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ORIGINAL ARTICLE

Color, COD, and turbidity removal from surface water by using linseed and alum coagulants: optimization through response surface methodology

Abdi Kemal Husen[1,2] · **Firomsa Bidira**[2] · **Endrias Adane Bekel**[3] · **Melaku Tegegn**[2] · **Wendesen Mekonin Desta**[2] · **Perumal Asaithambi**[2]

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Abstract

This study examined the treatment of surface water using a mixed natural (linseed) and chemical (alum)-based coagulant in terms of color, turbidity, and chemical oxygen demand (COD) (%) removal in a laboratory jar test. Experimental results showed that using a combined coagulant has shown higher removal of color (99.72%) and turbidity (97.76%) at pH values of 3.5 using a 1.5 g/L dosage and a stirring time of 38.58 min. Similarly, at the same pH value and 2.5 g/L dosage, the COD removal was 96%. To determine the optimum value with the highest percent removal efficiency of the coagulation–flocculation process, several experimental parameters including blended dosage, pH, COD concentration, and initial turbidity have been studied in terms of the percent of color, chemical oxygen demand, and turbidity removal. The optimum value was found for the highest removal of color-97.75%, turbidity-96.86%, and COD-90.33% with the pH values of 7.0, at a dosage of 2.5 g/L and a stirring time of 40 min, respectively. Statistical techniques of response surface methodology were used in experimental design and optimization, in order to calculate the confidence intervals to assess population parameter precision. An ANOVA-95% confidence interval ensures that the high reliability optimizes the result. The findings proved the excellent adsorption potential and high performance of the blended coagulant in the removal of contaminants from surface water.

Keywords Linseed and alum · Combined coagulant: surface water · Jar test · Pollutant removal · Optimization

Introduction

The scarcity of freshwater is a significant global concern in today's world (Kaswan and Kaur 2023). A major issue confronting both rural and urban water resources is the pollution of freshwater caused by the combination of population growth and declining water quality (Jeong et al. 2016). Based on the research conducted by (Santos et al. 2023), they stated that the water used for domestic and other purposes accounts for approximately 70% of the world's freshwater, but this share varies from country to country, and this significant dependence on freshwater resources indicates the need for wastewater reuse. Recent studies on the freshwater worldwide reveal that the amount of organic and inorganic contaminants polluting water has increased significantly over the time (Assegide et al. 2022). According to (Eriksson and Sigvant 2019), the Ethiopia has one of the fastest-growing populations in the continent of Africa. The population of urban areas increased to 19 million in year of 2015, and by the year of 2030, it is expected to reach 37 million peoples. So, the growing industrialization and population have not only led to a greater need for freshwater but also considerable misuse of this natural resource; wastewater and chemical wastes that are dumped carelessly into rivers have made these bodies of water unable to manage

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Abdi Kemal Husen and Firomsa Bidira have contributed equally to this work.

✉ Perumal Asaithambi
asaithambi.perumal@ju.edu.et;
drasaithambi2014@gmail.com

[1] Jimma Zone, Mencho Woreda Irrigation Team, Jimma, Ethiopia

[2] Department of Water Supply and Environmental Engineering, Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, Po Box – 378, Jimma, Ethiopia

[3] Faculty of Materials Science and Engineering, Jimma Institute of Technology, Jimma University, Po Box – 378, Jimma, Ethiopia

the pollution load (Mahudeswaran et al. 2017). All of these issues have arisen as a consequence of surface water contamination caused by both pointed and non-pointed sources, which can be attributed to the increasing population pressure (Shahabudin and Musa 2018). These alterations impact the chemical and physical characteristics of the surface water (Gandiwa et al. 2020).

Activated carbon adsorption and enhanced oxidation technologies have been widely employed in numerous researches to eliminate diverse organic and inorganics compounds from surface water (Hussein et al. 2018), while other researchers had developed the methods for wastewater treatment such as advanced oxidation (Bermúdez et al. 2021), chemical precipitation (Correia et al. 2020), reverse osmosis (Jiang et al. 2018), biological treatment(Shankar et al. 2021), agricultural waste materials(Shitu et al. 2014), and ion exchange (Kansara et al. 2016) processes. Another highly effective approach for treating surface water is the coagulation–flocculation process, which has been utilized for centuries to purify water (Bote and Desta 2022). Natural flocculants are organic compounds obtained from plants, seeds, algae, or microbes (Onukwuli et al. 2021; Nnaji et al. 2022, 2023). They cause suspended particles in water to come together and form aggregates, making it easier to remove them from the solution (Nnaji et al. 2020b; Alazaiza et al. 2022). Due to their eco-friendly nature, low cost, and frequent biodegradability, they are well-suited for wastewater treatment (Nath et al. 2019; Nazari et al. 2023; Shabanizadeh and Taghavijeloudar 2023a, b). Natural flocculants function by employing methods such as adsorption, charge neutralization, and bridging, which involve attaching to the surface of suspended particles and modifying their characteristics (Badawi et al. 2023). Additionally, they may have functional groups that engage with charged particles in wastewater, so neutralizing their charges and facilitating aggregation (Shamsnejati et al. 2015). The benefits of natural flocculants include their eco-friendliness, affordability, biodegradability, and efficacy across a broad spectrum of pH and temperature conditions (Yin 2010).

This study utilized a combination of natural and synthetic coagulants in a blended form to treat surface water through the process of coagulation–flocculation. This method is employed in water treatment, namely for the purpose of eliminating turbidity and color particles through the process of coagulation (Prihatinningtyas 2020), and it employs a coagulant to disrupt the stability of colloid particles (Prihatinningtyas 2019). So changes to water quality need to be made to reuse turbid water for various purposes safely and sustainably (Khadhraoui et al. 2019). Coagulation and flocculation methods are mostly used in water and wastewater treatment to remove suspended particles and organic substances, and different studies have supported the effectiveness of this method using natural coagulants to remove impurities from water (Zajda and Aleksander-Kwaterczak 2019). The aim of the coagulation and flocculation processes is to destabilize the charged solid particles and neutralize the negative charge of particles floating in the water by adding coagulants (Ukiwe et al. 2014) (using a blended form of *linseed* and alum as a coagulant).

Linseed, also known as flaxseed, is a versatile crop cultivated for its seeds, fibers, and oil (Haseeb et al. 2017). Linseed contains phytochemicals like lignans, which have antioxidant properties and potential health benefits (Li et al. 2009). Linseed extracts have been studied for their potential as natural coagulants or flocculants in water treatment. These extracts help in the aggregation of suspended particles in water, facilitating their removal through sedimentation or filtration (Jhala and Hall 2010). Linseed-based coagulants/flocculants offer an eco-friendly alternative to synthetic chemicals, are cost-effective, and can be produced relatively inexpensively, especially in regions with flax cultivation (Torres et al. 2014). They can be used in conjunction with conventional water treatment processes, improving the efficiency of these processes (Jhala and Hall 2010).

