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Primary treatment of fishery wastewater using chemical and natural coagulants

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ABSTRACT

The Peruvian fishing industry is responsible for generating large volumes of effluents, whose treatment is complicated due to their high content of salts, organic matter and total suspended solids (TSS). The coagulation-flocculation method, utilizing chemical agents, has been employed for this purpose due to its efficacy. However, given that its use has negative impacts on health and the environment, the search for sustainable alternatives is a priority. In that sense, the objective of this study was to evaluate the efficacy of natural coagulants (chitosan and *Moringa oleifera* seeds powder) and chemicals (ferric chloride) to reduce total dissolved solids (TDS) in fishery wastewater. To that end, coagulant solutions were prepared, wastewater samples were collected to perform jar tests based on the established operating conditions, and finally, the reduction percentages were calculated. The results showed that natural coagulants are more effective than chemical coagulants to reduce TDS. Specifically, the application of chitosan and *Moringa oleifera* seeds powder generated maximum reductions of 98 ± 0.71% and 86.98 ± 1.92%, respectively, at a dose of 160 mg/0.5 L, while ferric chloride produced a maximum decrease of 83.64 ± 0.14% at a dose of 120 mg/0.5 L. Therefore, those findings support the idea that natural coagulants represent an effective and sustainable way to reduce physicochemical parameters from water.

Keywords: chitosan, *Moringa oleifer*a seeds, ferric chloride, coagulation-flocculation, fishery wastewater, total dissolved solids.

INTRODUCTION

Globally, the fishery sector represents a highly relevant economic activity, because it provides food resources as well as generates employment opportunities for millions of people (González et al., 2025). Those opportunities benefit those who are directly engaged in fishing and who are involved in the entire production chain, including vessel construction, equipment supply and marketing of fishery products on large and small scales (Tursi et al., 2015). According to food and agriculture organization (FAO, 2016), artisanal fishing contributes approximately 40% of the world's catch and provides a livelihood for 90% of the people involved in fishing. In Peru, more than 64% of hydrobiological products for direct human consumption come from artisanal fishing, highlighting its importance as an economic activity for thousands of families (Ministry of Production [PRODUCE], 2020).

To ensure proper sanitary conditions during the landing, handling, storage and marketing of hydrobiological resources from artisanal fishing, the National Fund for Fisheries Development (FONDEPES) oversees the implementation of Artisanal Fishing Landing Sites (DPA), which are facilities required to achieve minimum sanitary standards for carrying out each of the stages (PRODUCE, 2020).

The series of post-capture stages requires large quantities of water for cleaning operations (Liu et al., 2022), which in turn generates significant volumes of wastewater. According to Al-Dawery et al. (2023), nearly 30% of the total volume of industrial effluents originates from activities related to fishing and fishery product processing. Wastewater from fishing activities is characterized by the presence of blood, feces, tissues, salts, oils and fats (Anh et al., 2021; Ayyoub et al., 2022). Those components contribute high concentrations of nutrients such as nitrogen and phosphorus as well as organic matter and other contaminants associated with physicochemical parameters such as turbidity, total suspended solids (TSS) and total dissolved solids (TDS) (Ribeiro and Juarez, 2021). Regarding this last parameter, it is important to mention its great relevance in fishing effluents, since they are characterized by the high content of dissolved organic matter such as blood, mucus and undissolved fats generated during the washing, cutting and gutting of hydrobiological resources (Kusumanti et al., 2021). Moreover, TDS are more difficult to eliminate through conventional treatments for fishing effluents (Pushpalatha et al., 2022).

Based on Singh and Kumar (2020), effluents pose an environmental threat if they are not treated but are discharged directly into surface water bodies. That's because practices like that lead to phenomena such as freshwater pollution, eutrophication, bioaccumulation and loss of aquatic organisms (Ojewole et al., 2024). For example, in Indonesia, 81.25% of wastewater generated by 16 fishery industries is discharged into water bodies without prior treatment (Ariyunita and Listyawati, 2020), whereas in the peruvian context, only about 32% of effluents produced nationwide are treated (Environmental Assessment and Enforcement Agency [OEFA], 2014)

One of the most widely used alternatives for reducing pollutant loads in fishery effluents is coagulation–flocculation as a primary treatment method (Land et al., 2020). That process occurs in two successive stages: coagulation, which involves the addition of one or more chemical or natural coagulants to destabilize suspended, dissolved or colloidal matter, and flocculation, in which particles aggregate to facilitate their removal (Sheng et al., 2022). Among the most used chemical coagulants, ferric chloride stands out due to its high efficacy in reducing turbidity, phosphorus (P), TSS and TDS (Ettaloui et al., 2021). However, its application presents certain drawbacks such as acidification (Winfield et al., 2016), sludge generation with high metal content (Koul et al., 2022) and environmental contamination due to the formation of toxic residues.

