorting and *Linseeds* were washed using distilled water, and 35 g were used for coagulation-flocculation process, as shown in Fig. 2.

After the seeds were dried, they were kept in an airtight plastic vessel and stored at 4°C in a refrigerator for three to four days for the moisture to distribute uniformly throughout the samples. Before being used for coagulation, the seeds were taken out of the refrigerator and allowed to warm up to room temperature.

2.4.1. *Coagulant (Linseed) characterization*

(a) **X-ray diffraction (XRD) analysis**

The X-ray diffraction (XRD) analysis of Linseed is depicted in Fig. 3, which displays the characteristic properties of linseed. The graph exhibits a peak at an angle of 20.024°. The broad baseline with smaller peaks suggests the presence of less-ordered or amorphous phases in the linseed sample.

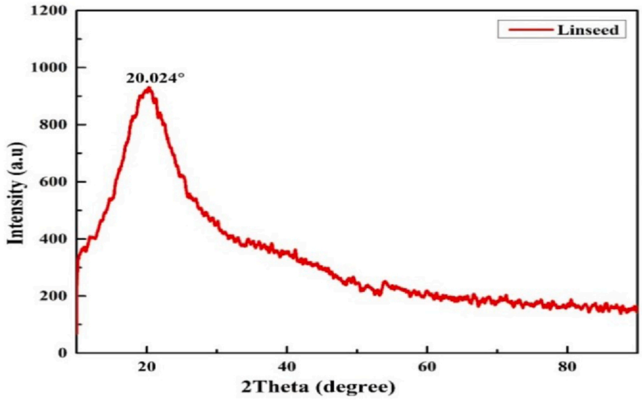

Fig. 3. X-ray diffraction analysis.

With a peak at 20.024°, the XRD pattern of flaxseed (linseed) shows the existence of a small crystalline phase. Determining the precise crystalline phase, however, is difficult in the absence of further context or knowledge about the following other peaks. Linseed often has crystalline phases of cellulose, lignin, and other plant-based substances. In general, the graph indicated that most of the properties of linseed are amorphous. The amorphous powders have a desirable property of high dispersibility in water. The X-ray diffraction shows that, in contrast to crystalline materials, which produce sharp peaks, the diffuse and large peaks are caused by disorderly displayed molecules[37].

(a) **Fourier Transform Infrared Spectroscopy (FTIR) analysis**

Phytochemicals, proteins, fats, and carbohydrates are among the many organic compounds found in linseed, commonly referred to as flaxseed. Vitamins, minerals, proteins, phospholipids, lignans, carbohydrates, and omega-3 fatty acids are some of its primary functional groups[38]. Long hydrocarbon chains and carboxylic acid functional groups are found in fatty acids, especially alpha-linolenic acid (ALA) [39]. The building blocks of proteins are amino acids, which make up proteins. Additionally, phytosterols with hydroxyl groups and a sterol backbone are found in linseed[40].

As indicated in Fig. 4, the FTIR spectrum of linseed powder reveals several peaks, including O-H stretching vibrations, C-H stretching vibrations, nitriles, C=O stretching vibrations, bending vibrations, C-O stretching vibrations, out-of-plane C-H bonds, and C-O stretching

Fig. 2. Coagulant preparation.

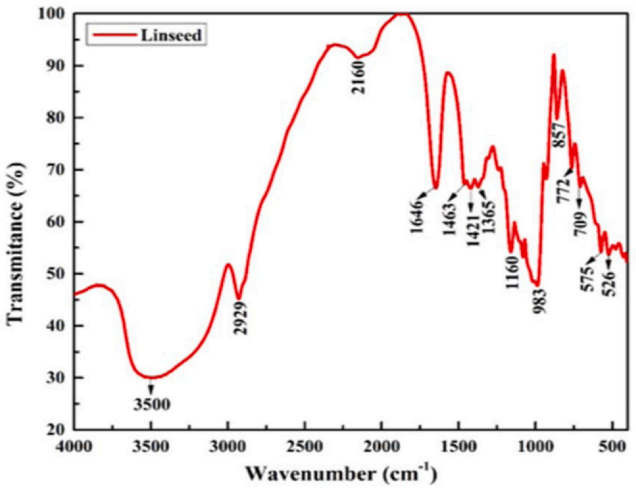

Fig. 4. Fourier Transform Infrared Spectroscopy (FTIR) analysis.

vibrations. These peaks are associated with various functional groups and structural features in the complex organic molecules present in linseed. The broad absorption peak of 3500 cm^{-1} is characteristic of O-H stretching vibrations, typically associated with hydroxyl groups in alcohols, phenols, or water content. The C-H stretching vibrations are commonly observed in alkanes and are indicative of CH_2 and CH_3 groups in fatty acids.