Many researchers have concentrated on natural coagulants because of the disadvantages of chemical coagulants (Saritha et al. 2017). Several studies have shown that there are several problems with utilizing chemical coagulants for the treatment of water and wastewater, including health risks that could result from the generation of large residual sludge (Jassim et al. 2020). Researching new coagulants as a replacement for chemical coagulants has attracted a lot of interest (Prihatinningtyas 2020). As such, it needs to search for environmentally sound coagulant materials that can provide an acceptable replacement for water treatment processes (Ghawi 2017). At the moment, environmental engineers are mainly concerned with reducing the cost of coagulants and improving the safe-use properties of the resulting sludge (Abdelaal 2004). The study needed to address the fact that alum has long-lasting or powerful impacts on health and the environment. So this study was focused on the use of blended forms of natural (*linseed*) and synthetic (alum) coagulants to remove pollutants (COD, color, and turbidity) from surface water. These blended forms of coagulants have several benefits, including reduced sludge generation, cost, and pollution. This study presents the novel discovery of *linseed* technology, which has not been previously utilized for treatment purposes in any published literature, maintaining for medical applications.

Prior research primarily concentrates on synthetic methodologies for eliminating pollutants, with limited investigation into the elimination of industrial effluent (Wu et al. 2022). For this, the response surface methodology is used together with an optimization technique. In this study, focused on the removal of pollutants in terms of percent color, turbidity, and COD removal using combined *linseed–alum* from surface water in order to minimizing the usage of alum concentration. The objective of the research is to enhance the effectiveness of removing surface water contaminants such as turbidity, color, and COD by taking into account operational factors such as pH, dose concentration, and contact time. This will be achieved through the use of coagulation–flocculation techniques that involve the combination of alum and linseed as coagulants. Furthermore, a response surface method (RSM) technique was employed for the purpose of statistical analysis and process optimization.

Material and methods

Sample and sampling techniques

Surface water sample was collected from the Awetu River in Jimma town, Ethiopia, and transferred to cleaned glass sample containers. Based on the APHA (1998), standard procedures were followed for the collection of the sample in this study. The grab sampling was applied to collect the sample at a precise moment when water was distributed equally, both horizontally and vertically, in the center of the flow channel, preventing the accumulation of settled solids and floating scum. The sample was transported within 15 min and preserved in a refrigerator at 4 °C for three days to minimize the chances of their characteristics until the analysis was completed. The $Al_3SO_4.18H_2O$ was used as an alum, and the NaOH, and H_2SO_4 solution were used for pH adjustment. The color of the water sample measured by using the UV–Vis-Spectrophotometer and the turbidity valued was measured by using the turbidity meter. The concentration of chemical oxygen demand was measured using a COD reactor (HACH type) (Sivaranjani and Rakshit 2017). All the chemicals used were fulfills analytical quality, also readily available from stores, moreover no needed additional purification. There are several equipment's used in this investigation to achieve the objective of this study, like the jar test apparatus. The jar test analysis was conducted using a methodology that was further outlined in the jar test procedures.

Coagulants (synthetic and natural based) preparation

Prior to usage, linseed requires many preparatory processes for coagulation–flocculation. First, purchase the quality linseed from the reputable supplier, and wash the linseed thoroughly with clean water. Next, the linseed is thoroughly dried on a clean surface and proceed with grinding it into a fine powder. Finally, utilize the linseed powder for coagulation–flocculation by adhering to the prescribed dosage and procedure for adding the linseed powder into the process.

Linseed and alum coagulants were combined to produce the 2:1 ratio, which is increased the *linseed* coagulants' dosages while maintaining the standard alum concentration. The main aim of this blending coagulant is to investigate the potential benefits of replacing alum in surface water treatment by combining two coagulants (*linseed* and alum) designed in a 2:1 ratio to minimize the health and environmental impacts of alum. By refereeing this studies (Sivaranjani and Rakshit 2017), it is feasible to address sensitive issues sustainably and it can save the money on chemicals and sludge handling costs by using combining natural coagulants with synthetic alum. So, the focus of this investigation is reduce the alum concentration while increasing removal performance and minimizing human health issues. This process was designed to use blending to generate the desired results (Park et al. 2021). After prepared linseed with required conditions, it was further characterized by using XRD, FTIR and point of zero charge which was used to know its property.

Sample characterization

X-ray diffraction (XRD) analysis

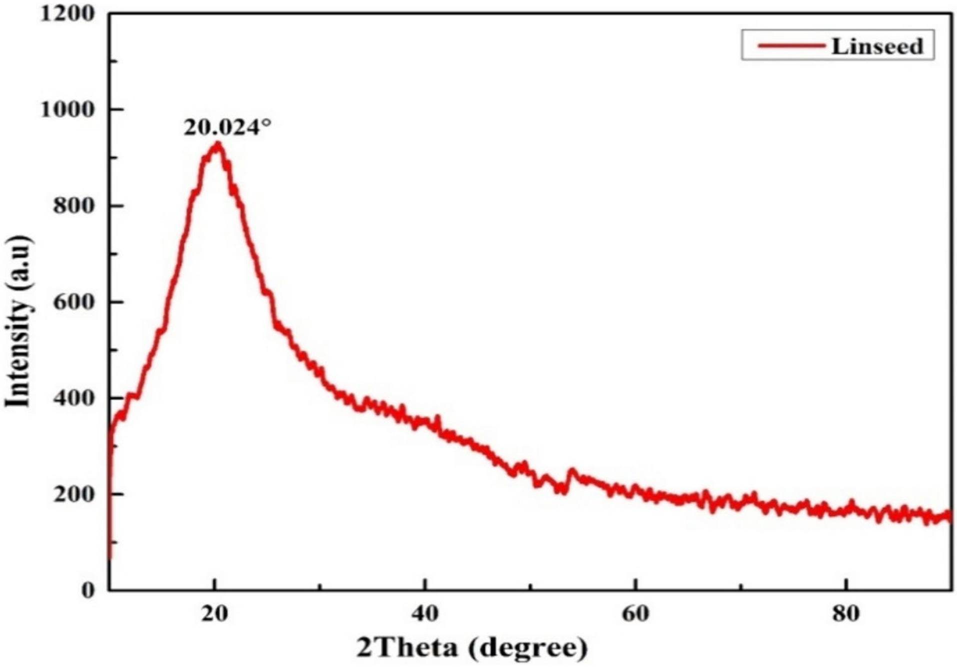
The X-ray diffraction (XRD) analysis of linseed, as depicted in Fig. 1, displays the characteristic properties of linseed. The graph exhibits a peak at an angle of 20.024°.