In response to those limitations, there is growing interest in the use of natural coagulants, which are positioned as more sustainable alternatives compared to chemical coagulants. Among natural coagulants, *Moringa oleifera* seeds powder – hereafter referred to as Moringa – and chitosan are noteworthy. On the one hand, Moringa seeds contain cationic proteins that act as coagulant agents, facilitating charge neutralization and particle aggregation, which contributes to reduce turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), TSS and TDS (Belbali et al., 2023). Chitosan, on the other hand, contains amino groups that impart high adsorption and flocculation abilities, thus effectively reducing those parameters (Yang et al., 2016). In that context, the present study aims to evaluate the efficacy of natural coagulants, such as chitosan and Moringa seeds powder, in comparison with ferric chloride (a chemical coagulant) for reducing TDS in wastewater from the Pucusana DPA, located in Lima, Peru.

MATERIALS AND METHODS

Acquisition of coagulants

The chitosan was supplied by AGRYLAAP S.A.C.S. company through its supplier Qingdao Habón Fertilizer Co. Ltd., while the ferric chloride was provided by Peruvian University of Applied Sciences after being obtained from Grupo Grat S.A.C. In turn, mature Moringa seeds were purchased to remove their shells manually and process them according to the series of steps followed by Desta and Bote (2021). In that sense, first, the seeds were ground into a fine powder, which was dried in an oven at 105 °C for 3 h after a pretreatment at 55 °C for 30 min and finally, sieved to ensure uniform particle size.

Preparation of coagulant solutions

To prepare the chitosan solution, 3 g of the biopolymer were dissolved in 96 mL of distilled water and 1 mL of 1% acetic acid, maintaining continuous stirring at 500 rpm at 25 °C for 1 h (Ariffin et al., 2009). To obtain the Moringa seeds powder solution, 5 g of seed powder were diluted in 100 mL of distilled water with constant stirring at 500 rpm at 25 °C for 30 min (Fagundes-Klen et al., 2023). Finally, to prepare the ferric chloride solution, 1 g of the compound was dissolved in 100 mL of distilled water, maintaining continuous stirring at 375 rpm at 25 °C for 10 min (Chen et al., 2023). The coagulant solutions used in the study are shown in Figure 1.

a) (b) (c)

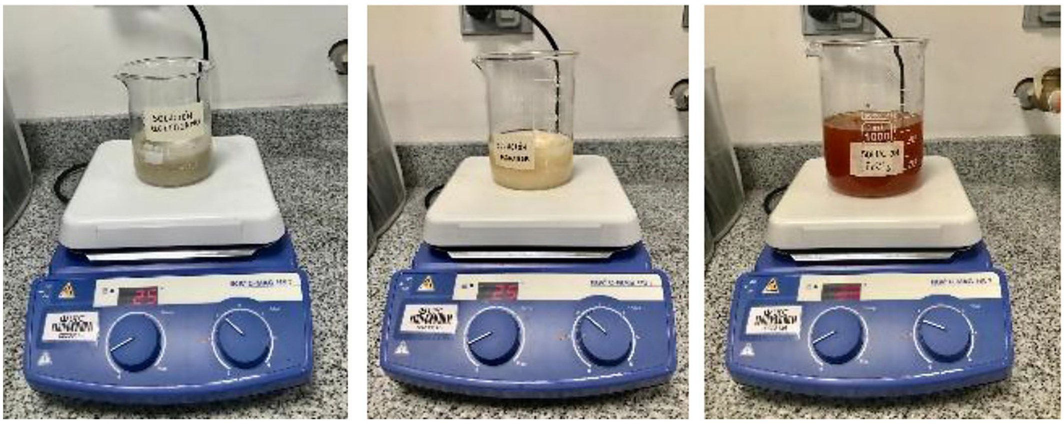

Figure 1. Coagulant solutions of (a) chitosan, (b) Moringa seeds powder and (c) ferric chloride

Collection and characterization of sewage

Wastewater samples were collected at the Pucusana DPA, Lima, Peru, specifically at the outlet of the operational area where the discharge from the processing of hydrobiological resources is concentrated. First, 3 simple samples of 7 L each were taken between 4:00 a.m. and 5:00 a.m., a period of peak operational activity and consequently, higher effluent volume. Each simple sample was placed in a sterile container forming a composite sample representative of DPA's operations, which was homogenized by manual stirring for 5 min and stored again in the containers used for its collection. Each container was properly labeled with an identification code, date, time and sampling location. In addition, the samples were preserved at approximately 4 °C using refrigerants and transported to the water and renewable energy laboratory at the UPC within a period of no more than 6 h to ensure the integrity of each sample. The collection, preservation and handling of the samples were carried out following and adapting the guidelines established in the National Protocol for the Monitoring of the Quality of Surface Water Resources (National Water Authority [ANA] & Ministry of Agrarian Development and Irrigation [MIDAGRI], 2016), thereby ensuring the reliability of the results.

