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Performance Assessment of *Descurainia Sophia* Seed Extract as a Natural Coagulant in Combination with Aluminium Sulfate for Turbidity Removal in Water

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ABSTRACT

Background: The combined use of plant-based and chemical coagulants, such as aluminium or iron salts can reduce the use of chemical coagulants while providing sufficient efficiency in removing suspended solids. This experimental research investigated the effect of *Descurainia sophia* seed extract (DSSE) in conjunction with the aluminium sulphate (alum) on turbidity removal efficiency.

Methods: D-Optimal design using Response Surface Methodology (RSM) was used for experimental design to investigate the effects of operating factors on responses and the potential interactions between these factors.

Results: The results showed that, when starting with an initial turbidity of 200 NTU, the maximum achieved turbidity removal efficiency of 91.45% (Run 1) was attained by using only alum at an optimized concentration of 59.5 mg/L and a pH 6. However, when the initial turbidity was 200 NTU, pH 7, and the alum concentration was reduced to 40 mg/L, and the DSSE/water ratio was increased to 16 mL/L, a turbidity removal efficiency of 93.45% (Run 35) was obtained.

Conclusion: DSSE can be used as a plant-based coagulant along with alum to reduce alum consumption and improve the coagulation and flocculation of suspended solids in water. By incorporating this extract, the removal of impurities and reduction of turbidity can be effectively promoted.

1. Introduction

In water and wastewater treatment, coagulation and flocculation processes are crucial for the elimination of suspended particles that contribute to turbidity and discoloration in the water. These processes involve the application of coagulants, such as polyaluminium chloride (PACL) and aluminium sulphate ($Al_2(SO_4)_3$), commonly known as alum [1]. Although these types of coagulants are widely used due to their high production and favorable coagulation performance [2], the high cost of producing these materials and their negative impact on the environment and human health have raised concerns [3, 4]. When aluminium-based coagulants are used in water treatment processes, treated water can contain significant amounts of dissolved aluminium, particularly at pH levels of 8 or above. Additionally, the presence of complex inorganic ligands such as fluoride can further increase the amount of soluble aluminium concentrations, even to a non-negligible amount at pH levels of 6 and 7. The results of a meta-analysis show that people who are chronically exposed to aluminium have a 71 % higher risk of developing Alzheimer's disease [5, 6]. Bones are the main site for the accumulation of absorbed aluminum in the human body, but it also accumulates to a lesser extent in the brain, liver, and kidneys [7]. The systemic absorption rate of monomeric aluminium salts from drinking water (0.28 %) exceeds that from food sources (0.1 %). The intake of large amounts of aluminium through drinking water consumption has been associated with various complications, including microcytic anaemia, osteoporosis,

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and kidney failure in dialysis patients. There is ample evidence of a link between bone disease and aluminum concentration in water [8]. The application of chemical coagulants in water treatment has its limitations. For instance, their effectiveness diminishes considerably under low water temperatures, and they can have considerable impacts on the pH of the treated water [9]. In addition, this type of coagulant produces a large amount of non-degradable sludge, which increases the cost of water treatment [10]. In recent years, there has been an increasing trend towards the use of natural coagulants derived from various sources such as plants [11], microorganisms [12], or animals [13]. This growing inclination towards natural coagulants can be attributed to the desire to overcome potential problems caused by the use of chemical coagulants [14]. Compared to chemical coagulants, natural coagulants have several advantages. These include source stability, environmental friendliness, reduced dependence on chemicals, lower costs for sludge treatment and management, availability and locality, independence of pH and alkalinity, as well as relatively lower production costs [15]. In addition, natural coagulants are non-corrosive and safe to use, particularly when compared to chemical coagulants. Furthermore, they produce less sludge that is biodegradable [16]. However, it is important to note that certain natural coagulants may have disadvantages. These can include an increase in the organic content of the water, an increase in microbial activity, a higher chlorine requirement during disinfection, and an extended settling time [17]. Natural coagulant sludge contains many nutrients and can be used as fertilizer and soil conditioner [18]. Plant-based coagulants are also used in wastewater treatment. Studies have shown that the extract of *G. ulmifolia* demonstrates a remarkable removal efficiency of 95.8 % for turbidity and 81.2 % for biochemical oxygen demand (BOD) in dairy wastewater in a combined system of coagulation followed by dissolved air flotation (DAF) [19]. The improved and optimized processes compared to the conventional coagulation process have many advantages in improving the removal rates of natural organic matter (NOM) and disinfection by-products [20]. During the coagulation process, particle coagulation can be attributed to four mechanisms: double-layer compression, polymer bridging, charge neutralization, and sweep coagulation [21]. In water treatment practice, polymer bridging and charge neutralization are two possible coagulation mechanisms for plant-based coagulants [22]. Research conducted on the individual and simultaneous application of plant-based and chemical coagulants shows promising results in terms of improving the quality of raw water by reducing dependence on harmful compounds [23, 24]. The results of a study on the effect of plant-based coagulant aid to reduce medium water turbidity and color showed that the simultaneous use of watermelon seed powder with 20 % alum improved water quality to meet the guidelines set by the World Health Organization (WHO) [23]. Studies have demonstrated that rice starch is capable of reducing water turbidity by approximately 50 %. Moreover, when rice starch is employed simultaneously with chemical coagulants, the removal efficiency of water turbidity can be enhanced by up to 80%. Additionally, this combined approach leads to a reduction of approximately 60 % in the volume of sludge generated from chemical-based coagulation processes [25]. *Lablab purpureus* is a species of bean in the *Fabaceae* family. The ability of *L. purpureus* has been studied as a coagulant as well as a coagulant aid to reduce water turbidity. The ability of *L. purpureus* to reduce water turbidity was about 80 % when used alone as a coagulant, and when used as a coagulant aid with alum, the removal efficiency increased up to 95.6 % [24]. The use of (*phaseolus mungo/vigna mungo*) extract as a coagulant aid with alum can increase the efficiency of turbidity removal to 100 % while reducing the consumption of alum by 20 % [24]. The study of the effectiveness of using *Moringa oleifera* seed extract with alum in reducing water turbidity showed that the settling time is reduced and the consumption of alum is reduced by 30 % [26]. Similar results of another study showed that the use of cassava peel starch and alum together can eliminate water turbidity by 91.47 % and reduce settling time by 50 % [27]. The simultaneous use of cactus extract with PACL has shown higher efficacy in removing turbidity from water compared to the use of PACL with alum. In addition, the use of PACL with cactus extract has a lower effect on lowering pH than the use of alum with cactus extract [28]. *Descurainia sophia* is a plant of the *Brassicaceae* family that produces a large number of seeds from early to late summer. In Iran, the seeds are called *khak-e shir* (*khakshir*). This plant is native to temperate and tropical regions of Asia and Europe and has mucilaginous seeds of dull red to light brown color and 0.7-1.5 mm in length. *DSSE* has been used for centuries in traditional medicine for its various health benefits [29]. It contains a variety of bioactive compounds, including alkaloids, Tannins, and saponins [30], which are believed to be responsible for its therapeutic properties [31]. Studies on the coagulant activity of *DSSE* have shown that the coagulant extracted by the optimal method is capable of removing water turbidity with a removal efficiency of 94.98 % [32, 33]. Before using plant-based coagulants for water treatment, it is crucial to evaluate their effectiveness and potential impacts. The performance and impacts of these coagulants may vary depending on the specific coagulant and the water being treated. This study aims to assess the effectiveness of using DSSE and alum together in reducing chemical coagulant consumption and improving turbidity removal efficiency. Additionally, the impact of this approach on NOM in water will also be evaluated.

2. Materials and Methods

The seeds of *Descurainia sophia* were purchased from local markets in *Kurdistan*, Iran. Kaolin powder, sodium chloride, sodium hydroxide, and hydrochloric acid were purchased from Merck (Germany), and aluminium sulfate from Carlo Erba (Italy).

2.1 Preparation of the turbid water

Approximately 10 g of kaolin powder was added to 1 L of distilled water. The resulting suspension was stirred gently for 24 h and then kept at rest for 24 h to allow the particles to settle. The supernatant was used as a stock solution, which was subsequently employed to prepare water samples with different turbidities. To adjust the initial pH, solutions of hydrochloric acid and sodium hydroxide (1 N) were used.