The XRD pattern for linseed (flaxseed) indicates the presence of a small crystalline phase, with a peak at 20.024 degrees. However, determining the specific crystalline phase is challenging without additional context or information about the next other peaks. Common crystalline phases in linseed may include cellulose, lignin, or other plant-based compounds. Generally, the graph showed that the linseed has mostly amorphous characteristics. The powders with an amorphous state exhibit high dispersibility in water with a desirable property. X-ray diffraction reveals that the diffuse and large peaks are due to disorderly displayed molecules, unlike crystalline materials which yield sharp peaks (Pui et al. 2023).

Fourier transform infrared spectroscopy (FTIR) analysis

Linseed, also known as flaxseed, is a rich source of organic compounds including carbohydrates, proteins, fats, and phytochemicals. Its main functional groups include omega-3 fatty acids, phospholipids, proteins, carbohydrates, lignans, phytosterols, and vitamins and minerals(Haseeb et al. 2017). Fatty acids, particularly alpha-linolenic acid (ALA), contain carboxylic acid functional groups and long hydrocarbon chains (Li et al. 2009). Proteins, composed of amino acids, are the building blocks of proteins. Linseed also contains phytosterols

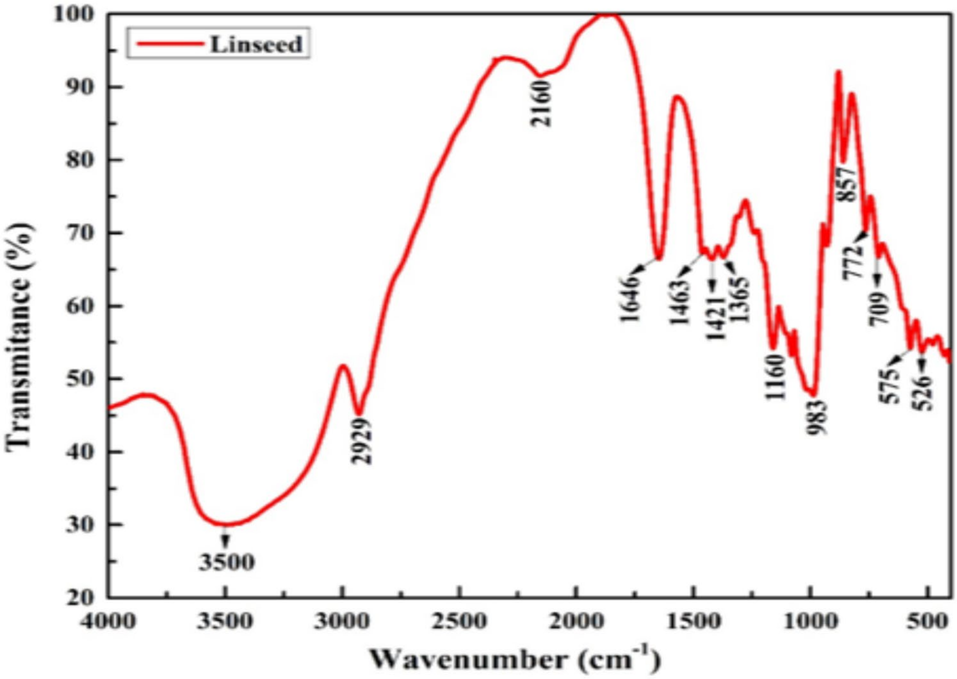
Fig. 1 X-ray diffraction analysis



with hydroxyl groups and a sterol backbone. As shown in FTIR result (Fig. 2), FTIR spectrum graph displays transmittance versus wavelength, revealing spectral peaks representing vibrational frequencies of functional groups in the sample. The graph's y-axis represents transmittance, while the *x*-axis represents wavelength or wavenumber. The baseline represents transmittance, while the "fingerprint region" contains overlapping peaks characteristic of the sample's structure. Interpretation involves identifying peaks associated with specific functional groups.

The FTIR spectroscopy uses wave numbers to measure the wavelength of infrared radiation transmitted by a sample. These wave numbers are expressed in units of reciprocal centimeters (cm^{-1}). They represent the frequency of vibrational modes, which are influenced by the vibrational motions of atoms. The higher wave numbers correspond to

Fig. 2 FTIR analysis



higher frequencies, indicating that bonds with higher force constants or lighter atoms vibrate at higher frequencies. Analyzing these peaks provides valuable information about the linseed sample's chemical structure and composition. A broad peak observed at 3500 cm^{-1} as shown on graph indicates the presence of an O–H free hydroxyl bond which originated from hydroxide residual. This linseed coagulant has large absorption peak at 983 cm^{-1}.

Point of zero charge

The point of zero charge is the pH at which the total surface charge of the coagulant is neutral (Ramavandi and Farjadfard 2016). In this study, the pH was adjusted to a value between 2 and 10 using H_2SO_4 or NaOH solution. A coagulant (1.5 g) was added to 1 L of the pH-adjusted solution and agitated at 120 rpm for 24 h by jar test apparatus. Then, the pH of each solution was measured, and the diagram of the initial pH versus the final pH is plotted in Fig. 3.

As can be seen from Fig. 3, the pH point of zero charge of linseed and alum blended at 6.85. i.e., at pH 6.85, the surface of the coagulant is negatively charged. Therefore, the removal efficiency decreases at pH greater than 6.85. The removal efficiency was increased by decreasing the pH of the solution and obtaining the highest removal efficiency of the adsorbent at a pH of 3.5. The reason for this observation could be due to an increase in electrostatic attraction between the negatively charged in surface water molecule and the positively charged linseed alum blended coagulant (Kristianto et al. 2018).

Coagulation–flocculation (jar test) experimental procedure

Jar tests are the most common method used for studying the coagulation and flocculation processes of surface water treatment. It was employed to determine the optimal dosage of coagulant. Initial coagulants were utilized for preliminary screening tests. Before the test was carried out, the sample was well mixed. The study consists of a batch experiment with three different mixing processes: rapid mixing, slow mixing, and sedimentation. The jar test apparatus has a maximum stirring capacity of 300 rpm. The proper doses of the coagulant were added to the prepared beaker with the capacity of 1L. To disperse the coagulant dosage uniformly in the jar test, rapid mixing at 150 rpm for 5 min was done. Following breakage, the speed of the stirrer was dropped to 40 rpm, and it continued stirring for 15 min to promote larger floc size formation. Finally, the stirrers were turned off, and the flocs were allowed to settle for a sufficient amount of time (10-min). 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 3.0, 5.0, 7.0, 9.0, and 11.0, as shown in Fig. 4.

