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Comparative Evaluation of Coagulation - Flocculation Performance of Peat Water from Sumatra and Kalimantan

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ABSTRACT

Peat water is a potential alternative water resource in Indonesia, particularly in the peatlands of Sumatra and Kalimantan. However, its high acidity and elevated concentrations of natural organic matter (NOM) prevent its direct use as drinking water. Since the physicochemical characteristics of peat water vary among regions, chemical dosage requirements and ionic behavior may differ under identical operating conditions. Therefore, as a preliminary optimization phase, this study comparatively evaluated the coagulation–flocculation performance of peat water collected from Sumatra and Kalimantan using the Jar Test method. Polyaluminium chloride (PAC) was employed as the primary coagulant, while burnt lime (CaO) and hydrated lime (Ca(OH)₂) were evaluated as alkaline agents. We assessed treatment performance using baseline ionic responses, including pH, total dissolved solids (TDS), and electrical conductivity (EC). We performed statistical analyses using two-way analysis of variance (ANOVA) followed by Tukey's honestly significant difference (HSD) test at a 95% confidence level. The results showed that sampling location, chemical treatment, and their interaction significantly affected all measured parameters ($p < 0.001$). Hydrated lime combined with PAC effectively increased pH, whereas TDS and EC responses varied according to treatment dosage and peat water origin. Among the evaluated treatments, HL200-PAC80 produced pH values closest to the Indonesian drinking water standard, whereas HL200-PAC20, when applied to Kalimantan peat water, resulted in the lowest residual TDS and EC. These findings demonstrate that regional variations in peat water characteristics strongly influence coagulation–flocculation performance, providing a foundational basis for site-specific dosage optimization prior to main-stage NOM and color removal processes.

Contribution to Sustainable Development Goals (SDGs):

SDG 6: Clean Water and Sanitation

SDG 11: Sustainable Cities and Communities

SDG 13: Climate Action

SDG 15: Life on Land

1. INTRODUCTION

1.1. Research Background

Peatlands are among Indonesia's most important natural ecosystems, covering extensive areas primarily in Sumatra and

Kalimantan. These regions contain abundant peat water resources that can serve as alternative raw water sources for domestic and municipal water supply, particularly in areas with limited access to freshwater. In several regions of Indonesia, including Riau, Jambi, South Kalimantan, and Central Kalimantan, peat water serves as the primary, and often the only, available source of surface water for local communities [1]. However, despite its



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abundance and importance, peat water cannot be directly utilized because its quality generally does not comply with drinking water standards. Its physicochemical characteristics vary across peatland regions because of differences in peat formation, hydrological conditions, vegetation, and environmental factors [2].

Peat water is characterized by a dark brown to reddish-brown color, acidic conditions (pH 3-5), high concentrations of natural organic matter (NOM) and iron (Fe), and low hardness [3]. These characteristics primarily result from the decomposition of peat vegetation, including wood, leaves, and other plant residues, which release substantial amounts of dissolved organic matter into the water. The accumulation of these organic compounds, particularly humic and fulvic substances, imparts the characteristic dark brown color of peat water [4]. The high concentration and variable characteristics of natural organic matter complicate conventional water treatment because they significantly influence the selection, design, and operational performance of treatment processes [5].

Researchers have investigated several treatment technologies to improve peat water quality for clean water applications, including coagulation, filtration, oxidation, adsorption, and integrated treatment processes [2]. Coagulation-flocculation is a key physicochemical process in drinking water treatment that destabilizes suspended particles and natural organic matter (NOM), enabling their aggregation into larger flocs that can subsequently be removed through sedimentation or flotation [6]. Several operational parameters influence the effectiveness of the coagulation-flocculation process, including coagulant type and dosage, pH, mixing conditions, temperature, and raw water characteristics [7]. Therefore, the Jar Test method is widely used to optimize coagulant dosage and operating conditions, allowing the coagulation-flocculation performance of different raw water characteristics to be evaluated under controlled laboratory conditions [8].

Previous studies have investigated various methods for improving peat water quality, including coagulation-flocculation, adsorption, filtration, oxidation, and integrated treatment processes [1][4][9][2]. Among these methods, coagulation-flocculation has been widely applied because of its effectiveness in removing natural organic matter and reducing water color. Previous studies have also reported the application of coagulation-flocculation for peat water collected from both Kalimantan [1][4][9] and Sumatra [10][11][12]. However, these investigations were conducted independently using peat water collected from individual locations under different experimental conditions, making direct comparisons of treatment performance difficult. Considering that peat water characteristics vary among peatland regions, comparative studies evaluating the coagulation-flocculation performance of peat water collected from Sumatra and Kalimantan under identical Jar Test conditions remain limited.