Experimental design

The design to evaluate the influence of dose and type of coagulant on TDS reduction was completely randomized with a factorial arrangement, considering dose and coagulant type as factors A and B, with *a* and *b* levels respectively for the response variable. Factor A, referring to dose, included 3 variants: chitosan, Moringa seeds powder and ferric chloride. Factor B, corresponding to coagulant type, was also analyzed considering 3 levels: 80 mg/0.5 L, 120 mg/0.5 L and 160 mg/0.5 L. Table 1 summarizes the levels established for each defined factor.

Similarly, the factorial design was structured based on the basic principles of experimental design. First, to comply with the principle of replication, the number of replicates per treatment was determined through a power analysis in the statistical software MINITAB (version 21.4, 64-bit). In that regard, 3 levels per factor were considered based on previous studies, where it is common to evaluate low, medium and high doses in addition to the coagulants under study (Karnena et al., 2022; Singh and Kumar, 2020). Also, a 0.05 significance level was established as the standard and 0.8 was set as the acceptable statistical power for a hypothesis test to be effective (Triola, 2018). Likewise, a maximum difference between means of 20 was assumed, considering that the parameter is set by the same author (Gutierrez and De la Vara, 2012) and a standard deviation of 1.03 was estimated based on studies conducted under similar conditions (Singh and Kumar, 2020; Sulistyowati et al., 2023; Worku and Abate, 2025). The result indicated a minimum of 2 replicates per treatment; however, 3 replicates were chosen to increase the reliability of the results and strengthen the statistical analysis (Jones and Montgomery, 2020). Second, to ensure the randomization of the experiments, the random function of Microsoft Excel (version 2401) was used to establish the execution order of the 30 experimental runs, resulting from a 3 × 3 factorial design involving 3 replicates per treatment and 3 controls. The random distribution of treatments is shown in Table 2. Finally, to comply with the principle of blocking, mixing speeds and times as well as sedimentation period for coagulation–flocculation were fixed to reduce their influence on the response variable. Rapid mixing is performed at high speeds and for short durations to promote the initial dispersion of the coagulant in the water, ensuring its efficient interaction with TSS (Ghernaout and Boucherit, 2015). In contrast, slow mixing is carried out at low speeds and over longer periods to facilitate floc formation (Al-Risheq et al., 2022). In addition, fixing the sedimentation time allows for effective settling of the flocs (Bhagavatula et al., 2021). In that way, each experimental run was conducted under homogeneous operating conditions to ensure comparability of results among the different treatments.

Experimental procedure

Figure 2 shows the simulation of the coagulation–flocculation method using a jar test apparatus (PEF, EDIBON). The tests were conducted in 1 L beakers, to which 500 mL of the composite effluent sample and the corresponding coagulant dose were added. The operating conditions for each test sequence were 150 rpm for 2 min as rapid mixing, followed by 40 rpm for 30 min as slow mixing, and subsequently 30 min as the sedimentation time. Those periods were established after a review of previous studies related to the treatment of fishery effluents, which demonstrated the adequate formation and sedimentation of flocs through the sequence of times and mixing speeds considered in this study (Iber et al., 2023a, 2023b, 2023c). First, the rapid mixing time ensures the proper dispersion and contact of the coagulant with colloidal particles, facilitating charge destabilization (Ramphal and Sibiya, 2014). Subsequently, the slow mixing time allows already destabilized particles to collide and aggregate (Lin et al., 2013). Finally, according to Costa and Fioravante (2024), the sedimentation time provides an appropriate balance between solids removal and practical process operation, thus reducing TDS.

Table 1. Levels of the factors studied

Factor	Code	Level
Dosage (mg/0.5 L)	A	80, 120 y 160
Type of coagulant	B	NC1, NC2 y CC

Note: Chitosan was classified as natural coagulant 1 (NC1), Moringa seeds powder as natural coagulant 2 (NC2), and ferric chloride as chemical coagulant (CC).

Response variables

For the estimation of TDS reduction after the application of the treatments, 20 mL of sample was extracted from each beaker using a volumetric pipette positioned 3 cm below the surface

Table 2. Randomized trial sequence of the experimental runs

Trial sequence	Experimental run number	Treatment	
		Factor A	Factor B
1	20	160	NC2
2	1	0	ND
3	19	160	NC2
4	24	80	CC
5	14	80	NC2
6	27	120	CC
7	15	80	NC2
8	7	120	NC1
9	13	80	NC2
10	22	80	CC
11	4	80	NC1
12	10	160	NC1
13	17	120	NC2
14	2	0	ND
15	26	120	CC
16	3	0	ND
17	12	160	NC1
18	21	160	NC2
19	6	80	NC1
20	25	120	CC
21	11	160	NC1
22	28	160	CC
23	8	120	NC1
24	30	160	CC
25	9	120	NC1
26	29	160	CC
27	5	80	NC1
28	16	120	NC2
29	18	120	NC2
30	23	80	CC

Note: A value of 0 in factor A and ND (Not Defined) in factor B correspond to the control conditions (beakers without treatment).