Analysis

Based on the laboratory investigation, Eqs. (1–3) were used to compute the removal efficiency of color, turbidity, and COD, respectively.

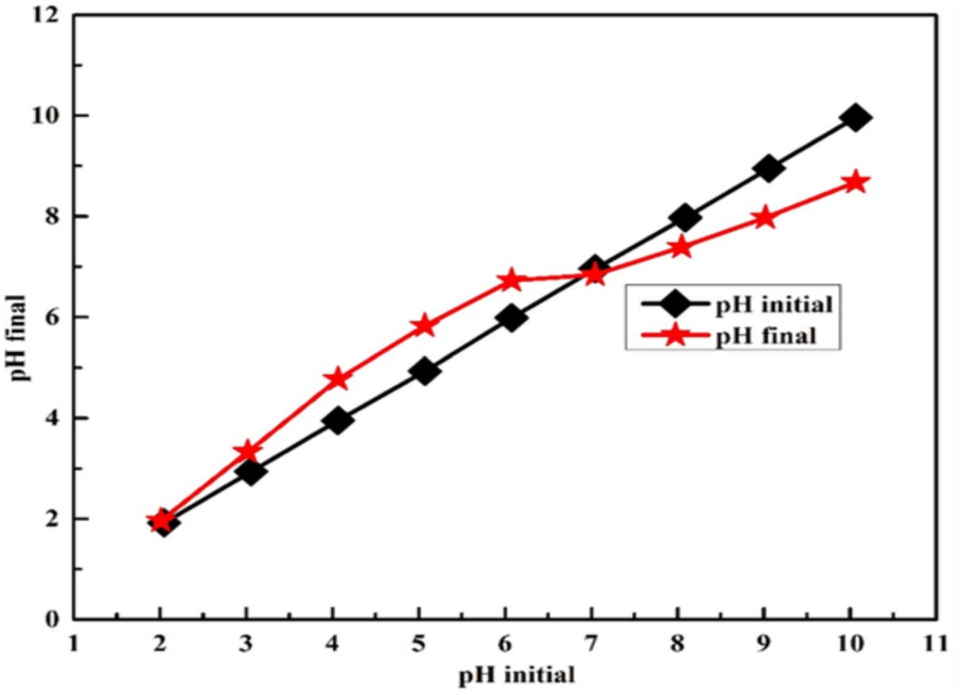


Fig. 3 Point of zero charge analysis

(A). Before treatment (B). After treatment

Fig. 4 Experimental Setup

Color removal, (%)

$$\text{Color removal, } \% = \frac{\text{Abs}_o - \text{Abs}_f}{\text{Abs}_o} \times 100 \quad (1)$$

where Abs_o and Abs_f are the initial and final absorbance of water sample.

Turbidity removal, (%)

$$\text{Turbidity removal, } \% = \frac{C_o - C_f}{C_o} \times 100 \quad (2)$$

where C_o is the initial and C_f is final turbidity.

Chemical oxygen demand (COD) removal, (%)

$$\text{COD removal, } \% = \frac{\text{COD}_o - \text{COD}_f}{\text{COD}_o} \times 100 \quad (3)$$

where COD_o is the COD in the raw water sample (before reaction) and COD_f is after treatment.

Optimization approach methodology

Response surface methodology (RSM) is a powerful approach in experimental design and for the optimization process (Bidira et al. 2023). It involves the conducting experiments with various combinations of input variables to model the response variable of interest (Keshmiri-Naqab and Taghavijeloudar 2023). For this study, RSM was used for model building using data from the experiments, and ANOVA analysis is used to assess the significance of each variable and interaction term (Nnaji et al. 2020a). Model evaluation was done using the techniques like cross-validation or comparing predicted values with actual experimental data. A confidence interval of 95% estimates was calculated for the estimated coefficients.

The experimental tests were used with the use of Design of expert (DoE) 13.0.5.0, a central composite design (CCD) system based on RSM. The coagulation and flocculation processes were optimized using CCD to examine the effect of dosage at various pH and mixing times. Considering the (Abbas et al. 2021) this investigation, the pH range, coagulant dosage and stirring time were specified the levels and ranges (Table 1).

Results and discussion

This study investigated and optimized for the color, COD, and turbidity removal (%) from surface water using blended forms of *linseed*–alum coagulants. Studied several investigation to identify the optimum operating parameters (pH and dosage) for the process in order to achieve the highest efficiency and minimize costs while making with competing processes(Lucas and Peres 2006). Treatment of surface wastewater is necessary due to sustainable considerations

Table 1 Shows each independent variable's maximum and minimum value

Parameters	Independent variable	Units	Levels and ranges		
			− 1.0	0.0	1.0
A	pH		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

and water utilization. According to the treatment process, the obtained wastewater samples underwent tests for color, COD, and turbidity to assess the water quality (Abbas et al. 2021). The raw surface water contains high turbidity, and the initial COD concentration was high, indicating that there were organic and inorganic contaminants in the water. The sample is also reddish-brown in color, and the measured result implies that it is strongly colored. The physiochemical characteristics of surface water have been examined using the standard analytical method, and the sample was analyzed in terms of pH (8.6), COD (340 mg/L), color (red), Conductivity (189.8 µS/cm), TDS (1720 mg/L) and turbidity (47.8 NTU). The World Health Organization (WHO) guidelines were used to compare the characterization results. According to the (Rusydi 2018), the pH values were within the range (6.5–8.5) of the WHO standard before discharge or reuse. As a result, according to (Meride and Ayenew 2016), the 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.

Mechanism for removal of contaminants by coagulation–flocculation using linseed

The study used a process called coagulation–flocculation to remove the turbidity, color, and COD from surface water. It is involved the weighing, adding blended *linseed–alum* coagulants, and gently mixing to create flocs, which could then be removed through sedimentation. Jar test was used in this procedure, where samples of wastewater were placed in jars containing varying dosages of coagulants and flocculants with varying the pH, and using different contact times, the jars were then gently mixed to ensure proper dispersion. After mixing, the jars were left undisturbed to allow the flocs to settle, carrying suspended particles and impurities (Kumar et al. 2017; Morosanu et al. 2021). The settling flocs and suspended particulates are removed by carefully decanting or siphoning off the purified water at the top of the jar. After that, the treated water is examined for turbidity, color, and COD levels to evaluate how well the blended linseed–alum coagulation–flocculation process removes pollutants from the surface water (Shukla et al. 2022).