The FTIR spectrum indicates the presence of significant amounts of fatty acids, esters, and possibly some moisture content, which aligns with the known composition of linseed, which is rich in oils and fatty acids. The analysis of these peaks provides valuable information about the linseed sample's chemical structure and composition. A broad peak observed at 3500 cm^{-1} indicates the presence of an O-H free hydroxyl bond, originating from hydroxide residual.

2.5. Jar test experimental procedure

Jar tests are the most common method used for studying the coagulation and flocculation processes of surface water treatment. Jar tests were applied to determine the optimal dose for the coagulant. Initially, screening tests were carried out on coagulants. The sample was carefully mixed before the test was performed. The study consists of a batch experiment with three different processes such as rapid mixing, slow mixing, and sedimentation process. The jar test apparatus has a maximum stirring capacity of 300 rpm. The depending on the design of the jar test, the measured weight of the coagulant was added. To disperse the coagulant dosage uniformly in the jar, rapid mixing at 150 rpm for 2 minutes was done. Following breakage, the speed of the stirrer was dropped to 40 rpm, and it continued stirring for 15 minutes to promote larger floc size formation. Lastly, the stirrers were turned off, and the flocs were allowed to settle down for a sufficient amount of time (20–50 minutes). The optimum dosages were evaluated by varying the dosages of 0.25, 1.0, 1.75, 2.5, and 3.25 g/L at pH of 5.0, 7.0, 9.0, and 11.0. Consequently, the jar test analysis was conducted utilizing a technique that was elaborated upon in these experimental jar test methods.

2.5.1. Analysis

Analysis of sample water based on the laboratory investigation was done for surface water parameters like turbidity, COD, and color using empirical formulas indicated in Eqs. (1–3) under different operating parameters. Eqs. (1), (2), and (3) were used to compute the removal efficiency of turbidity, color, and chemical oxygen demand, respectively.

Turbidity removal, (%)

$$\mathit{Turbidityremoval}, \% = \frac{C_o - C_f}{C_o} \times 100 \tag{1}$$

Where, C_o is the initial and C_f is final turbidity of the water sample.

Color removal, (%)

The percentage color removal efficiency is calculated by using Eq. (2):

$$\mathit{Colorremoval}, \% = \frac{Abs_o - Abs_f}{Abs_o} \times 100 \tag{2}$$

Where, Abs_0 is the initial and $Abs_f$is a treated water sample.

Chemical Oxygen Demand (COD) removal, (%)

$$\mathit{CODremoval}, \% = \frac{COD_o - COD_f}{COD_o} \times 100 \tag{3}$$

Where, $COD_o$is the Chemical Oxygen Demand in the raw water sample (before reaction) and COD_f is after coagulant and flocculants process.

2.6. Optimization

The study utilized Design Expert 13.0.5.0 software and a CCD to optimize coagulation and flocculation processes. The experimental runs were planned and executed using CCD, and the RSM was used to optimize the processes. The study focused on examining the effect of different dosages of coagulant at different pH levels and mixing times [41]. Table 2 shows each independent variable's maximum and minimum values. The number of runs was determined by using the maximum and minimum points of operating parameters of the experiment which was a totally of 20 runs.

The objective was to identify conditions that maximize the removal efficiency of contaminants, such as color, turbidity, and chemical oxygen demand (COD) by using Linseed as a coagulant. The results were validated through confirmatory experimental runs, and the optimal condition was identified as the run number with the highest removal efficiency of contaminants. The optimization process aimed to maximize contaminant removal efficiency, with optimal parameters (pH, stirring time, and coagulant dosage) determined through experimental validation.