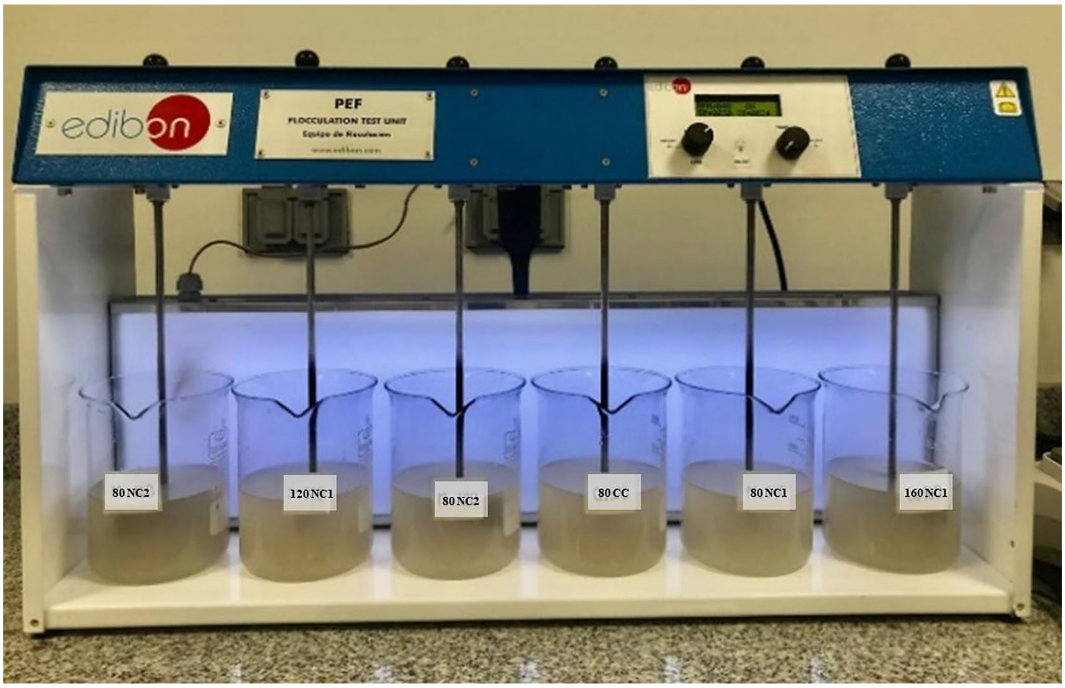

Figure 2. Simulation of the coagulation/flocculation method using jar tests

(Chen et al., 2023). The percentage of TDS reduction was calculated based on Equation 1.

$$Removal\ rate\ (\%) = \left(\frac{Ci - Cf}{Ci}\right) \times 100 \qquad (1)$$

where: Ci and Cf represent the initial and final concentrations respectively for the parameter under study.

Statistical analysis

Since the proposed design was factorial, the statistical analysis was a two-way analysis of variance (ANOVA) with a significance level of 5% ($\alpha = 0.05$) to statistically assess whether the dose and type of coagulant influence TDS reduction. It should be noted that before performing the ANOVA, its assumptions were verified, namely normality, homogeneity of variances and error independence (Hernández et al., 2014).

Likewise, to validate the experimental design, compliance with its basic principles was ensured, while, based on the factorial design, a mathematical model was established to describe the relationship between the factors and the analyzed response variable.

In the same manner, multiple comparison tests were performed using Tukey's method with a 95% confidence level to identify the most effective treatments as well as those which differ significantly from each other.

Additionally, 95% confidence intervals were determined for the meaning of each treatment to narrow the range in which the true population value is likely to be found. Furthermore, from the lower and upper limits of each interval, the error margin was calculated through the half-difference of its extremes for each treatment (Hazra, 2017).

The data analysis as well as the tabular and graphical representation of the results was carried out using MINITAB software version 21.4 (64-bit) and Microsoft Excel 2401, respectively.

RESULTS AND DISCUSSION

Physicochemical characteristics of the sewage

Physicochemical parameters such as pH, turbidity, COD, TSS and TDS are crucial indicators for establishing water quality (Sulistyowati et al., 2024). Therefore, the concentration of TDS in wastewater generated by the Pucusana DPA was studied. Table 3 shows the initial quality of the effluent in terms of TDS and pH using a conductivity meter and a pH meter, respectively. Regarding its TDS concentration (82.7 ± 1.62 mg/0.5 L), it is important to highlight that it is a relatively low value, like the one obtained by Das et al.