Effecting the operating parameters

Coagulation and flocculation processes removal efficiency was affected by design parameters like pH and blended dosage. According to the studies conducted by (Asaithambi et al. 2017), the operating parameters such as blended dosage concentration, pH values, initial turbidity, and COD concentration have an impact on the percent COD, color, and turbidity removal processes. The methodology has demonstrated that the optimal dosage was efficiently and directly achieved by lowering the pollutants by taking into consideration various coagulant dosages. The source of the increasing or decreasing pollutant removal effectiveness as a result of changes in pH may be the interaction between H^+ ions in the acidic region and OH^- ions in the basic region, which react and compete with the flocculant adsorption site (Kenea et al. 2023).

Effects of coagulant dosage

When determining the optimum conditions for the flocculation and coagulation processes, a key factor that has been taken into consideration is the coagulant dosage (Prihatinningtyas 2019). Poor performance in the flocculation process would arise from either an insufficient dosage or an over dosage concentration. Figure 5 shows the effects of blended dosages varied from 1 to 2.5 g/L on the removal efficiency. The coagulant dosage was changed while keeping the pH level maintained in order to perform the tests. The removal rates

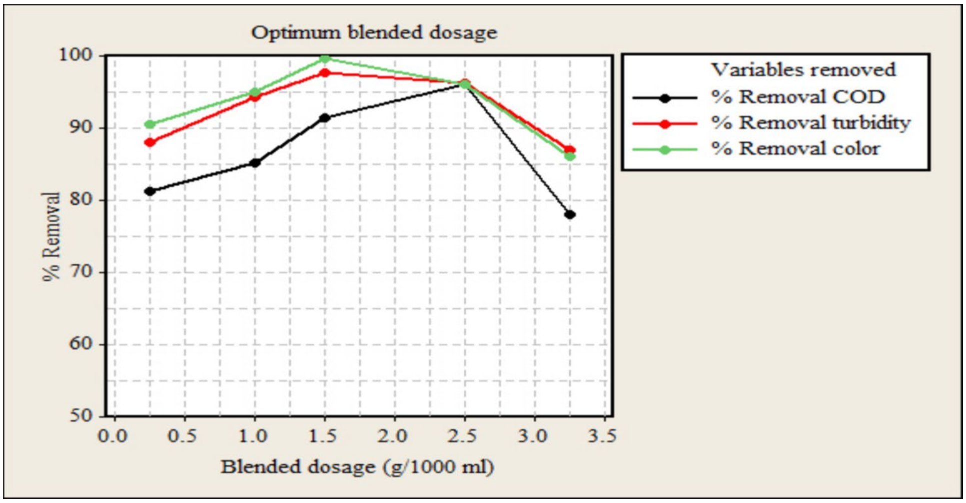


Fig. 5 Effect of blended dosage on removal efficiency

of color, COD, and turbidity increased with the increase in dosage from 1.0 to 2.5 g/L. However, as the blended dosage was raised to greater than 2.5 g/L, the rates of COD, color, and turbidity reduction dropped. With a dosage of 1.5 g/L, the maximum percentage of color and turbidity removal was achieved; the removal rates were 99.72 and 97.76%, respectively. With a dosage of 2.5 g/L, the removal efficiency of COD increased by 96%, respectively.

According to the findings of our research, pH value and coagulant dosage have an effect on the samples' final coagulation outcome (Klimiuk et al. 1999). The predicted turbidity and color removal performance ranged from 92 to 97.62% and 94–99.75%, respectively, for the dosage between 1 and 2.5 g/L. With a dosage (X_2) of 2.5 g/L, the color, COD and turbidity achieved the highest removal rates, determined to be 97.76, 90.33 and 96.86% at a pH of 7. The removal of these parameters decreased after a dosage greater than 2.5 g/L was added, indicating that there were more cations than anions in the water sample. 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.

Effects of pH

The pH value has a direct effect on the processes (Modirshahla et al. 2007), and the process is significantly influenced by the pH of the solution (Vaishnave et al. 2014). The impact of pH level on blended dosage use is shown in Fig. 6. Color, COD and turbidity reduction decreased with increasing pH from acidic to basic. At a similar pH of 3.5, color removal was 99.72%, turbidity was 97.85%, and COD removal was 96%. On the other hand, turbidity removal drops from 97.76 to 96.86%, color from 99.72 to 97.85%, and COD removal also decreases from 96 to 90.33% as the pH is raised from 3.5 to 7. According to (Ernest et al. 2017), pH also has an effect on the size of the coagulated particles, which in turn affects the flocculated sludge's concentration and rate of settling. The outcomes of this study are in line with those of previous investigations (Modirshahla et al. 2007). This coagulant hydrolyzes in water to produce a range of products, including cationic species that can adsorb negatively charged particles and neutralize their charge (Malik 2018).

According to Fig. 6, as pH increased from 7 to 9, the reduction of turbidity, chemical oxygen demand and color declined to 92, 85, and 93.5%, respectively. As to experimental evidence, blended coagulant operates well at a pH of 3.5–7.5 at its best. The finished water has problems with high color when the pH is higher than this desired level. This has occurred as pH increased beyond the optimum positive charges of the dosage surface. Therefore, at pH 3.5–7.5, it was found that adsorption predominates in the coagulation–flocculation charge neutralization process. So the controlling the pH would greatly improve the coagulation process because pH values affect the surface charges, forms of coagulants, and impurities to be removed (Naceradska et al. 2019).

Comparing with other studies

This research points out that treating raw surface water with a blend of alum (aluminum sulfate) and *linseed*, a plant-based natural coagulant, is effective or not (Gandiwa et al. 2020). The study focuses on investigating and optimizing parameters involved in treating surface water through flocculation and coagulation processes with blended coagulants. Because the sustainability of these methods for treating water is examined by comparing the computed results with the prediction and experimental efficiency of the coagulant (Muruganandam et al. 2017).