2.2 Extraction of Descurainia sophia seed

For the optimal extraction of *Descurainia sophia* seeds, the results of previous studies were used [32]. Briefly, 10 g of ground *Descurainia sophia* seeds were added to 250 mL of distilled water containing 1 g/L sodium chloride and 0.03 g/L sodium hydroxide. The mixture obtained was stirred with a magnetic stirrer for 5 min. After 48 h of storage at room temperature, the obtained suspension was sonicated at 75 kHz for 13 min. Then the mixture was filtered with filter paper. The filtered extract was used as DSSE.

2.3 Prepare a stock solution of alum

To prepare a 1000 ppm stock solution, 1 g of the alum was added to 1 L of distilled water, and the resulting solution was mixed for 10 min to obtain a homogeneous solution.

2.4 Design of experiments and statistical analysis

This experimental study was conducted on a laboratory scale with the aim of performance assessment of turbidity removal by DSSE with alum and evaluating the simultaneous application of alum with DSSE. Design-Expert 11.0 software was used to design the experiments and statistically analyze the experimental results. In this study, the independent variables (factors) are initial pH, initial turbidity, DSSE volume ratio to water(DSSE/water), and alum concentration. Due to the ease and accuracy of the setting, initial pH and initial turbidity were considered categorical variables, while the remaining two factors were treated as continuous variables. The dependent variables (response) are removal efficiency of water turbidity, final pH after the coagulation sedimentation process, and NOM in water. Table 1 represents the details of the selected continuous and categorical factors with the appropriate levels. The effects of the operational factors on the responses and the interaction among factors were assessed using the D-Optimal design using the RSM. The sequential backward elimination method was used to remove statistically ineffective variables. The diagnosis of the statistical properties of the model was made using the normal probability plot of the difference between the value of the dependent variable predicted by the model and the results obtained in each run (residuals). The normal probability plot shows whether the residuals follow the normal distribution or not. In a normal distribution, the residuals follow a straight line. The distribution of the residuals and following certain patterns, e.g. S-shape, shows that a better analysis can be achieved by transforming the values of the dependent variable. The investigation of the effect of the factors on the responses as well as the interaction effect was determined with analysis of variance (ANOVA) and the probability value *P-value* < 0.05. The adjusted coefficient of determination R^2 was evaluated to measure the fit of the model.

Table 1. The range of factors studied for the experimental design to determine the effect of the simultaneous use of DSSE with alum in the removal of turbidity (coded values)

Factor	Name	Unit	Range/Categories		
			Minimum		maximum
A	DSSE/water	mL/L	0 (-1)		50 (+1)
B	Alum concentration	mg/L	0 (-1)		100 (+1)
			levels		
C	Initial pH	-	6 (1 0)	7 (0 1)	8 (-1 -1)
D	Initial Turbidity	NTU	10 (1 0)	100 (0 1)	200 (-1 -1)

2.5 jar test

The jar test was used to determine the effects of the factors (DSSE/water, alum concentration, initial pH, and initial turbidity) on the responses (final pH, turbidity removal efficiency, and NOM at room temperature (23 ± 1 °C). Briefly, different amounts of DSSE and alum (according to the experiments described in Table 2) were poured into jars and made up to 1 L with turbid water. The jar test machine was set for rapid mixing at 120 rpm for 2 min, followed by flocculation at 60 rpm for 20 min and settling for 30 min. Water samples were taken with a pipette 3 cm deep from the top of the liquid. The turbidity of the water was measured using a turbidimeter (HACH 2100AN) with a maximum sensitivity of 0.01 NTU. Final pH values were measured with a pH meter (Metrohm696). NOM in water was measured with a spectrophotometer (DR6000) at 254 nm wavelength.

3. Results and Discussion

The experiments conducted to study the effect of simultaneous application of alum and DSSE and the results obtained are shown in Table 2. According to the results shown in Table 2, the combined use of DSSE and alum demonstrates a wide range of turbidity removal efficiency, spanning from 96.7 % to -164 %. Moreover, the final pH of the water is in the range of 3.34 to 7.65, and NOM is in the range of 0.915 to 0.035. The DSSE has a background turbidity. Therefore, if DSSE is added to water with a low initial turbidity (10 NTU), the final turbidity will increase compared to the initial turbidity. In a series of runs (Table 2), the final turbidity was higher than the initial turbidity due to the increase in turbidity from adding DSSE. As a result, the calculated removal efficiency was negative. The results of this study show that the efficiency of turbidity removal increases as the initial turbidity increases.

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Table 2. The Designed experiments and results of the use of alum in conjunction with DSSE to remove water turbidity

Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3
	A: DSSE/water mL/L	B: Alum concentration mg/L	C: Initial pH	D: Initial turbidity NTU	Final pH	Turbidity removal efficiency %	NOM UV Absorption at 254 nm
1	0	59.5	6	200	4.08	91.45	0.052
2	0	100.0	8	200	5.41	1	0.51
3	0	0.0	8	100	7.42	1.7	0.316
4	50	7.5	6	10	4.5	-37	0.445
5	0	32.5	8	200	5.51	1.5	0.556
6	33	54.0	6	100	3.61	-15	0.673
7	50	0.0	7	200	5.21	2	0.725
8	0	0.0	7	100	5.78	6.6	0.311
9	0	31.0	6	100	4.02	84.1	0.051
10	39	0.0	7	100	5.55	2.3	0.574
11	50	0.0	7	10	5.42	-13	0.359
12	0	0.0	6	200	5.81	3	0.513
13	19	100.0	8	100	4.24	30.4	0.386
14	43	100.0	7	200	4.51	81.05	0.478
15	50	40.0	8	10	4.31	-102	0.507
16	50	100.0	8	100	3.61	-3	0.503
17	43	100.0	8	10	3.71	23.7	0.364
18	33	0.0	8	10	6	-15	0.31
19	22	62.0	6	10	3.64	-56	0.256
20	23	35.0	8	100	5.76	-8	0.509
21	20	100.0	6	200	3.81	93.2	0.179
22	0	0.0	6	10	5.45	-3	0.041
23	50	100.0	6	10	3.34	-164	0.537
24	0	0.0	7	200	6.11	14	0.504
25	50	0.0	6	200	5.21	0	0.915
26	50	0.0	8	200	7.55	-0.5	0.848
27	0	100.0	7	100	3.99	12.8	0.301
28	45	53.6	6	10	3.45	-125	0.485
29	36	33.5	7	10	3.75	-32	0.296
30	0	65.0	7	10	3.65	13.8	0.04
31	15	0.0	8	200	7.65	2	0.646
32	50	70.5	6	200	3.65	0	0.78
33	50	100.0	7	10	3.35	-65	0.412
34	0	0.0	8	10	6.55	4.3	0.041
35	16	40.0	7	200	5.01	93.45	0.253
36	50	18.5	8	100	5.71	1.4	0.636
37	0	71.5	8	100	4.45	5.7	0.325
38	0	49.0	7	100	3.81	1.4	0.32
39	35	65.5	8	200	5.55	87.6	0.331
40	15	100.0	7	10	3.55	3.1	0.144
41	50	48.0	7	100	3.65	4.6	0.642
42	0	100.0	6	100	3.81	85.8	0.048
43	9	67.0	8	10	4.25	-40	0.144
44	0	100.0	6	10	3.79	2.6	0.042
45	50	100.0	6	100	3.46	-14	0.797
46	21	74.0	7	100	3.65	7.6	0.439
47	0	100.0	6	10	3.65	53.3	0.035
48	20	100.0	6	200	4.01	79.4	0.221
49	0	100.0	7	200	5.34	20	0.462
50	0	100.0	6	100	4.02	67.3	0.082
51	0	100.0	7	100	4.78	2.8	0.311
52	6	0.0	7	10	5.98	-15	0.084
53	50	0.0	6	100	5.02	0	0.735
54	50	100.0	8	200	4.22	96.72	0.302
55	23	0.0	6	100	5.02	-1	0.53
56	50	48.0	7	100	3.68	24.9	0.727

For example, at an initial turbidity of 200 NTU, under the same other factors, the turbidity removal efficiency is 81.05% (run 14), while at an initial turbidity of 10 NTU, it decreases to -65 % (run 33). The increase in initial turbidity of water leads to an increase in suspended solids and colloidal particles, resulting in a higher probability of coagulants hitting them and forming larger flocs. Similar results have been reported in studies involving other plant-based natural coagulants (Quercus Branti) [14].