Table 3. Physicochemical characteristics of the sewage

Parameter	Unit	Value
TDS	mg/0.5 L	82.7 ± 1.62
pH	pH unit	6.8 ± 0.25

(2023). In turn, its pH value (6.8 ± 0.25) shows a slight tendency towards alkalinity despite having been affected by factors such as temperature and decomposition of organic matter in the water (Olaoluwa et al., 2024).

Effect of parameters studied on TDS reduction

The interaction of the factors in the TDS reduction is shown in Figure 3 and validated by the p-value obtained (0.00), which is lower than the significance level considered (0.05), according to the significance test that will be detailed as part of the statistical results. Based on Figure 3, there is an interaction effect between the dose and the type of coagulant, since the straight-line segments symbolizing the doses of 80 mg/0.5 L, 120 mg/0.5 L and 160 mg/0.5 L intersect. Likewise, the straight-line segments representing the dose of 160 mg/0.5 L are located at a higher position than the straight-line segments corresponding to the doses of 80 mg/0.5 L and 120 mg/0.5 L. Therefore, it is evident that at a dose of 160 mg/0.5 L, the TDS reduction is usually greater. About chitosan, it is noteworthy that it generated reductions of up to approximately 98%. Specifically, doses of 80 mg/0.5 L, 120 mg/0.5 L, and 160 mg/0.5 L reduced the presence of TDS by 84.16 ± 0.80%, 95.08 ± 1.49% and 98 ± 0.71%, respectively. In other words, the efficacy of chitosan increased as the dose increased. That behavior coincides with the findings of Sulistyowati et al. (2024), who indicate that as the chitosan dose increases, the TDS concentration decreases. In agreement with Muniz et al. (2022), chitosan, a branched nuclear polymer, can absorb onto the active sites of colloids, causing their destabilization and therefore, the formation of agglomerates that easily sediment or float. In that sense, the proportional relationship identified is because as the dose increases, a larger number of branches that can remove TDS predominate. However, Chen et al. (2023) note that chitosan overdosing can cause a reversal in the surface charge of the particles, which would increase their concentration and decrease their capacity as a coagulant.

Similarly, the application of Moringa seed powder doses reduced the presence of TDS by up to approximately 87%, which is lower than the maximum reduction obtained after the use of chitosan. Specifically, the addition of 80 mg/0.5 L, 120 mg/0.5 L and 160 mg/0.5 L as doses in the effluent samples produced reductions of 70.98 ± 2.09%, 79.26 ± 1.17% and 86.98 ± 1.92%, respectively. To put it another way, it was observed that the TDS reduction increased in parallel with the dose, like chitosan works, as reported by Ogunshina et al. (2023). That efficacy was attributed to

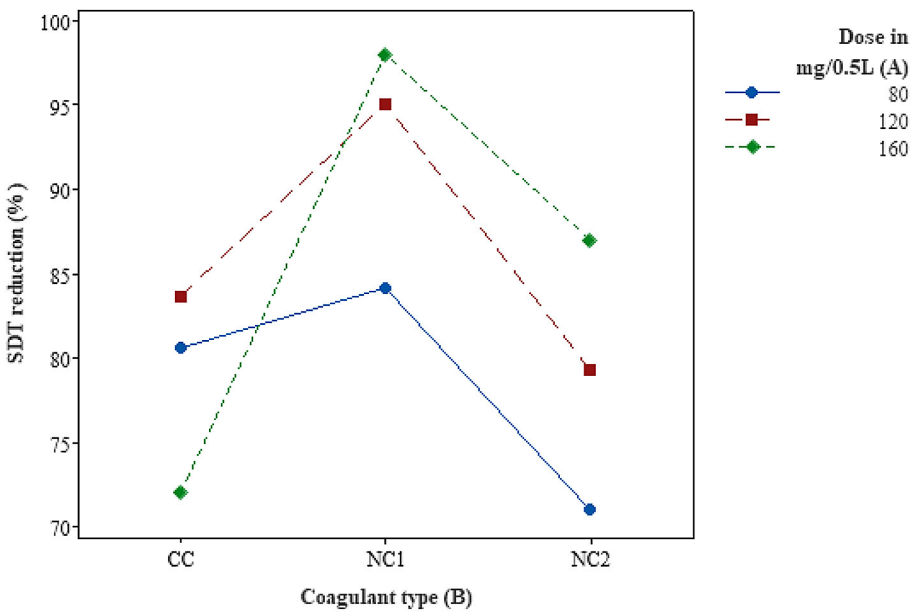

Figure 3. Interaction plot for TDS reduction

the composition of Moringa seeds, as they contain low molecular weight, water-soluble cationic proteins that interact with the organic material in the effluent, causing its instability and thus facilitating its removal by sedimentation (Hadadi et al., 2022; Souza et al., 2021). In other words, the direct relationship observed can be explained by the fact that higher doses contain a higher content of active proteins capable of reducing particle concentration. Nevertheless, it is important to emphasize as a possible environmental limitation that an overdose of Moringa seed powder can promote the generation of organic matter in the treated effluent, which contributes to the formation of carcinogenic trihalomethanes if the organic matter comes into contact with chlorine during a disinfection process (Diver et al., 2023).