The numerical optimization system found the optimum conditions and responses for dosage, pH, and corresponding responses based on the findings of the experiment. It

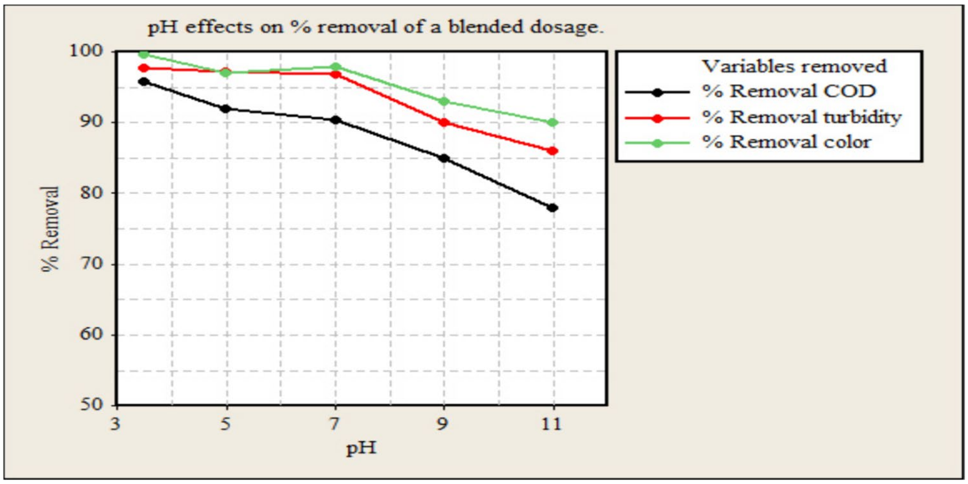


Fig. 6 Effects of pH on removal efficiency

was found that blended dosages were the most efficient at removing turbidity, COD, and color from surface wastewater samples. A blended dosage 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 1.0 to 2.5 g/L. The maximum removal achieved for color and turbidity was 99.72% and 97.85%, respectively, at a pH of 3.5, a dosage of 1.5, and a stirring time of 38.58 min. So the optimum removal performance was observed at a pH of 3.5–7.0. The optimum removal of color, COD, and turbidity was at 97.85%, 90.33%, and 96.86% at a pH value of 7.0 and a dosage of 2.5 g/L, respectively. All of these demonstrated that the pH increased with increasing dosage.

Previous study showed that removal rates of color and turbidity rose along with the increase in $FeCl_3$ dosage from 3.0 g/L to 3.6 g/L. As a result, when $FeCl_3$ reached 4.0 g/L, the rates of color and turbidity reduction declined. Thus, 3.6 g/L was the optimum $FeCl_3$ dosage. At a $FeCl_3$ 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 (Ramli and Abdul Aziz 2015). As in the previous study done by (Zainol et al. 2022), the findings indicate a good agreement between the experimental and estimated values for COD, color, and turbidity removal. Therefore, results were in line with earlier studies that found adding MO seed to water samples decreased turbidity, and up to 85–94% of the turbidity was eliminated following the treatment (Shan et al. 2017).

Model validation

Response surface methodology (RSM), a statistical technique, was used to evaluate the accuracy and reliability of mathematical models. It involves fitting, assessing model adequacy, conducting experiments, comparing predictions with results, adjusting, and cross-validating (Nnaji et al. 2023). The cross-validation techniques assess model generalizability beyond the specific dataset used. Measure of the degree of agreement between predicted and observed values, statistical metrics like the coefficient of determination (R^2), mean absolute percentage error and root mean square error are employed.

Regression analysis

The response model based on the experimental data determined the optimum parameters for maximum color, turbidity and COD removal(Dawood and Li 2013). The main benefit of RSM with CCD is having the ability to determine the optimal value for the removal degree of pollutants under various conditions. Process optimization for water treatment is essential since it reduces treatment costs and boosts effectiveness (Benouis et al. 2022). Numerous factors were considered to determine the optimization of coagulation and flocculation process (Prihatinningtyas 2020). Based on the CCD, the results were optimized using the RSM (Design expert13.0.5.0). Process optimization is the art of changing a process to use a collection of parameters in the most efficient way possible while remaining true to any constraints. The most typical goals involve lowering costs while raising capacity and efficiency. 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 response surface methodology can successfully optimize the coagulation and flocculation processes in the purification of surface water. So this method is economical and useful for maximizing the coagulation–flocculation process's outcome by adjusting the coagulation parameters (Mensah-Akutteh et al. 2022).

An analysis of variance was used to determine the interaction between the process variable and the response. The model F-value of 291.86 for color, 68.89 for COD, and 191.42 for turbidity 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 for color removal; A, B, A^2 for COD removal; and A, B, AB, B^2 for turbidity removal are 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 6, 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—p values—were both less than 0.05, suggesting that the factor influencing the response characteristics.

Using RSM, the treatment process was optimized to reduce coagulant dosages and save operational costs and time. Tests for color, COD, and turbidity reported that the treated surface sample obtained positive values. As shown in Table 2, a total of twenty experimental runs were conducted with different experimental dosages. The highest COD removal effectiveness was attained with a blended dosage (X_2) of 2.5 g/L, achieving a 96.0% removal rate. Figure 6 shows that increasing the dosage enhanced the elimination of COD. However, when the dosage was increased to

Table 2 Removal efficiency of contaminants for observed and predicted

Run	Color removal (%)		Turbidity removal (%)		COD removal (%)	
	Observed	Predicted	Observed	Predicted	Observed	Predicted
1	97.85	96.72	95.82	95.27	89.98	89.43
2	94.52	94.46	92.58	92.83	84.24	83.92
3	96.61	96.69	94.56	94.4	86.36	87.00
4	96.58	96.49	95.28	95.03	86.95	87.01
5	95.25	95.22	92.15	91.98	83.65	83.55
6	94.36	94.46	92.55	92.83	82.68	83.92
7	99.72	99.02	97.76	97.64	96.00	95.59
8	94.58	94.77	91.25	91.44	78.23	78.61
9	96.52	96.46	93.99	93.84	85.24	85.51
10	92.75	92.88	88.25	88.36	81.12	81.66
11	92.98	92.84	88.26	88.13	79.58	79.14
12	94.25	94.27	89.79	89.88	81.26	81.05
13	93.68	93.5	90.88	90.72	79.68	79.21
14	97.65	97.7	95.35	95.15	89.98	90.6
15	95.87	95.95	92.99	93.22	84.68	84.72
16	93.58	93.58	89.9	89.83	81.26	81.37
17	94.37	94.46	92.86	92.83	84.25	83.92
18	94.36	94.46	92.89	92.83	84.26	83.92
19	94.45	94.46	92.9	92.83	84.27	83.92
20	94.58	94.46	92.88	92.83	83.98	83.92

above 3.25 g/L, the excessive amount of coagulant caused the water particles to re-stabilize, resulting in a fall in COD removal.

Model evaluation

The model proved to be reliable and accurate for predicting the percentage removal of a water sample when applied to a combined form of the two coagulants listed as coagulants. This prediction was validated by performing an experiment and computing the results with the prediction. Using Design expert version 13.0.5.0's response optimizer, numerical optimization was done based on the second-order models to increase the removal efficiency. This is more clearly illustrated in Table 2, using a blend, and the actual and predicted values indicate 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.