3.1 Effect of operational factors on turbidity removal efficiency

The investigation of the influence of the factors on the efficiency of turbidity removal was carried out with a 2FI model (*p-value* < 0.0001). Notably, in comparison to alternative models, the sum of squared errors in the 2FI model was minimal (1.007E + 05). ANOVA was adopted to test the significance of the model at the % 95 confidence level.

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The *p-values* below 0.05 indicate that the model terms are significant. The results of the analysis of variance are shown in Table 3. In Table 3, the Model *F-value* of 8.47 indicates the significance of the model. There is only a 0.01 % chance that such a large *F-value* occurs due to noise. Furthermore, *P-values* of less than 0.0500 mean the statistical significance of the model terms being examined. In this case, the DSSE/water ratio (A), the initial turbidity (D), the interaction between DSSE/water ratio and the initial pH (AC), the interaction between DSSE/water ratio and the initial turbidity (AD), and the interaction between alum concentration and the initial turbidity (BD) are significant model terms. The lack-of-fit *F-value* of 2.97 suggests that the lack-of-fit in relation to the pure error is not statistically significant. There is an 11.25 % chance that such a large lack-of-fit *F-value* is due to noise. A non-significant lack-of-fit means that the model fits well. The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded model shown in Equation 1 is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Equation 1: Final model in Terms of Coded Factors for turbidity removal efficiency Prediction.

RE = + 6.29 - 14.60A + 8.52B - 1.22C [1] + 4.64C [2] - 38.16D [1] + 5.56D [2] - 31.48AC [1] + 13.15AC [2] - 19.54AD [1] + 0.8061AD [2] - 16.54BD [1] - 4.25BD [2].

RE = Turbidity removal efficiency (%) A = Ratio of DSSE/water (mL/L), B = Concentration of Alum (mg/L), C-Initial pH and D-Initial Turbidity.

3.2 Investigation of the interaction between the DSSE/water ratio and the alum concentration (AC) on the efficiency of turbidity removal

The results displayed in Figure 1 indicate that increasing the ratio of DSSE to water at pH 7 and 8 improves the efficiency of turbidity removal when the initial turbidity is 200 NTU and alum concentration is 100 mg/L (a) or 0.0 mg/L (b). However, at a pH of 6, the efficiency of turbidity removal decreases rapidly. Several studies have established that alum coagulation efficiency is highly sensitive to solution pH [34]. It was demonstrated that turbidity was removed more effectively at pH levels between 7.0 and 8.5, indicating the use of sweep flocculation. On the other hand, color removal is supported at lower pH levels between 6.0 and 6.9 through charge neutralization [35]. The initial pH value equal to 6 has a negative effect on coagulation, as it can decrease the effectiveness of the coagulant and the efficiency of the turbidity removal. These results are similar to the findings of other studies, which have proven that the coagulation process is significantly affected by the amount of bio-coagulant (*Cactus*) used and the pH level [36]. Figure 2 illustrates that for an initial pH of 7 and alum concentration of either 100 mg/L (a) or 0.0 mg/L (b), increasing the ratio of DSSE to water in high initial turbidity of 200 NTU can improve the turbidity removal efficiency. However, in the case of an initial turbidity of 10, increasing the DSSE concentration increases the final turbidity. Simultaneously using alum (100 mg/L) and DSSE (50 mL/L) results in a high level of turbidity removal efficiency (Run#14, 81.05 %). Low initial turbidity in water can negatively affect coagulation, as it can lead to decreased coagulation efficiency and increased coagulant consumption [37]. Similar results were achieved in a pilot scale study to treat turbid surface water from a stream using processed *Moringa oleifera* seed and alum. *Moringa oleifera* seed extract was utilized as a primary coagulant to treat raw water with turbidity levels ranging from 21 NTU to 479 NTU. The treatment resulted in residual turbidities of 2.7 NTU and 1.9 NTU for the high and low turbidity levels respectively [38]. A low initial turbidity can reduce removal efficiency. This is because the coagulation process relies on the collision and aggregation of particles to form larger flocs that can be easily removed. When there are fewer particles to collide and aggregate, the formation of larger flocs can be impeded, leading to reduced removal efficiency [39]. The results depicted in Figure 3 indicate that when the initial pH is 7 and the DSSE/water ratio is 50 mL/L, increasing the concentration of alum in the highest initial turbidity (200NTU) enhances the efficiency of turbidity removal. However, in the case of the lowest turbidity (10NTU), increasing the concentration of alum leads to an increase in water turbidity. The DSSE has background turbidity. The water treated with DSSE may experience an increase in turbidity compared to the initial levels due to background turbidity. This can result in negative removal efficiency values. In addition, excessive concentration of alum causes the aluminium ions to hydrolyse and form aluminium hydroxide, which has a positive charge and may lead to the restabilization of particles [40, 41].

Table 3. Analysis of variance for the prediction model of turbidity removal efficiency when DSSE is used in conjunction with alum

Source	Sum of Squares	df	Mean Square	*F-value*	*p-value*	
Model	1.007E+05	12	8395.06	8.47	< 0.0001	significant
A- DSSE/water	10883.54	1	10883.54	10.98	0.0019	
B-Alum concentration	2839.02	1	2839.02	2.87	0.0977	
C-Initial pH	380.57	2	190.28	0.1920	0.8260	
D-Initial Turbidity	44681.28	2	22340.64	22.55	< 0.0001	
AC	20146.05	2	10073.02	10.17	0.0002	
AD	8868.02	2	4434.01	4.47	0.0172	
BD	8841.40	2	4420.70	4.46	0.0174	
Residual	42606.95	43	990.86			
Lack-of-Fit	40799.31	38	1073.67	2.97	0.1125	not significant
Pure Error	1807.63	5	361.53			

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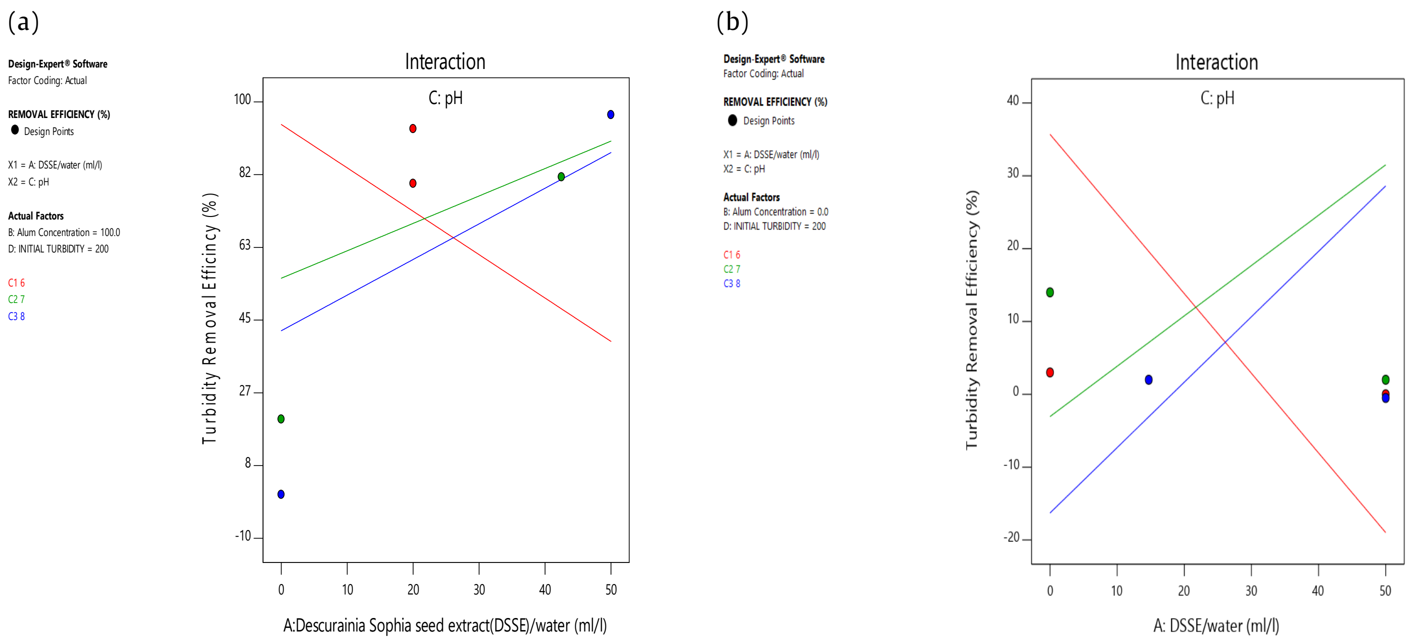