3. Results and discussion

This study investigated and optimized the use of natural coagulants as the removal of color, turbidity, and chemical oxygen demand were found to be 94.0 %, 95.5 %, and 86.35 %, respectively, at pH of 7.0, the dosage of 2.5 g, and stirring time of 40 minutes for surface water treatments. To be able to get the best results at the lowest cost and make the process competitive with other processes, studies were conducted to determine the optimum operating conditions for the process (pH and dosage) [42]. Given reasons that are sustainable and the use of water, the surface water is treated. Before the treatment process, tests performed for color, COD, and turbidity in water quality were conducted on the samples that were collected to determine the capacity for *Linseed* removal and its effects on water quality[41]. The raw surface water contains high turbidity (47.8 NTU). The initial COD concentration was 340 mg/L, indicating that there were organic and inorganic

Table 2
Experimental Design.

Parameters	Independent variable	Levels and ranges		
		-1.0	0.0	1.0
A	pH(units)	5.00	7.00	9.00
B	Coagulant dosage (g/L)	1.0	1.75	2.50
C	Stirring time (minutes)	20.00	40.00	50.00

contaminants in the water. The collected sample is reddish-brown in color; the measured result is 0.46 Abs, implying that it is strongly colored. World Health Organization (WHO) guidelines were used to compare the characterization results. As to [43], the pH values were within the range (6.5–8.5) of the WHO standard before discharge or reuse.As a result, according to [44], reports based on WHO Standard Values (1993) guidelines showed that the value for initial characterization of an untreated surface water sample was above permissible limits. The result from laboratory experimentation and analysis showed that a *Linseed* coagulant works well in removing the physicochemical characteristics of water quality.

In this investigation, the use of natural coagulants on the characteristics of acidic, neutral, and basic water was examined in surface water treatment. The coagulants are efficient in removing the pollutants, as observed from the results of the analysis. The reduction of pollutants in the surface water after treatment confirmed the efficacy of the coagulation-flocculation process.

3.1. Analysing processes

Design Expert 13.0.5.0 and Minitab 16 statistical software were used for the data analysis. The dosage was added to the sample water starting at 0.25–3.25 g/L. The maximum removal achieved for color, turbidity, and chemical oxygen demand is shown in Table 3 as an observed and predicted value**.** For this investigation, the optimum parameters for the removal of color, turbidity, and COD were optimized as 1-2.5 g/L dosage and pH (5–9). So, the optimum values for the removal of color and turbidity were also indicated in Table3

3.2. Optimization of processes

An analysis of variance was used to determine the interaction between the process variable and the response. The model *F*-value of 107.39 for color removal, 176.32 for COD removal, and 84.32for turbidity removal implies the model was significant. There was only a 0.01 % chance for color, COD, and turbidity that an F-value this large could occur due to noise. Model terms with *P*-values of less than 0.0500 were considered significant. In this case, A, B, AB, A^2, B^2, and for color removal, A, B, AB, B^2, for COD removal, and A, B, A^2 for turbidity removal were significant model terms in this study. Model reduction might be helpful if the value is more than 0.1000, the model terms are not relevant, and the model has a large number of inconsequential terms (apart from those required to enable hierarchy).The model passed the F-test with all p-values for the regression being 0.05, as shown in-table. 4 with a 95 % confidence level.

Furthermore, the model does not provide evidence of a lack of fit (P > 0.05).The lack of fit test assesses how well a model represents data in an experimental domain at locations not taken into account by the regression. If a model is significant, it means that it has one or more crucial terms and does not have fit problems. The residual, or that amount of data variability not explained by the model, may be considerable if certain significant factors are not included in the experiment. According to Table 4, the turbidity, COD, and color removals P-values were both less than 0.05, suggesting that the factor influencing the response characteristics. Using RSM, the *Linseed* treatment process was optimized to reduce coagulant dosages and save operational costs and time. Tests for color, COD, and turbidity removals reported that the treated surface sample obtained positive values. As shown in Table 3, a total of twenty experimental runs were conducted with different experimental dosages of *Linseed* (0.25, 1, 1.75, 2.5, and 3.25 g/L). The highest COD removal effectiveness was attained with a dosage (X_2) of 2.5 g/L, achieving a 90 % removal rate. The Fig. 5, and Table 3 show that increasing the dosage of *Linseed* enhanced the elimination of COD. However, when the dosage was increased to 3.25 g/L, the excessive amount of linseed caused the water particles to re-stabilize, resulting in a fall in COD removal.