Model summary and analysis of variance (ANOVA) for color removal, (%)

The summary of a statistical analysis involves calculating the sum of squares (SS) for each term in the model, determining the degrees of freedom (DF) for each sum of squares, and dividing the sum of squares by the degrees of freedom. The *F*-value for each term is calculated by dividing the mean square of the term by the mean square of the error term. The *p* value is determined for each *F*-test, indicating the probability of obtaining the observed *F*-value if the null hypothesis is true. The decision is made based on the *p* values, with terms with *p* values less than a predetermined significance level (≤ 0.05) considered significant. The model summary includes estimated coefficients, standard errors, *t*-values, and *p* values for each term, as well as the coefficient of determination (R^2). For this investigation, Table 3 shows the model and ANOVA summary of color by using blended linseed and alum.

Table 3 Model summary statistics for % of color using a blended

Source	Std. dev.	R^2	Adj. R^2	Pred. R^2	PRESS	Remarks
Linear	0.6135	0.8793	0.857	0.8172	9.12	
2FI	0.6335	0.8954	0.847	0.8019	9.88	
Quadratic	**0.1375**	**0.9962**	**0.993**	**0.9746**	**1.26**	Suggested
Cubic	0.1123	0.9985	0.995	0.8678	6.59	Aliased

According to Table 3, the model summary statistics from the analysis of variance result show that the selected model, the quadratic model, was acceptable. The Predicted R^2 of 0.9746 is in reasonable agreement with the Adjusted R^2 of 0.993, i.e., the difference is less than 0.2. Hence, quadratic model performance was good to predict the experimental data, and R^2 is close to one, which is good.

From Table 4, the model *F*-value of 291.86 implies the model is significant. *P* values less than 0.0500 indicate model terms are significant. In this case, A, B, C, AB, AC, BC, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit *F*-value of 3.32 implies the Lack of Fit is not significant relative to the pure error.

Model summary and analysis of variance (ANOVA) for turbidity removal, (%)

Table 5 shows that the model summary statistics from the ANOVA result show that the selected model, the quadratic model, has been suggested for study. The Predicted R^2 of 0.9633 is in reasonable agreement with the Adjusted R^2 of 0.9890, i.e., the difference is less than 0.2. Hence, quadratic model performance was good to predict the experimental data, and R^2 is close to one, which is good.

In Table 6, the model *F*-value of 191.42 implies the model is significant. *P* values less than 0.050 indicate model terms are significant. In this case, A, B, C, AB, AC, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

Model summary and analysis of variance (ANOVA) % of COD removal

Table 7 shows that the model summary statistics from the analysis of variance for quadratic model % of turbidity using a blended result show that the selected model, the quadratic model, has been suggested for the study. The predicted R^2 of 0.915 is in reasonable agreement with the Adjusted R^2 of 0.970, i.e., the difference is less than 0.2. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

In Table 8, the model F-value of 68.89 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P values less than 0.0500 indicate model terms are significant. In this case, A, B, C, A^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 1.31 implies the Lack of Fit is not significant relative to the pure error.

Table 4 Analysis of variance for % of color using a blended

Source	Sum of squares	df	Mean square	*F*-value	*p* value	Remarks
Model	49.68	9	5.52	291.86	< 0.0001	Significant
A-pH	37.22	1	37.22	1968	< 0.0001	Significant
B-Coagulant dosage	2.81	1	2.81	148.78	< 0.0001	Significant
C-Stirring time	3.81	1	3.81	201.56	< 0.0001	Significant
AB	0.2016	1	0.2016	10.66	0.0085	Significant
AC	0.1275	1	0.1275	6.74	0.0267	Significant
BC	0.4753	1	0.4753	25.13	0.0005	Significant
A^2	3.42	1	3.42	180.65	< 0.0001	Significant
B^2	0.6661	1	0.6661	35.22	0.0001	Significant
C^2	2.62	1	2.62	138.48	< 0.0001	Significant
Residual	0.1891	10	0.0189			
Lack of fit	0.1453	5	0.0291	3.32	0.107	
Pure error	0.0438	5	0.0088			
Cor total	49.87	19				

Table 5 Model summary statistics on % of turbidity using a blended

Source	Std. dev.	R^2	Adj. R^2	Pred. R^2	PRESS	
Linear	0.5613	0.9488	0.939	0.9077	9.08	
2FI	0.506	0.9662	0.951	0.9344	6.45	
Quadratic	**0.2383**	**0.9942**	**0.989**	**0.9633**	**3.61**	Suggested
Cubic	0.2969	0.9946	0.983	0.1781	80.89	Aliased

Table 6 Analysis of variance for the quadratic model % of turbidity using a blended

Source	Sum of squares	df	Mean square	*F*-value	*p* value	Remarks
Model	97.85	9	10.87	191.42	< 0.0001	Significant
A-pH	78.87	1	78.87	1388.65	< 0.0001	Significant
B-Coagulant dosage	11.17	1	11.17	196.74	< 0.0001	Significant
C-Stirring time	3.33	1	3.33	58.66	< 0.0001	Significant
AB	0.9736	1	0.9736	17.14	0.002	Significant
AC	0.6446	1	0.6446	11.35	0.0071	Significant
BC	0.0949	1	0.0949	1.67	0.2253	
A^2	0.0016	1	0.0016	0.0275	0.8715	
B^2	2.56	1	2.56	45.09	< 0.0001	Significant
C^2	0.3576	1	0.3576	6.3	0.0309	Significant
Residual	0.568	10	0.0568			
Lack of fit	0.4319	5	0.0864	3.17	0.1154	
Pure error	0.1361	5	0.0272			
Cor total	98.41	19				

Table 7 Model summary statistics for % of COD using a blended

Source	Std. dev.	R^2	Adj. R^2	Pred. R^2	PRESS	
Linear	1.95	0.7885	0.749	0.5806	121.07	
2FI	2.1	0.8006	0.709	0.5798	121.3	
Quadratic	**0.677**	**0.9841**	**0.970**	**0.9151**	**24.51**	Suggested
Cubic	0.591	0.9927	0.977	0.9126	25.23	Aliased

Table 8 Analysis of variance for the quadratic model for COD removal (%) using blended

Source	Sum of squares	df	Mean square	*F*-value	*p* value	Remarks
Model	284.13	9	31.57	68.89	< 0.0001	Significant
A-pH	180.29	1	180.29	393.41	< 0.0001	Significant
B-Coagulant dosage	13.45	1	13.45	29.34	0.0003	Significant
C-Stirring time	33.91	1	33.91	74	< 0.0001	Significant
AB	1.01	1	1.01	2.2	0.1684	
AC	0.2801	1	0.2801	0.6113	0.4524	
BC	2.2	1	2.2	4.8	0.0492	Significant
A^2	31.17	1	31.17	68.02	< 0.0001	Significant
B^2	1.68	1	1.68	3.67	0.0842	
C^2	9.03	1	9.03	19.7	0.0013	Significant
Residual	4.58	10	0.4583			
Lack of fit	2.6	5	0.5193	1.31	0.388	
Pure error	1.99	5	0.3973			
Cor total	288.71	19				

Interactions of pH and coagulant dosage on COD removal

The concentration of coagulant dosage has a significant effect on the removal process's performance (Asaithambi et al. 2017). Studies (Zhao et al. 2021) have indicated that a significant determinant of the process's effectiveness is the influent's organic concentration, which is determined by COD removal efficiency, (%). Figure 7 shows that as the pH values rise from 3.5 to 9, there was a decline in the COD removal from 96 to 85%.