Figure 1. The interaction effect of DSSE with initial pH (AC) on the efficiency of turbidity removal
* (a) alum concentration = 100 mg/L, (b) alum concentration = 0 mg/L

3.3 Effect of operational factors on final pH

A reduced quadratic model was used to investigate the effects of the factors studied on the final pH value of the water (*p-value* < 0.0001). ANOVA was used to check the agreement of the presented model with the performance results and to determine the significant effect of the independent variables on the dependent variable of final pH. The results of this analysis are presented in Table 4. The model F value of 51.58 means that the model is significant. There is only a 0.01 % chance that such a large *F-value* occurs due to noise. *P-values* of less than 0.0500 mean that the model terms are significant. In this case, the DSSE/water ratio (A), alum concentration (B), initial pH (C), initial turbidity (D), and the interaction effect of alum concentration and initial pH (BC), initial pH and initial turbidity (CD) and the squared effect of alum concentration (B^2) are significant model terms. The *F-value* for the lack-of-fit of 1.37 means that the lack-of-fit is not significant in terms of pure error. Also, the *p-value* for the lack-of-fit ($p > 0.05$) shows that the predictions of the model agree with the experimental data. The selected quadratic model for predicting the final pH of water is shown in Equation 2.

Equation 2: Final model in Terms of Coded Factors for final pH prediction.

$$pH = +4.19 - 0.2517A - 0.9611B - 0.4924C[1] - 0.1339C[2] - 0.3431D[1] - 0.0844D[2] + 0.1859BC[1] + 0.2120BC[2] + 0.2193C[1]D[1] + 0.0151C[2]D[1] - 0.0190C[1]D[2] - 0.0532C[2]D[2] + 0.8001B^2.$$

A = Ratio of DSSE/water (mLL), B = Concentration of Alum (mg/L), C-Initial pH and D-Initial Turbidity.

Table 4. ANOVA for the final pH prediction model using DSSE in conjunction with alum

Source	Sum of Squares	df	Mean Square	*F-value*	*p-value*	
Model	64.80	13	4.98	51.58	< 0.0001	significant
A- DSSE/water	2.44	1	2.44	25.21	< 0.0001	
B-Alum concentration	31.71	1	31.71	328.11	< 0.0001	
C-Initial pH	11.78	2	5.89	60.97	< 0.0001	
D-Initial Turbidity	4.96	2	2.48	25.65	< 0.0001	
BC	2.68	2	1.34	13.86	< 0.0001	
CD	1.05	4	0.2623	2.71	0.0425	
B^2	6.52	1	6.52	67.50	< 0.0001	
Residual	4.06	42	0.0966			
Lack-of-Fit	3.69	37	0.0998	1.37	0.3944	not significant
Pure Error	0.3643	5	0.0729			

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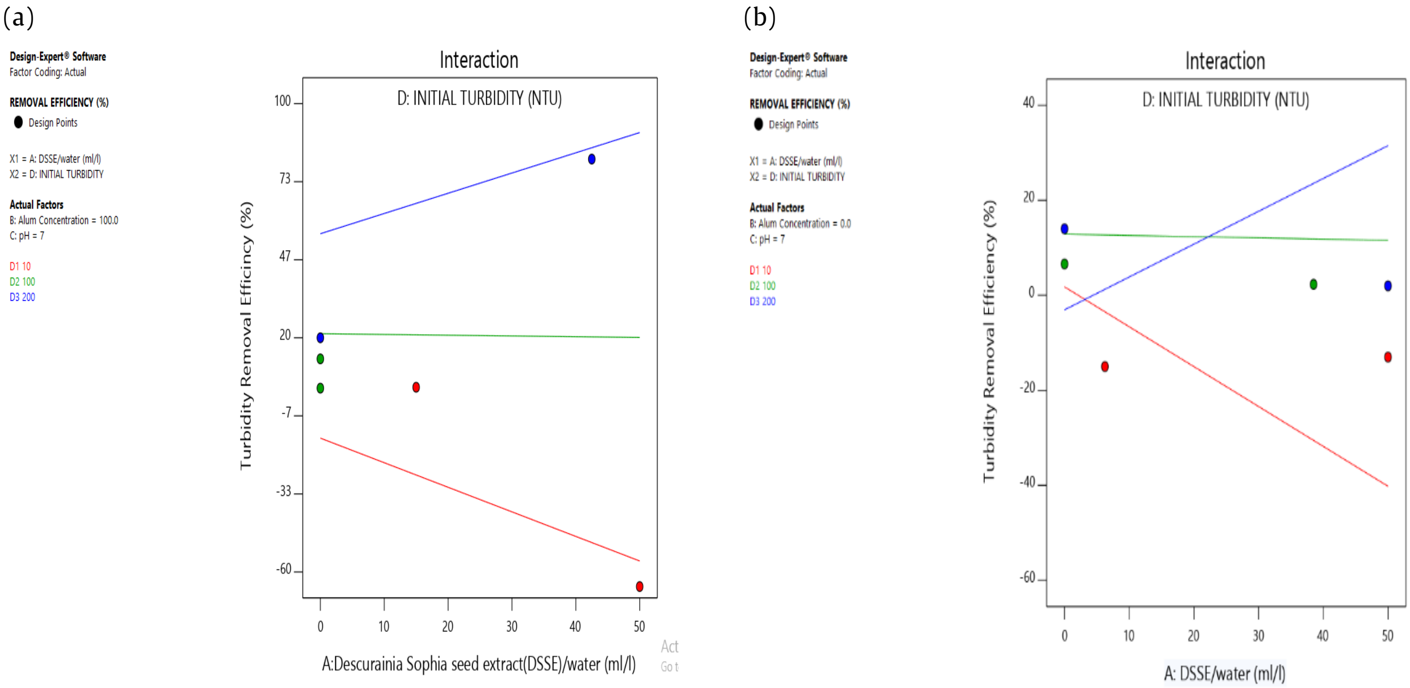

Figure 2. The interaction effect of DSSE with initial turbidity (AD) on the efficiency of turbidity removal
* (a) alum concentration = 100 mg/L, (b) alum concentration = 0 mg/L