Finally, the chemical coagulant, ferric chloride, produced reductions of up to 84%. Specifically, the dose of 80 mg/0.5 L produced a decrease of 80.57 ± 0.5%, a percentage that increased to 83.64 ± 0.14% with a dose of 120 mg/0.5 L but decreased to 71.95 ± 0.5% with a dose of 160 mg/0.5 L. That behavior is like the one obtained by Singh and Kumar (2020), who showed that the TDS reduction using ferric chloride partially decreased with increasing dose. That tendency according to the cited authors could be explained by the phenomena of adsorption and/or sweep flocculation, since a saturated adsorbent surface immediately loses its ability to retain more contaminants, while very dense flocs settle so quickly that they fail to adequately capture the finer particles. In addition, that behavior is explicated because chemical coagulants perform better at maximum pH levels but high doses of ferric chloride in this case tend to significantly decrease the pH of the effluent (Liu et al., 2024; Singh and Kumar, 2020). However, given that those percentages are above 50%, Karnena et al. (2022) highlight its efficacy, which is facilitated by the solubility of ferric hydroxide at high ionic strength.

To sum up, the dose and type of coagulant influence the TDS reduction as shown in Table 4, because natural coagulants produce greater decreases compared to chemical coagulants at higher doses. Specifically, chitosan produced the greatest reduction (98 ± 0.71%) at a dose of 160 mg/0.5 L, followed by Moringa seeds powder (86.98 ± 1.92%) also at a dose of 160 mg/0.5 L and ferric chloride (83.64 ± 0.14%) at a dose of 120 mg/0.5 L. In that regard, it was demonstrated that natural coagulants improved their efficacy as their doses increased. However, that behavior was due to the pH level of effluent, since natural coagulants perform better in near-alkaline conditions (Jaganathan et al., 2022; Nouj et al., 2021). In addition, that type of coagulant is cost-effective, since its low-cost acquisition generates effective results and in turn sustainable, since it does not produce large amounts of non-biodegradable sludge or alter the pH level of water bodies, compared to chemical coagulants (Desta and Bote, 2021; Kurniawan et al., 2021; Wagh et al., 2022). Therefore, currently, its use is being studied for the treatment of various sources of wastewater.

Statistical analysis

Validation of the experimental design

The experimental design was structured in accordance with its fundamental principles. The principles of replication and randomization were satisfied by conducting each treatment up to three times, following the randomization scheme presented in Table 2. Furthermore, the principle of blocking was addressed by controlling mixing speeds and times, as well as the sedimentation period in each test sequence, since these operating conditions may influence the efficacy of the observed response variable.

Development of the mathematical model equation

The equation of the mathematical model based on the factorial design is depicted in Equation 2:

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk} \qquad (2)$$

$$i = 1, 2, 3 = a;\ j = 1, 2 = b;\ k = 1, 2, 3 = n$$

where: μ – global average effect, τ_i – effect of the i-th level of the factor A, β_j – effect of the j-th level of the factor B, $(\tau\beta)_{ij}$ – interaction effect between the factors, ε_{ijk} – random error with a normal distribution that has a mean of zero and constant variance; that error is also linked to y_{ijk}, representing the k-th half-liter of the sewage where the i-th dose of the j-th type of coagulant is applied.

Analysis of variance – ANOVA

ANOVA is a technique that is used to assess the impact of one or more factors and their interaction on one or more response variables (Jasim and Salman, 2024). Table 5 provides a summary of the findings obtained from the analysis. Based on those values, it was rejected that the interaction of

Table 4. TDS reduction according to the applied treatment

Treatment		TDS in the sewage			
Factor A	Factor B	Before treatment (mg/0.5 L)	After treatment (mg/0.5 L)	TDS reduction (%)	
80	NC1	82.7	12.83	84.49	84.16 ± 0.8
		82.7	13.36	83.85	
		82.7	13.12	84.14	
120	NC1	82.7	4.25	94.86	95.08 ± 1.49
		82.7	3.51	95.76	
		82.7	4.45	94.62	
160	NC1	82.7	1.70	97.94	98 ± 0.71
		82.7	1.40	98.31	
		82.7	1.86	97.75	
80	NC2	82.7	23.55	71.52	70.98 ± 2.09
		82.7	23.65	71.40	
		82.7	24.80	70.01	
120	NC2	82.7	17.45	78.90	79.26 ± 1.17
		82.7	17.30	79.08	
		82.7	16.71	79.79	
160	NC2	82.7	10.94	86.77	86.98 ± 1.92
		82.7	10.06	87.84	
		82.7	11.30	86.34	
80	CC	82.7	15.87	80.81	80.57 ± 0.51
		82.7	16.15	80.47	
		82.7	16.18	80.44	
120	CC	82.7	13.57	83.59	83.64 ± 0.14
		82.7	13.48	83.70	
		82.7	13.53	83.64	
160	CC	82.7	23.30	71.83	71.95 ± 0.5
		82.7	23.00	72.19	
		82.7	23.28	71.85	

factors has no influence on the TDS reduction. In other words, it was assumed that it had an impact, because the p-value obtained (0.00) was lower than the significance level considered (0.05) in the criterion for rejection and non-rejection of H_0.