3.3. Model validation

The model proved to be reliable and accurate for predicting the percentage removal of a water sample when applied to a coagulant. This prediction was validated by performing an experiment and computing the results with the prediction. Using Design Expert version 13.0.5.0 response optimization was done based on the second-order models to increase the removal efficiency. An experimental (actual) and predicted value for the removal percentage of the response is indicated in Fig. 5.**.** This was more clearly illustrated in Table 3, using a blend, and the actual and predicted values were plotted, indicating that the model was good and that it was also a good fit. For all coagulants, the value of the regression coefficient (R^2) was greater than 0.70 in the suggested model. This indicated that the validity of the model was good.

Table 3
Removal efficiency of Linseed on turbidity, color, and COD.

	Color removal, (%)		**Turbidity removal, (%)**		**COD removal, (%)**	
Run	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
1	94.00	93.58	95.50	94.65	86.35	85.85
2	91.25	91.43	89.59	89.52	81.64	81.77
3	94.65	94.54	91.69	91.87	83.32	83.5
4	94.28	94.0	91.96	91.82	83.55	83.81
5	92.65	92.48	88.33	88.62	79.10	79.49
6	91.65	91.43	88.99	89.52	81.63	81.77
7	97.76	97.75	96.58	96.54	90.00	89.86
8	90.25	90.54	88.25	88.52	76.46	76.51
9	93.58	93.46	91.46	91.22	82.68	82.63
10	89.98	90.16	87.98	87.82	75.35	75.27
11	89.25	88.96	87.26	87.26	76.24	76.12
12	92.56	92.68	88.98	88.93	79.35	79.48
13	90.69	90.51	88.25	88.14	75.85	76.01
14	94.12	94.12	91.99	92.04	85.55	86.01
15	93.65	93.82	90	89.98	82.35	81.89
16	91.89	91.88	87.95	88.16	78.19	78.27
17	91.28	91.43	89.65	89.52	81.74	81.77
18	91.27	91.43	89.65	89.52	81.63	81.77
19	91.23	91.43	89.65	89.52	82.12	81.77
20	91.58	91.43	89.65	89.52	82.21	81.77

Table 4
Analysis of variance (ANOVA) for the quadratic model.

Source	Sum of square	df	Mean square	F-value	P-value	Remark	Response
Model	213.49	9	23.72	176.32	< 0.0001	Significant	COD removal
A-pH	169.97	1	169.97	1263.41	< 0.0001		
B-dose	5.79	1	5.79	43.04	< 0.0001		
AB	0.8305	1	0.8305	6.17	0.0323		
A^2	0.0004	1	0.0004	0.0029	0.9579		
B^2	1.86	1	1.86	13.84	0.004		
Residual	1.35	10	0.1345				
Lack of fit	0.9973	5	0.1995	2.87	0.1363		
Cor Total	214.83	19					
Model	59.5	9	6.61	107.39	< 0.0001	Significant	Color removal
A-pH	37.74	1	37.74	613.02	< 0.0001		
B-dose	1.29	1	1.29	21.02	0.001		
AB	0.5151	1	0.5151	8.37	0.016		
A^2	5.13	1	5.13	83.29	< 0.0001		
B^2	5.24	1	5.24	85.1	< 0.0001		
Residual	0.6156	10	0.0616				
Lack of Fit	0.4413	5	0.0883	2.53	0.1655		
Cor Total	60.11	19					
Model	64.67	9	7.19	84.32	< 0.0001	Significant	Turbidity removal
A-pH	54.5	1	54.5	639.63	< 0.0001		
B-dose	1.11	1	1.11	12.99	0.0048		
AB	0.0408	1	0.0408	0.4783	0.5049		
A^2	6.21	1	6.21	72.84	< 0.0001		
B^2	0.0062	1	0.0062	0.0733	0.7921		
Residual	0.8521	10	0.0852				
Lack of Fit	0.4945	5	0.0989	1.38	0.3655		
Cor Total	65.52	19					