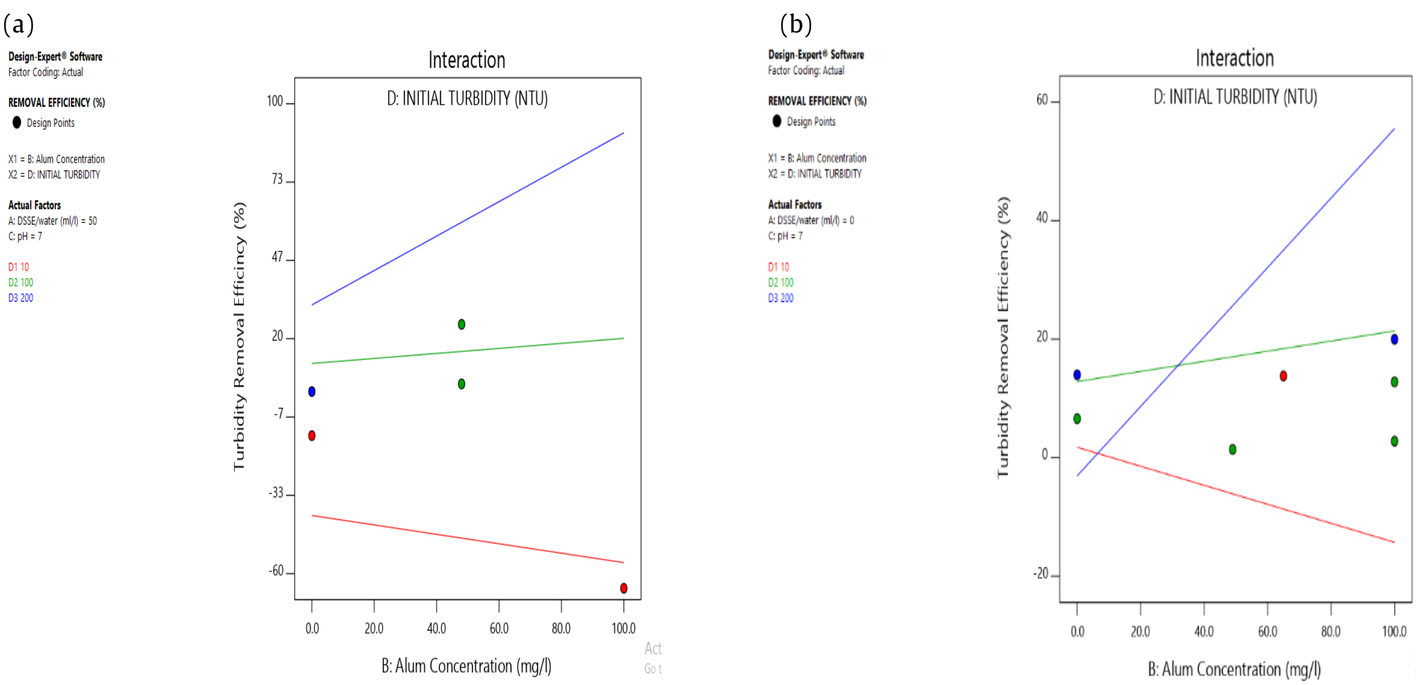

Figure 3. The interaction effect of alum concentration with initial turbidity (BD) on the efficiency of turbidity removal
* (a) DSSE/water = 50 mL/L, (b) DSSE/water = 0.0 mL/L

Based on Figure 4, it is evident that the addition of DSSE to water with an initial pH of 8 and initial turbidity of 200 NTU results in a decrease in the final pH of the water. *Descurainia sophia* seed extract is typically considered to be acidic, as it

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contains various fatty acids [42]. Fatty acids can indeed reduce pH, especially when present in high concentrations. This is because fatty acids, being organic acids, have a carboxyl group (-COOH) at the end of their hydrocarbon chain. When the carboxyl group dissociates, it releases a hydrogen ion (H^+), which can contribute to the acidity of a solution [43]. The pH correction is only recommended in the case of ionic plant-based coagulants/flocculants due to promoting the electrostatic interactions between suspended particles and the ionized biopolymer active compounds, such as amine (NH_2), carboxyl (COO), and hydroxyl groups (OH) [44]. In many cases, amphoteric bio-flocculants can be effective without pH adjustments, as they can interact with particles in water over a wide range of pH values [45]. Based on Figure 5, when the initial turbidity is 200 NTU and the ratio of DSSE to water is 50 mL/L, the final pH of the water decreases with the addition of alum, regardless of the initial pH values.

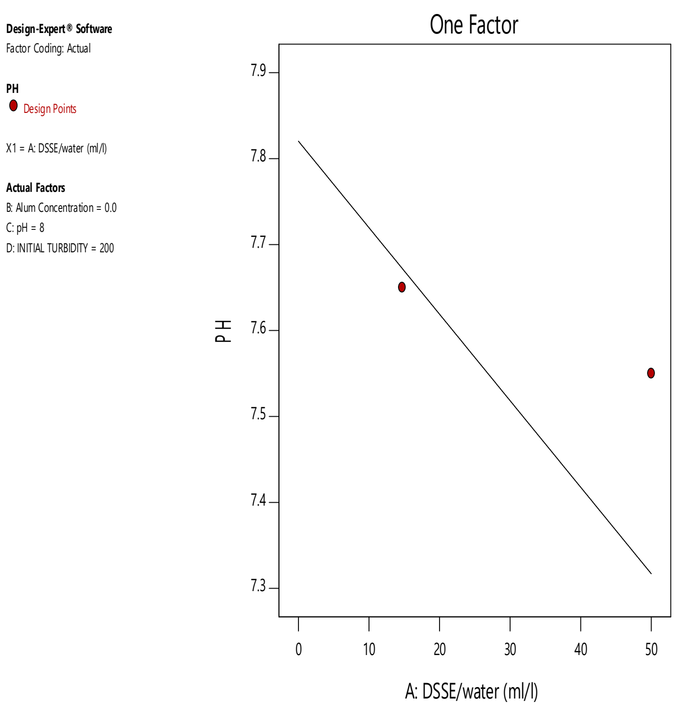

Figure 4. The effect of DSSE/water on the final PH

Chemical coagulants neutralize charges on suspended particles to prevent electrostatic repulsion. Positively charged particles attract negative particles, resulting in electrical neutrality. Van der Waal's forces then take over, allowing attraction to occur. The particles eventually become floc and settle out of solution [46]. Traditional coagulants like alum hydrolyse quickly and their products can destabilize kaolin particles through precipitation charge neutralization (PCN) after dosing. PCN zone can be extended by increasing alkalinity, which also enhances the efficiency of alum through sweep flocculation [47].

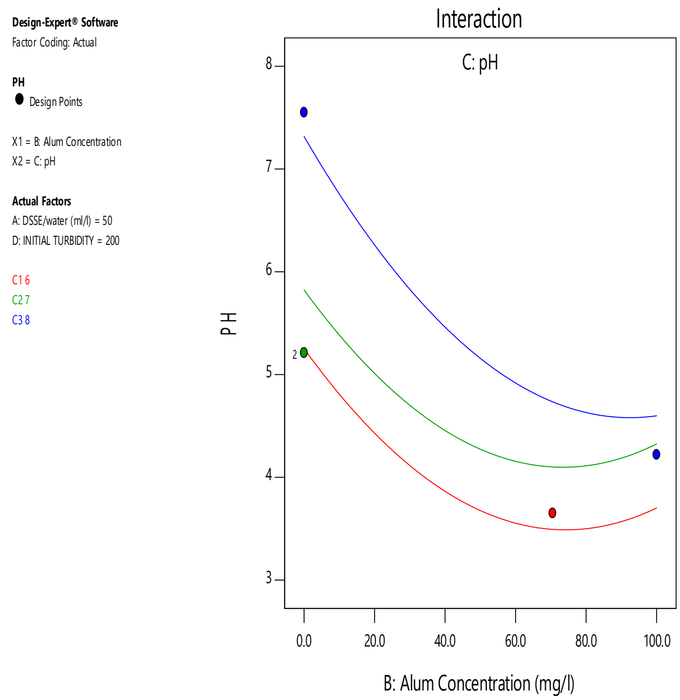

Figure 5. The interaction effect of alum concentration and initial pH (BC) on the final PH

The chemical reaction that occurs when alum is added to water involves the formation of positively charged aluminium hydroxide flocs, which attract and bind with negatively charged particles in the water. The chemical equation for the reaction is:

$$Al_2(SO_4)_3 + 6H_2O \rightarrow 2Al(OH)_3 + 6H^{1+} + 3SO_4^{2-}$$

Adding alum to water causes a reaction with the alkalinity in the water, resulting in the formation of aluminium hydroxide, which attracts small impurities in the water and settles easily during sedimentation. In the absence of other chemicals, 1 mg l^{-1} of alum theoretically destroys 0.5 mg l^{-1} of total alkalinity [48]. The degree of pH reduction is dependent on both the initial pH level and the amount of alum added, as illustrated in Figure 5. Figure 6 presents the enhanced stability of the final pH, namely in highly turbid water (200 NTU). In this context, the ratio of DSSE to water is maintained at 50 mL/L, while alum concentration is held constant at 100 mg/L. The addition of plant extracts as coagulants leads to a decrease in the pH of the water due to the presence of acidic compounds [49, 50]. Chemical coagulants also cause a decrease in the final pH of the water due to hydrolysis in the water and the combination with alkalinity in the water and the release of H^+ ions [51]. The observation of increased pH stability along with increased turbidity can be explained by the buffering effect of kaoli. The buffer capacity and carbonate content of the kaolin clay used in this study maintain a stable pH level in a solution. Kaolin buffer works by absorbing excess hydrogen ions (H^+)

or hydroxide ions (OH^-) in a solution, thereby preventing significant changes in pH [52]. The initial alkalinity of the water was 210.0 (mg/L CaCO3), while the final alkalinity was 6.3 (mg/L CaCO3).