It should be emphasized that the fulfillment of its assumptions is reflected in the p-values obtained through the Normality Test (Anderson-Darling) and Homogeneity of Variance Test (Bartlett) for the assumption of normality and homogeneity of variances, respectively. Specifically, the p-values for the first and second assumptions mentioned were 0.43 and 0.13, respectively, which are greater than the pre-established significance level (0.05). Likewise, the assumption of error independence was also fulfilled, as only random behavior patterns were observed in Figure 4.

Tukey's HSD (honestly significant difference)

Table 6 displays the results of the multiple range tests using Tukey's method with a 95% confidence level. Based on that, the most effective treatments were those involving the application of natural coagulants at generally higher doses, as they yielded higher mean values and belonged to only one group due to significant difference. In contrast, treatments with ferric chloride at doses of 120 mg/0.5 L, 80 mg/0.5 L and 160 mg/0.5 L didn't differ significantly from those with chitosan at 80 mg/0.5 L or Moringa seeds powder at 120 mg/0.5 L and 80 mg/0.5 L, respectively. Figure 5 displays the visual differences or absence of differences between the reduction percentages obtained after applying the treatments to the effluent samples.

Table 5. ANOVA results for TDS reduction

Source	DF	Adj SS	Adj MS	F-value	P-value
Dose in mg/0.5 L (A)	2	315.92	157.96	660.08	0.00
Coagulant type (B)	2	1096.48	548.24	2291.01	0.00
Dose in mg/0.5 L (A) × coagulant type (B)	4	608.13	152.03	635.32	0.00
Error	18	4.31	0.24		
Total	26	2024.82			

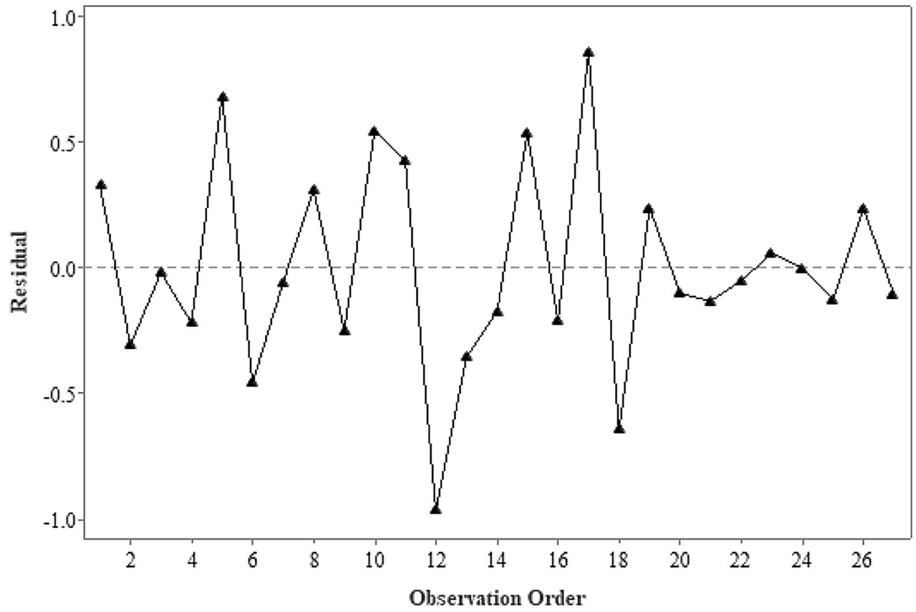

Figure 4. Residual vs order

Comparison of the maximum reduction of TDS with literature values

Table 7 illustrates the results of previous studies, in addition to those obtained in the present study. Based on the results of this investigation, the application of coagulants to reduce TDS is promising, because they generated removals greater than 50%. Likewise, compared to the results of other studies, it was observed that the reduction percentages achieved are optimistic due to the favorable conditions of the effluent, for example, its initial TDS concentration and pH level, limiting factors in the efficacy of TDS reduction (Diver et al., 2023). According to Bhagavath and Subrahmanian (2025), the high presence of TDS tends to alter the density of wastewater and therefore, reduce the efficacy of coagulation-flocculation by

Table 6. Tukey's pairwise comparisons

Dose in mg/0.5 L (A) × coagulant type (B)	N	Mean	Grouping					
160 NC1	3	98.00	A					
120 NC1	3	95.08		B				
160 NC2	3	86.98			C			
80 NC1	3	84.16				D		
120 CC	3	83.64				D		
80 CC	3	80.57					E	
120 NC2	3	79.26					E	
160 CC	3	71.96						F
80 NC2	3	70.98						F

Note: Means that do not share a letter are significantly different.