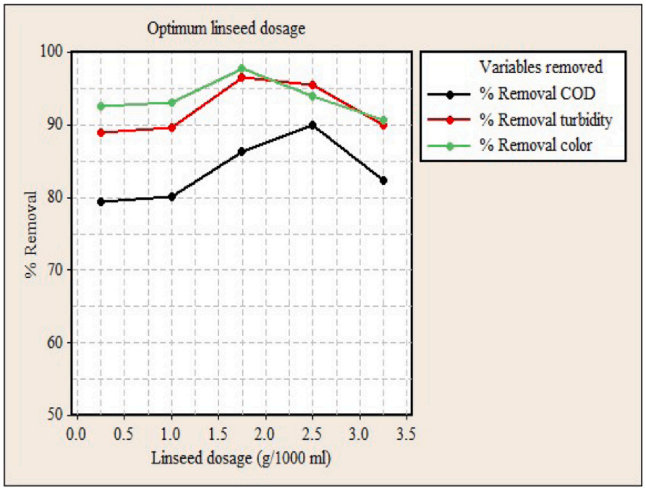

Fig. 5. Effects of coagulant dosage.

3.4. Comparing processes

This study focuses on investigating and optimizing parameters involved in treating surface water through coagulation and flocculation processes with natural coagulants. The sustainability of these methods for treating water is examined by comparing the computed results with the prediction and experimental efficiency of the coagulant [45]. According to the results of the experimental analysis, the optimal conditions and responses for coagulant dosage, pH, and their corresponding responses were found in the optimization system.

It was discovered that *Linseeds* were especially effective at removing COD, turbidity, and color from surface water samples. However, linseed works more effectively in acidic water than it does in basic water. It also functions well as the pH increases to 7.0, but the dosage increases from 1.75 to 2.5 g/L. The maximum removal achieved for color and turbidity was 97.76 % and 96.58 %, respectively, at a pH of 3.03, a dosage of 1.75, and a stirring time of 37.37 minutes. But the optimum parameters for the removal of color and turbidity were numerically optimized at 94.0 % and 95.5 %, respectively, at a pH value of 7.0 and a dosage of 2.5 g/L, respectively and the optimum COD reduction was 86.35 % at a dosage of 2.5 g/L. These all showed that as pH increases, the dose also increases. As a result of the previous study done by [46], the findings indicate a good agreement between the experimental and estimated values for COD, color, and turbidity removal. These results were in line with earlier studies that found adding Moringa oleifera (MO) seed to water samples decreased turbidity, and up to 85–94 % of the turbidity was eliminated following the treatment[47]. The same study also showed that removal rates of color and turbidity rose along with the increase in dosage from 3.0 to 3.6 g/L. However, when 4 g/L was reached, the rates of color and turbidity reduction declined. Thus, 3.6 g/L was the optimum dosage. At a dosage of 3.6 g/L, the greatest percentage of color and turbidity removal was attained, the removal rates were 97.77 % and 98.68 %, respectively [48].

3.5. Factors affecting the operating parameters

Design parameters such as pH and linseed dosage all affected the coagulation and flocculation processes. According to research conducted by [32], operating parameters like *Linseed* dose concentration, pH values, initial turbidity, and COD concentration have an impact on the percent COD, color, and turbidity removal processes. Increasing or decreasing one parameter affects process efficiency. This may have a positive or negative impact on removal efficiency. The methodology has demonstrated that the optimal dosage was efficiently and directly achieved by lowering the pollutants by taking into consideration various coagulation processes.

3.5.1. Effects of coagulant dosage

The dosage of coagulants is an essential factor that has been taken into consideration while determining the optimal conditions for the coagulation and flocculation processes. Poor performance in the flocculation process would arise from either an insufficient dosage or an overdose [18]. Fig. 5 shows the effects of coagulant dosages (1–2.5 g/L), *Linseed* was added in dosages ranging from 1-2.5 g/L. The removal rates of color, COD, and turbidity increased with the increase in *Linseed* dosage from 1.0 to 2.5 g/L. However, as linseed was raised to greater