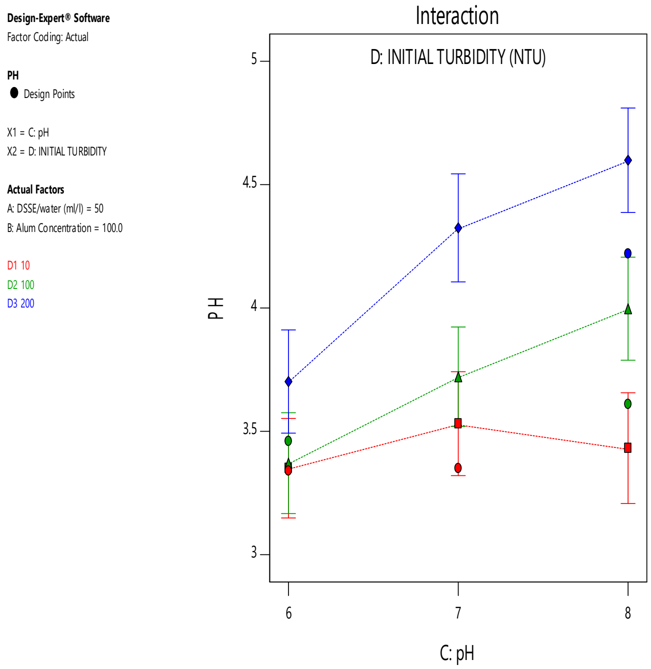

Figure 6. Interaction effect of initial pH and initial turbidity (CD) on the final pH value of the water

3.4 The effect of using DSSE with alum on NOM in water

NOM, which is found in surface waters, is a complex mix of organic compounds with varying chemical compositions and molecular sizes. It includes both aliphatic and highly colored aromatic compounds, some of which are negatively charged [53]. NOM in water can cause problems such as taste, odor, color, and formation of disinfectant by-products [54]. Plant-based coagulants, such as *Moringa oleifera* and other plant extracts, may increase the concentration of NOM in water during coagulation treatment [55]. During the process of disinfecting with chlorine, it is possible that the NOM present can create a need for more chlorine and also serve as a source for trihalomethanes [56]. A statistically significant cubic model (*p-value* < 0.0001) was used to investigate the effect of the factors studied on the response of NOM in water. To test the suitability of the model presented, an ANOVA was conducted. The results of ANOVA are shown in Table 5. Table 5 shows that the *F-value* of the model of 59.20 means that the model is significant. There is only a 0.01 % chance that such a large *F-value* occurs due to noise. *P-values* of less than 0.0500 mean that the model terms are significant. In this case, A, B, D, AC, AD, BC, BD, A^2, B^2, ABC, ACD, BCD, A^2D, AB^2, and B^2D are significant model terms. Values greater than 0.1000 indicate that the model terms are not significant. The *F-value* for lack-of-fit of 1.49 means that there is a 34.86 % chance that such a large *F-value* for lack-of-fit can occur due to noise. The cubic model selected for NOM prediction in water is presented in Equation 3.

Equation 3: Final model in Terms of Coded Factors for water NOM prediction.

$$NOM = + 0.3573 + 0.2352A - 0.0676B + 0.0002C\ [1] - 0.0156C\ [2] - 0.1081D\ [1] + 0.1682D\ [2] - 0.0072AB + 0.1173AC\ [1]\ 0.0338AC\ [2] + 0.0164AD\ [1] + 0.0315AD\ [2] - 0.0008BC\ [1] + 0.0246BC\ [2] + 0.0693BD\ [1] + 0.0189BD\ [2] + 0.0068C\ [1]\ D\ [1]\ 0.0123C\ [2]\ D\ [1] + 0.0047C\ [1]\ D\ [2] + 0.0127C\ [2]\ D\ [2] + 0.0508A^2 + 0.0184B^2 + 0.0460ABC\ [1] - 0.0057ABC\ [2] - 0.0746AC\ [1]\ D\ [1] + 0.0137AC\ [2]\ D\ [1] + 0.0359AC\ [1]\ D\ [2] - 0.0356AC\ [2]\ D\ [2] - 0.0021BC\ [1]\ D\ [1]\ 0.0269BC\ [2]\ D\ [1] + 0.0068BC\ [1]\ D\ [2]\ 0.0310BC\ [2]\ D\ [2] + 0.0342A^2B - 0.0351A^2D\ [1] - 0.0916\ A^2D\ [2] - 0.0822AB^2 - 0.0304B^2D\ [1] - 0.0665B^2D\ [2]$$

A (DSSE /water Ratio), B (Alum concentration), C (initial pH) and D (initial turbidity).

Investigation of the presence of NOM in water under the influence of the interaction between the DSSE/water ratio and the concentration of alum (A^2B). Based on Figure 7, when the initial pH is 7 and the initial turbidity is 200 NTU, the concentration of NOM in the water increases as the DSSE/water ratio increases. However, the increase in NOM is less pronounced in the presence of high concentrations of alum (100 mg/L) compared to when alum is absent.

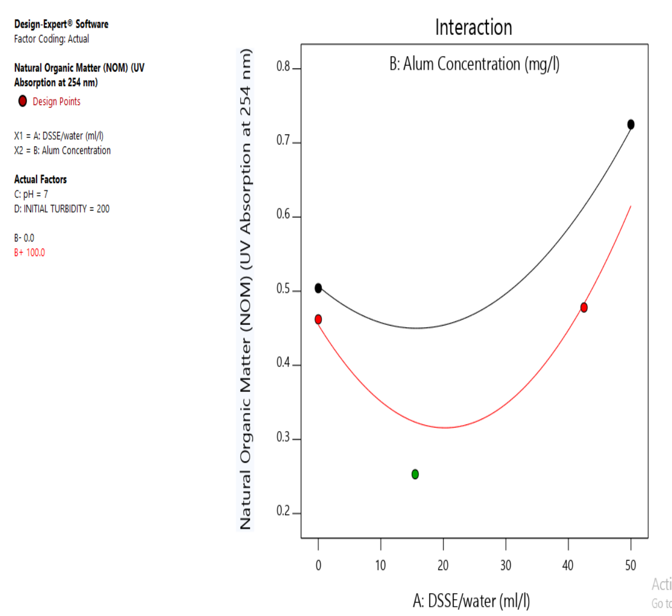

Figure 7. Interaction effect of DSSE/water ratio and alum concentration (A^2B) on NOM in water

One of the limitations of using natural plant-based coagulants is the increase in organic load in the coagulation process. This may be due to the dissolution of carbohydrates

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in plant extracts [57]. To reduce the impact of plant-based coagulants on the taste and color of water, simple methods for purification and filtration of this type of coagulant have been proposed [58].