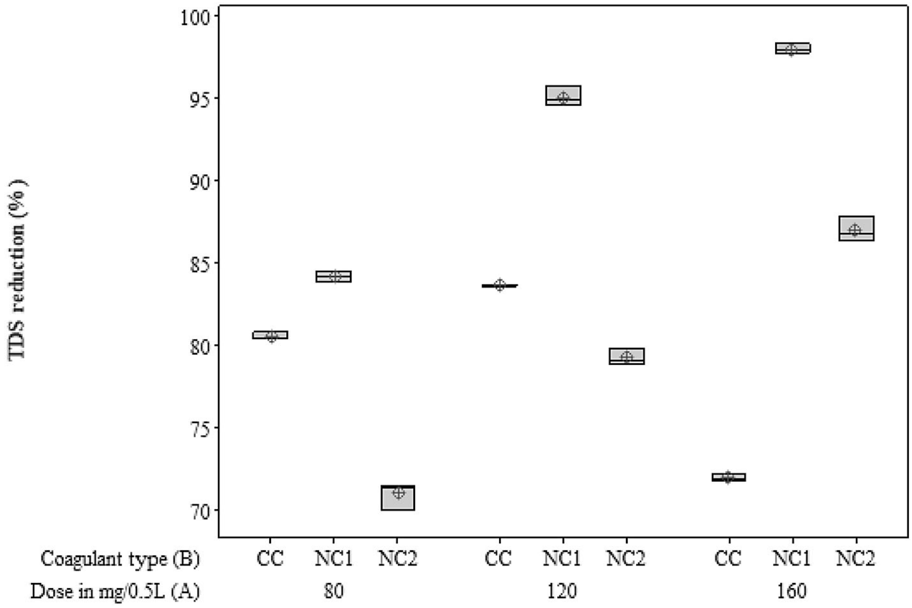

Figure 5. Boxplot of TDS reduction

Table 7. Results of the present study, with some previous studies

Sewage before treatment		Treatment		TDS reduction (%)	Reference
TDS	pH	Coagulant	Dose		
82.7 mg/0.5 L	6.8	Chitosan	160 mg/0.5 L	98 ± 0.71%	This study
16.064 mg/L	7.32		80 mg/L	81.49%	(Sulistyowati et al., 2023)
80.8 g/L	7.8		0.20 g/L	79%	(Das et al., 2023)
6.480 mg/L	9.02		0.5 g/100 mL	66%	(Al Ajmi et al., 2023)
82.7 mg/0.5 L	6.8	Moringa seeds powder	160 mg/0.5 L	86.98 ± 1.92%	This study
4.000 mg/L	8.5		5 mg/L	75.8%	(Worku and Abate, 2025)
3.256 mg/L	11.65		80 mL	63.2%	(Balaji et al., 2018)
82.7 mg/0.5 L	6.8	Ferric chloride	120 mg/0.5 L	83.64 ± 0.14%	This study
4.761 mg/L	7		0.20 g/L	93.68%	(Singh and Kumar, 2020)

hindering the sedimentation of particles. That's why TDS reductions in this study were greater than those in the other studies. In the same way, natural coagulants were found to perform better under near-alkaline conditions, since the TDS reductions in this study were higher than those in the other studies, which had effluents with predominantly alkaline pH levels (Jaganathan et al., 2022; Nouj et al., 2021). Additionally, as reported by Singh and Kumar (2020), the optimal TDS reduction after applying chemical coagulants occurs at a maximum pH level and a minimum coagulant dose. In other words, the TDS reduction increases with increasing pH but decreases with increasing dose. That's why the percentage referring to the application of ferric chloride in this study is lower than the percentage obtained by the cited authors.

CONCLUSIONS

The study demonstrated that the coagulants performed remarkably well in reducing TDS in the wastewater of DPA Pucusana, as they achieved reductions greater than 70% in all treatments. The highest reductions were achieved specifically with chitosan at doses of 160 mg/0.5 L (98 ± 0.71%) and 120 mg/0.5 L (95.08 ± 1.49%), followed by Moringa seeds powder at a dose of 160 mg/0.5 L (86.98 ± 1.92%). In that regard, the results indicate that natural coagulants proved to be more effective than ferric chloride, which decreased its performance at higher doses, although it is essential to keep in mind that natural coagulants require a near-alkaline pH level to generate those high percentages. In summary, the findings support natural coagulants as a viable alternative for the treatment of wastewater from the fishing sector, as they are effective and have positive environmental impacts.

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