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 COD (Modirshahla et al. 2007). To confirm whether the sample is really mineralized, the COD of the surface water was tested following oxidative decline.

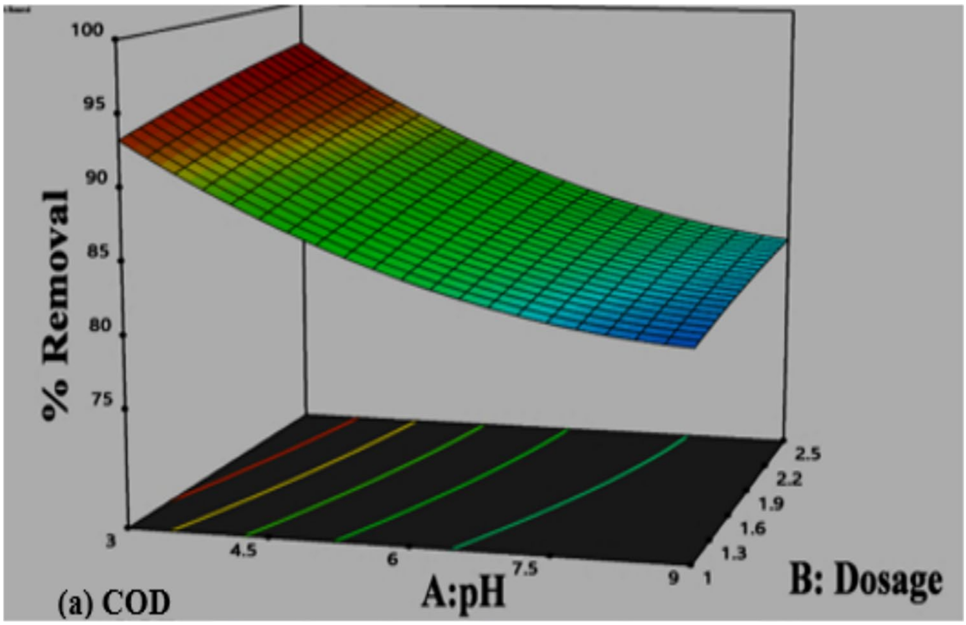


Fig. 7 Interactions of pH and coagulant dosage on COD removal

Interactions of pH and coagulant dosage on turbidity removal

Effect on coagulation rate seen that the blended dosage was able to lower turbidity from 47.80 to 1.07 NTU. It implies that a 1.5 g/L dose could result in a 97.76% turbidity reduction. In accordance with the turbidity of the raw water (Tsamo et al. 2021) likewise noted a reduction in turbidity level. As indicated in, at pH 7 and a coagulant dosage of 2.5 g/L, turbidity removal decreased to 96.86%. This indicated that as pH was increased and removal rate was decreased (Fig. 8).

Conclusion

These studies were to investigate and optimize for the removal of color, turbidity, and chemical oxygen demand removal from surface wastewater using a central composite design from the response surface methodology. The

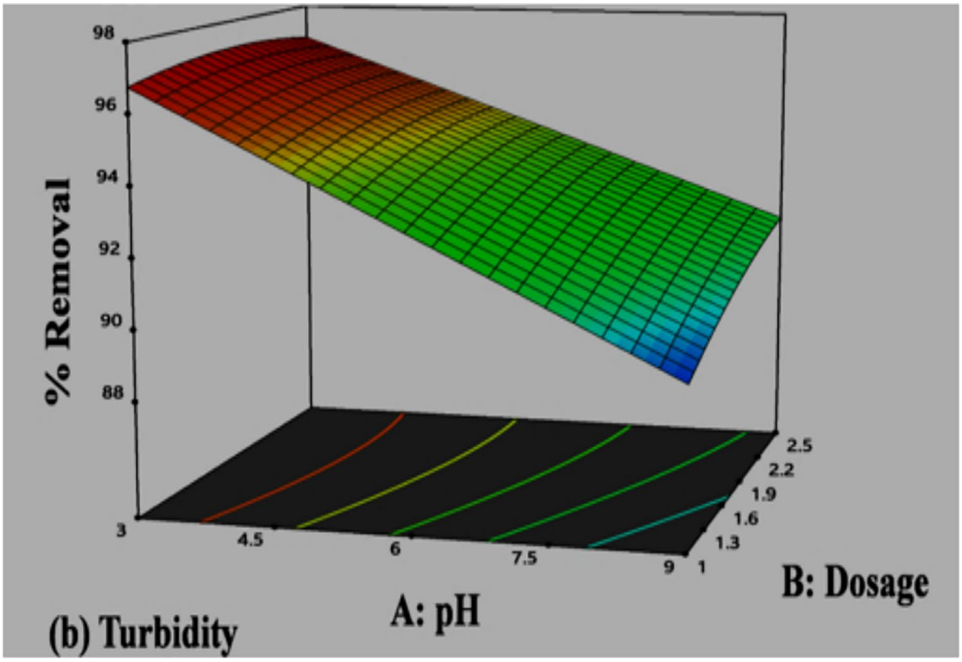


Fig. 8 Interactions of pH and coagulant dosage on turbidity removal

coagulation and flocculation methods were effective for purifying surface water of contaminants. It was found that with the coagulation–flocculation process, blended coagulants were more efficient and significantly improved the removal of color-99.72%, turbidity-97.76%, and COD-96%. The process's performance was determined by examining and reporting operating parameters such as pH, dosage and stirring time. The results of the combined coagulant showed that it could be used as an efficient method for the complete removal of pollutants from water. The benefits of blended coagulants were the focus of this investigation, and the efficiency of removal was found to be higher. Thus, the use of this material in surface water treatment could be more suitable and advantageous when compared to chemical coagulants. In this approach, the amount of alum dosage has been decreased while increasing amounts of *linseed* coagulants have been introduced. Therefore, the finding indicated that the use of blended coagulants has a high potential for treating wastewater.

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Declarations

Conflict of interest The authors declare no conflicts of interest with regard to the publication of this research article.

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