Table 5. ANOVA for the NOM in water prediction model using DSSE in conjunction with alum

Source	Sum of Squares	df	Mean Square	*F-value*	*p-value*	
Model	3.05	37	0.0824	59.20	< 0.0001	significant
A-DSSE/water (mL/L)	1.29	1	1.29	924.03	< 0.0001	
B-Alum Concentration	0.0736	1	0.0736	52.91	< 0.0001	
C-pH	0.0054	2	0.0027	1.93	0.1743	
D-INITIAL TURBIDITY	0.6085	2	0.3043	218.71	< 0.0001	
AB	0.0002	1	0.0002	0.1615	0.6925	
AC	0.2797	2	0.1398	100.51	< 0.0001	
AD	0.0331	2	0.0166	11.91	0.0005	
BC	0.0209	2	0.0104	7.51	0.0043	
BD	0.1295	2	0.0648	46.55	< 0.0001	
CD	0.0068	4	0.0017	1.23	0.3339	
A^2	0.0078	1	0.0078	5.60	0.0293	
B^2	0.0080	1	0.0080	5.76	0.0275	
ABC	0.0274	2	0.0137	9.83	0.0013	
ACD	0.0672	4	0.0168	12.07	< 0.0001	
BCD	0.0323	4	0.0081	5.80	0.0035	
A^2B	0.0039	1	0.0039	2.78	0.1129	
A^2D	0.0535	2	0.0267	19.21	< 0.0001	
AB^2	0.0269	1	0.0269	19.31	0.0003	
B^2D	0.0389	2	0.0194	13.97	0.0002	
Residual	0.0250	18	0.0014			
Lack-of-Fit	0.0199	13	0.0015	1.49	0.3486	not significant

4. Conclusion

This study found that using DSSE in combination with alum can increase the efficiency of turbidity removal. This is due to the unique properties of both natural and chemical coagulants, which work together to improve particle coagulation and sedimentation. It is important to note that the combined use of DSSE and alum may result in a larger decrease in pH compared to using alum alone; therefore, it is crucial to adjust the dosage of both coagulants While DSSE alone may not have a high removal efficiency, its combined use with alum can be an effective and sustainable solution for improving coagulation in water treatment. However, it is important to carefully evaluate the performance and potential impacts of the coagulants and adjust the dosage accordingly. Additionally, during the coagulation process, DSSE may increase the concentration of NOM in water.

Authors' Contributions

Azam Mikaeili: Data curation; Writing-original draft. Mazyar Peyda: Project administration; investigation; Supervision; Writing- review & editing.

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Conflicts of Interest

The authors of this article declare that they have no conflict of interest.

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Ethical considerations

The ethics committee has ethically approved this project with the registration code number of IR.ZUMS.REC.1398. 431.

References

1. Jiang JQ. The Role of Coagulation in Water Treatment. *Curr Opin Chem Eng*. 2015; 8: 36-44.

2. Van Benschoten JE, Edzwald JK. Chemical Aspects of Coagulation Using Aluminum Salts-I. Hydrolytic Reactions of Alum and Polyaluminum Chloride. *Water Res*. 1990; 24(12): 1519-26.

3. McLachlan DC. Aluminum and Alzheimer's Disease. *Neurobiol Aging*. 1986; 7(6): 525-32.

4. Krewski D, Yokel RA, Nieboer E, Borchelt D, Cohen J, Harry J, et al. Human Health Risk Assessment for Aluminium, Aluminium Oxide, and Aluminium Hydroxide. *J Toxicol Environ Health*. 2007; 10(S1): 1-269.

5. Crisponi G, Nurchi VM, Faa G, Remelli M. Human Diseases Related to Aluminium Overload. *Monatsh Für Chem Mon*. 2011; 142: 331-40.

6. Wang Z, Wei X, Yang J, Suo J, Chen J, Liu X, et al. Chronic Exposure to Aluminum and Risk of Alzheimer's Disease: A Meta-analysis. *Neurosci Lett*. 2016; 610: 200-6.

7. Bjørklund G, Pivina L, Dadar M, Semenova Y, Chirumbolo S, Aaseth J. Long-term Accumulation of Metals in the Skeleton as Related to Osteoporotic Derangements. *Curr Med Chem*. 2020; 27(40): 6837-48.

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8. Willhite CC, Ball GL, McLellan CJ. Total Allowable Concentrations of Monomeric Inorganic Aluminum and Hydrated Aluminum Silicates in Drinking Water. *Crit Rev Toxicol*. 2012; 42(5): 358-442.

9. Bazrafshan E, Mostafapour FK, Ahmadabadi M, Mahvi AH. Turbidity Removal from Aqueous Environments by Pistacia Atlantica (Baneh) Seed Extract as a Natural Organic Coagulant Aid. *Desalination Water Treat*. 2015; 56(4): 977-83.

10. Dassanayake KB, Jayasinghe GY, Surapaneni A, Hetherington C. A Review on Alum Sludge Reuse with Special Reference to Agricultural Applications and Future Challenges. *Waste Manag*. 2015; 38: 321-35.

11. Ahmad A, Abdullah SR, Hasan HA, Othman AR, Ismail NI. Potential of Local Plant Leaves as Natural Coagulant for Turbidity Removal. *Environ Sci Pollut Res*. 2022; 29(2): 2579-87.

12. Sha'arani S, Azizan SN, Md Akhir FN, Muhammad Yuzir MA, Othman NA, Zakaria Z, et al. Removal Efficiency of Gram-positive and Gram-negative Bacteria Using a Natural Coagulant During Coagulation, Flocculation, and Sedimentation Processes. *Water Sci Technol*. 2019; 80(9): 1787-95.

13. Zahraa MF. Valorization of the Dromedary Bone as a Coagulant for Reduce the Turbidity of Polluted Water (Doctoral Dissertation, Faculté Des Sciences et Technologies).

14. Jamshidi A, Rezaei S, Hassani G, Firoozi Z, Ghaffari HR, Sadeghi H. Coagulating Potential of Iranian Oak (Quercus Branti) Extract as a Natural Coagulant in Turbidity Removal from Water. *J Environ Health Sci Eng*. 2020; 18: 163-75.

15. El Bouaidi W, Libralato G, Douma M, Ounas A, Yaacoubi A, Lofrano G, et al. A Review of Plant-based Coagulants for Turbidity and Cyanobacteria Blooms Removal. *Environ Sci Pollut Res*. 2022; 29(28): 42601-15.

16. Alnawajha MM, Kurniawan SB, Imron MF, Abdullah SR, Hasan HA, Othman AR. Plant-based Coagulants/Flocculants: Characteristics, Mechanisms, and Possible Utilization in Treating Aquaculture Effluent and Benefiting from the Recovered Nutrients. *Environ Sci Pollut Res*. 2022; 29(39): 58430-53.

17. Amran AH, Zaidi NS, Muda K, Loan LW. Effectiveness of Natural Coagulant in Coagulation Process: A Review. *Int J Eng Technol*. 2018; 7(3): 34-7.

18. Silva DF, Speranza LG, Quartaroli L, Moruzzi RB, Silva GH. Separation of Microalgae Cultivated in Anaerobically Digested Black Water Using Moringa Oleifera Lam Seeds as Coagulant. *J Water Process Eng*. 2021; 39: 101738.

19. Muniz GL, Da Silva TC, Borges AC. Assessment and Optimization of the Use of a Novel Natural Coagulant (Guazuma Ulmifolia) for Dairy Wastewater Treatment. *Sci Total Environ*. 2020; 744: 140864.

20. Sun Y, Zhou S, Chiang PC, Shah KJ. Evaluation and Optimization of Enhanced Coagulation Process: Water and Energy Nexus. *Water Energy Nexus*. 2019; 2(1): 25-36.

21. Li T, Zhu Z, Wang D, Yao C, Tang H. Characterization of Floc Size, Strength and Structure Under Various Coagulation Mechanisms. *Powder Technol*. 2006; 168(2): 104-10.

22. Kristianto H. The Potency of Indonesia Native Plants as Natural Coagulant: A Mini Review. *Water Conserv Sci Eng*. 2017; 2(2): 51-60.

23. Jayalakshmi G, Saritha V, Dwarapureddi BK. A Review on Native Plant Based Coagulants for Water Purification. *Int J Appl Environ Sci*. 2017; 12(3): 469-87.

24. Choy SY, Prasad KM, Wu TY, Ramanan RN. A Review on Common Vegetables and Legumes as Promising Plant-based Natural Coagulants in Water Clarification. *Int J Environ Sci Technol*. 2015; 12: 367-90.

25. Choy SY, Prasad KN, Wu TY, Raghunandan ME, Ramanan RN. Performance of Conventional Starches as Natural Coagulants for Turbidity Removal. *Ecol Eng*. 2016; 94: 352-64.

26. Cardoso Valverde K, Ferri Coldebella P, Fernandes Silva M, Nishi L, Carvalho Bongiovani M, Bergamasco R. Moringa Oleifera Lam. and Its Potential Association with Aluminium Sulphate in the Process of Coagulation/Flocculation and Sedimentation of Surface Water. *Int J Chem Eng*. 2018; 2018.