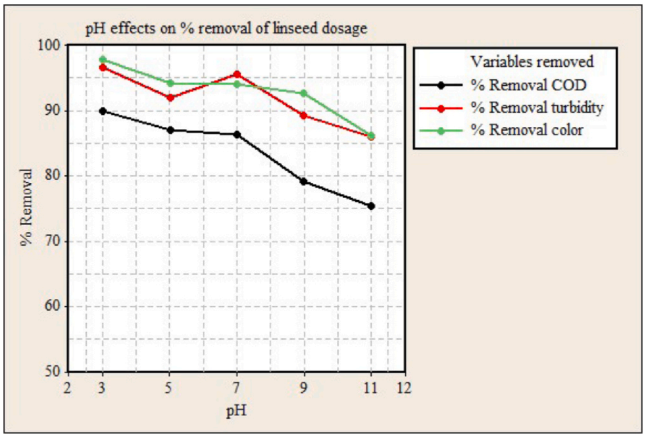

Fig. 6. Effects of pH.

than 2.5 g/L, the rates of COD, color, and turbidity reduction dropped. So at a *Linseed* dosage of 1.75 g/L, the maximum percentage of color and turbidity removal was achieved; the removal rates were 97.76 % and 96.58 %, respectively. These show how *Linseed* dosage affects the removal of color and turbidity from surface water.

According to the findings of research, coagulant dosage affect the samples' final coagulation outcome[49]. The predicted turbidity and color removal performance ranged from 90–96.52 % and 92–97.75 %, respectively, for the dosage between 1 and 2.5 g/L. With a dosage of 2.45 g/L, the color and turbidity achieved the highest removal rates, determined to be 94.0 % and 95.50 % at a pH of 7.0 (Table3). The removal of color, COD, and turbidity decreased after *Linseed* was added at a dosage greater than 2.5 g/L. As dosages of coagulants were increased, their removal rates rose to their optimal levels, but their removal rates dropped at dosages beyond the optimal range as a result of overdose, which destabilized the coagulation and lowered the removal rates.

3.5.2. Effects of pH

There are direct effects of pH on the processes [50], and the process is significantly influenced by the pH of the solution [51]. As shown on Fig. 6 color, COD, and turbidity reduction decreased with increasing pH from acidic to basic.At a similar pH of 3.03 (1.75 g/L), color removal was 97.76 %, turbidity was 96.58 %, and COD removal percent was 90. On the other hand, turbidity removal drops from 96.58 % to 95.5 %, color from 97.76 % to 94 %, and COD removal also decreases from 90 % to 86.35 % as the pH is raised from 3 to 7. As to[52], pH also affects the size of the coagulated particles, which in turn impacts the flocculated sludge's concentration, tendency, and rate of settling out. As to the study done by [50], the outcomes of this study are in line with those of previous investigations.

As pH increased from 7 to 9, the reduction of turbidity, COD, and color declined to 87.624 %, 79.491 %, and 92.478 %, respectively. *Linseed* coagulant has a limited pH range where it operates at its best, according to experimental evidence.

At a pH of 3.03–7.0, *Linseed* tends to function. The ended water has problems with high residual color when the pH is higher than this desired level. This has occurred as pH increased beyond the optimum positive charges of the *Linseed* surface. So it was observed that adsorption is predominant in the coagulation-flocculation charge neutralization at pH 3.03–7. As [53] controlling pH would greatly improve the coagulation process because pH values affect the surface charges, forms of coagulants, and impurities to be removed.

3.5.3. Effects of COD Concentration

The rate of the removal process was significantly affected by the initial concentration of chemical oxygen demand (COD)[32]. Studies done by [54] have indicated that a significant determinant of the process's effectiveness is the influent's organic concentration, which is determined by COD. The Fig. 7 shows that as the pH values rise from 3 to 9, there is a decline in the COD removal from 90 % to 79.49 %.

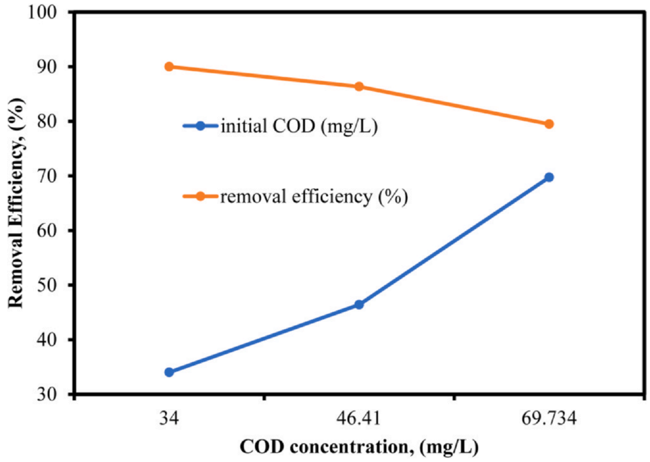

Fig. 7. Effects of COD Concentration.