27. Asharuddin SM, Othman N, Zin NS, Tajarudin HA, Din MF. Performance Assessment of Cassava Peel Starch and Alum as Dual Coagulant for Turbidity Removal in Dam Water. *Int J Integr Eng*. 2018; 10(4).

28. Mumbi AW, Fengting L, Karanja A. Sustainable Treatment of Drinking Water Using Natural Coagulants in Developing Countries: A Case of Informal Settlements in Kenya. *Water Util J*. 2018; 18: 1-1.

29. Nimrouzi M, Zarshenas MM. Phytochemical and Pharmacological Aspects of Descurainia Sophia Webb Ex Prantl: Modern and Traditional Applications. *Avicenna J Phytomed*. 2016; 6(3): 266.

30. Fazly Bazzaz BS, Haririzadeh G, Imami SA, Rashed MH. Survey of Iranian Plants for Alkaloids, Flavonoids, Saponins, and Tannins [Khorasan Province]. *Int J Pharmacogn*. 1997; 35(1): 17-30.

31. Hsieh PC, Kuo CY, Lee YH, Wu YK, Yang MC, Tzeng IS, Lan CC. Therapeutic Effects and Mechanisms of Actions of Descurainia Sophia. *Int J Med Sci*. 2020; 17(14): 2163.

32. Rezaeian RM, Peyda M, Mohammadian Fazli M. Optimization of Extraction Method of the Natural Coagulant from Descurainia Sophia Seed: Minimization of Color Generation. *J Hum Environ Health Promot*. 2016; 1(3): 166-71.

33. Yarahmadi T, Peyda M, Mohammadian Fazli M, Rezaeian R, Soleimani N. Comparison of Water Turbidity Removal Efficiencies of Descurainia Sophia Seed Extract and Ferric Chloride. *J Hum Environ Health Promot*. 2016; 1(2): 118-24.

34. Yang ZL, Gao BY, Yue QY, Wang Y. Effect of pH on the Coagulation Performance of Al-based Coagulants and Residual Aluminum Speciation During the Treatment of Humic Acid-Kaolin Synthetic Water. *J Hazard Mater*. 2010; 178(1-3): 596-603.

35. Mensah-Akutteh H, Buamah R, Wiafe S, Nyarko KB. Optimizing Coagulation-flocculation Processes with Aluminium Coagulation Using Response Surface Methods. *Appl Water Sci*. 2022; 12(8): 188.

36. Ayat A, Arris S, Abbaz A, Bencheikh-Lehocine M, Meniai AH. Application of Response Surface Methodology for Modeling and Optimization of a Bio Coagulation Process (Sewage Wastewater Treatment Plant). *Environ Manag*. 2021; 67(3): 489-97.

37. Xu Y, Chen T, Xu R, He L, Cui F. Impact of Recycling Alum Sludge on Coagulation of Low-turbidity Source Waters. *Desalination Water Treat*. 2016; 57(15): 6732-9.

38. Muyibi S, Alfugara A. Treatment of Surface Water with Moringa Oleifera Seed Extract and Alum-A Comparative Study Using a Pilot Scale Water Treatment Plant. *Int J Environ Stud*. 2003; 60(6): 617-26.

39. Pei H, Jin Y, Xu H, Ma C, Sun J, Li H. Using Quartz Sand to Enhance the Removal Efficiency of M. Aeruginosa by Inorganic Coagulant and Achieve Satisfactory Settling Efficiency. *Sci Rep*. 2017; 7(1): 13586.

40. Yukselen MA, Gregory J. The Effect of Rapid Mixing on the Break-up and Re-formation of Flocs. *J Chem Technol Biotechnol*. 2004; 79(7): 782-8.

41. Shirasaki N, Matsushita T, Matsui Y, Oshiba A, Marubayashi T, Sato S. Improved Virus Removal by High-basicity Polyaluminum Coagulants Compared to Commercially Available Aluminum-based Coagulants. *Water Res*. 2014; 48: 375-86.

42. HadiNezhad M, Rowland O, Hosseinian F. The Fatty Acid Profile and Phenolic Composition of Descurainia Sophia Seeds Extracted by Supercritical CO2. *J Am Oil Chem Soc*. 2015; 92(9): 1379-90.

43. Britannica T. Editors of Encyclopaedia. Argon. *Encyclopedia Br*. 2020.

44. Othmani B, Rasteiro MG, Khadhraoui M. Toward Green Technology: A Review on Some Efficient Model Plant-based Coagulants/Flocculants for Freshwater and Wastewater Remediation. *Clean Technol Environ Policy*. 2020; 22: 1025-40.

45. Agbovi HK, Wilson LD. Design of Amphoteric Chitosan Flocculants for Phosphate and Turbidity Removal in Wastewater. *Carbohydr Polym*. 2018; 189: 360-70.

46. Hanrahan G. Key Concepts in Environmental Chemistry. *Academic Press.* 2011.

47. Ye C, Wang D, Shi B, Yu J, Qu J, Edwards M, Tang H. Alkalinity Effect of Coagulation with Polyaluminum Chlorides: Role of Electrostatic Patch. *Colloids Surf A Physicochem Eng Asp*. 2007; 294(1-3): 163-73.

48. Boyd CE. Aluminum Sulfate (Alum) for Precipitating Clay Turbidity from Fish Ponds. *Trans Am Fish Soc*. 1979; 108(3): 307-13.

49. Cong-Cong XU, Bing WA, Yi-Qiong PU, Jian-Sheng TA, Zhang T. Advances in Extraction and Analysis of Phenolic Compounds from Plant Materials. *Chin J Nat Med*. 2017; 15(10): 721-31.

50. Sagar NA, Pareek S, Sharma S, Yahia EM, Lobo MG. Fruit and Vegetable Waste: Bioactive Compounds, Their Extraction, and Possible Utilization. *Compr Rev Food Sci Food Saf*. 2018; 17(3): 512-31.

51. Gandiwa BI, Moyo LB, Ncube S, Mamvura TA, Mguni LL, Hlabangana N. Optimisation of Using a Blend of Plant Based Natural and Synthetic Coagulants for Water Treatment: (Moringa Oleifera-cactus Opuntia-alum Blend). *S Afr J Chem Eng*. 2020; 34: 158-64.

52. Yong RN, Warkentin BP, Phadungchewit Y, Galvez R. Buffer Capacity and Lead Retention in Some Clay Materials. *Water Air Soil Pollut*. 1990; 53: 53-67.

53. Matilainen A, Gjessing ET, Lahtinen T, Hed L, Bhatnagar A, Sillanpää M. An Overview of the Methods Used in the Characterisation of Natural Organic Matter (NOM) in Relation to Drinking Water Treatment. *Chemosphere*. 2011; 83(11): 1431-42.

54. Dayarathne HN, Angove MJ, Aryal R, Abuel-Naga H, Mainali B. Removal of Natural Organic Matter from Source Water: Review on Coagulants, Dual Coagulation, Alternative Coagulants, and Mechanisms. *J Water Process Eng*. 2021; 40: 101820.

55. Ndabigengesere A, Narasiah KS. Quality of Water Treated by Coagulation Using Moringa Oleifera Seeds. *Water Res*. 1998; 32(3): 781-91.

56. Tian FX, Hu XJ, Xu B, Zhang TY, Gao YQ. Phototransformation of Iodate by UV Irradiation: Kinetics and Iodinated Trihalomethane Formation During Subsequent Chlor (Am) Ination. *J Hazard Mater*. 2017; 326: 138-44.

57. Okoro BU, Sharifi S, Jesson M, Bridgeman J, Moruzzi R. Characterisation and Performance of Three Kenaf Coagulation Products Under Different Operating Conditions. *Water Res*. 2021; 188: 116517.

58. Kurniawan SB, Abdullah SR, Imron MF, Said NS, Ismail NI, Hasan HA, et al. Challenges and Opportunities of Biocoagulant/Bioflocculant Application for Drinking Water and Wastewater Treatment and Its Potential for Sludge Recovery. *Int J Environ Res Public Health*. 2020; 17(24): 9312.