The Fig. 7 display the correlated between the concentration of Chemical Oxygen Demand (COD) and removal efficiency from the wastewater. It demonstrates that removal efficiency was high with low COD concentrations and decreased with COD concentration, along with the initial COD. The graph indicates that it is more difficult to eliminate COD at greater concentrations effectively, which is a common finding in treatment procedures. The overall concentration of organics in the solution has been linked to COD values, and the degree of mineralization is reflected in the decrease in chemical oxygen demand [50]. To confirm whether the sample is mineralized, the COD of the surface water was tested following oxidative decline. The removal rates of COD were 90 % (34 mg/L), 86.35 % (46.41 mg/L), and 79.49 % (69.734 mg/L).

3.5.4. Effect of initial turbidity

Effect of turbidity on coagulation and flocculation rate on removal efficiency is shown in Fig. 8. The outcome demonstrated that linseed was able to lower turbidity from 47.80 to 1.635 NTU. It implies that a 1.75 g/L *Linseed* dose could result in a 96.58 % turbidity reduction. Following the turbidity of the raw water, [55] likewise noted a reduction in turbidity level. As indicated in Figs. 5 and 6, at pH 7 and a coagulant dosage of 2.5 g/L, turbidity removal was decreased to 95.50 %.

4. Conclusion

The study exposes that *linseed*-based natural coagulants were

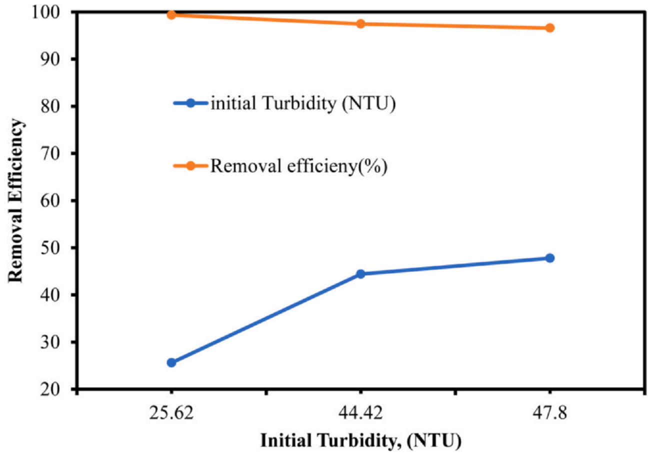

Fig. 8. Effect of Initial Turbidity.

effective in treating surface water, especially in rural areas where the costs of using chemical coagulants were high. It was achieves remarkable removal efficiencies for color, turbidity, and COD under optimized conditions. The findings presented confirm that the removal of COD, color, and turbidity was achieved effectively. It indicates that pH and dosage are the main factors that influence how efficiently COD, color, and turbidity are removed from surface water. The RSM model predicted optimal color and turbidity removal rates of 97.75 % and 96.54 % at conditions of pH (3.03) and dose (1.75 g/L).These predictions were validated by experimental validation at 97.76 % and 96.58 %, while the quadratic model predicted optimal COD removal of 89.86 % at a dose of 2.5 g/L and was tested at 90 %. So it was possible to state that the optimization methods are effective and suitable for surface water treatment enhancement. Response surface methodology with a CCD was easy and effective to optimize. The finding indicated that the use of linseed coagulants has a high potential for treating water. Numerous developing countries can greatly benefit from the promotion and development of linseed as a natural coagulant. Therefore, it is better to use linseed for surface water or any turbid water treatment in a small household, especially in rural areas where the treatment plant is not located, in addition to its nutritional value.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

CRediT authorship contribution statement

Firomsa Bidira: Validation, Supervision, Formal analysis. **Wendesen Mekonin Desta:** Validation, Supervision, Formal analysis, Conceptualization. **Abdi Kemal Husen:** Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Perumal Asaithambi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Formal analysis.

Data Availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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