To address this gap, this study aims to comparatively evaluate the coagulation-flocculation performance of peat water collected from Lubuk Babu Bridge, Riau (Sumatra), and Saraswanti Agro Estate, West Kalimantan (Kalimantan) using the Jar Test method under identical experimental conditions. Polyaluminium chloride (PAC) was employed as the primary coagulant, while burnt lime (CaO) and hydrated lime (Ca(OH)₂) were evaluated as alkaline agents to improve coagulation performance. This initial phase specifically focuses on assessing baseline ionic behavior and

chemical interactions through changes in pH, total dissolved solids (TDS), and electrical conductivity (EC). Establishing these fundamental physicochemical responses and optimal alkaline-coagulant dosing ratios is essential before evaluating full-scale NOM and color removal

1.2. Literature Review

Peatlands are terrestrial wetlands formed through the long-term accumulation of partially decomposed organic matter under waterlogged conditions. Several environmental factors influence their formation, including moisture, humidity, topography, geological characteristics, pH, and nutrient availability [13]. The formation of peat is initiated by the development of shallow lakes, which are gradually colonized by aquatic plants and wetland vegetation [14]. In peat ecosystems, natural organic matter (NOM) derives from the gradual decomposition of plant and animal biomass over long periods, accumulating in both peat water and peat soils [15]. These organic materials are predominantly composed of humic and fulvic substances, which are responsible for the dark brown color, acidic nature, and high organic content of peat water [8].

Peat water is typically characterized by a dark brown to reddish-brown color, acidic conditions (pH 3-5), high concentrations of natural organic matter (NOM), and elevated levels of dissolved iron and manganese [13]. These characteristics significantly deteriorate the physicochemical quality of peat water, preventing its direct use as drinking water without appropriate treatment [16]. The high concentration of NOM poses a major challenge for water treatment because it reduces the efficiency of conventional treatment processes and may promote the formation of disinfection by-products (DBPs) during chlorination if not adequately removed [5]. Therefore, appropriate treatment processes are required to improve peat water quality before it can be safely utilized as a drinking water source [6].

1.2.1. Coagulation-Flocculation

Coagulation-flocculation is one of the most widely applied physicochemical processes in drinking water treatment, which functions to destabilize suspended particles, colloids, and natural organic matter (NOM) through the addition of chemical coagulants [6]. During coagulation, suspended particles are destabilized through charge neutralization, allowing them to aggregate, whereas the subsequent flocculation stage involves gentle mixing to promote particle collisions and the formation of larger, stronger flocs. These flocs are then separated from the treated water through sedimentation or flotation, thereby improving overall water quality [8]. The effectiveness of coagulation-flocculation in reducing color and natural organic matter has been demonstrated in peat water treatment, making it one of the most commonly investigated treatment methods for improving peat water quality [1][12].

Several operational parameters influence the efficiency of the coagulation-flocculation process, including coagulant type and dosage, solution pH, mixing conditions, temperature, and the physicochemical characteristics of the raw water [7]. The jar test procedure generally consists of three sequential stages. The first stage is rapid mixing, which ensures the uniform dispersion of the coagulant throughout the water and promotes the destabilization of colloidal particles to initiate coagulation. This is followed by slow mixing, during which gentle agitation enhances particle

collisions and facilitates the formation of larger and stronger flocs. Finally, the settling stage involves stopping mixing and allowing the formed flocs to settle under gravity [17]. In addition, raw water characteristics, particularly the concentration and composition of natural organic matter, strongly influence coagulant demand and the overall efficiency of the coagulation-flocculation process [18]. Therefore, optimizing these operational parameters is essential for maximizing treatment performance and achieving effective pollutant removal.

1.2.2. Chemical Reagents for Coagulation-Flocculation

Polyaluminum chloride (PAC) is an aluminum-based polymeric coagulant with a more complex molecular structure and higher coagulation efficiency than conventional coagulants [19]. Several studies have reported that PAC performs effectively over a wider pH range and requires lower dosages than conventional coagulants while maintaining high turbidity removal efficiency [20]. The application of PAC effectively destabilizes and removes colloidal particles, resulting in improved water clarity after the coagulation-flocculation process [10]. However, despite these advantages, PAC treatment performance remains highly dependent on the applied coagulant dosage. One of the main challenges in coagulation is determining the optimum coagulant dosage to achieve the highest water quality [21].

Burnt lime (CaO), also known as quicklime, is an alkaline material that reacts rapidly with water to form calcium hydroxide [Ca(OH)₂]. This reaction increases the pH and alkalinity of acidic water, while the resulting calcium hydroxide facilitates the coagulation of organic matter, making it suitable for both drinking water and wastewater treatment processes [22]. Hydrated lime (Ca(OH)₂) is commonly used as a pH adjustment agent in water treatment to increase the alkalinity of raw water and establish favorable conditions for the coagulation process [6]. The effectiveness of polyaluminum chloride (PAC) is strongly influenced by pH because the hydrolysis of aluminum species and the formation of effective flocs depend on the solution pH [8]. Consequently, the combined application of burnt lime or hydrated lime with PAC can improve coagulation performance by providing the optimum pH conditions required for efficient particle destabilization and floc formation [19]. Since peat water is naturally acidic, typically with a pH ranging from 3 to 5, these alkaline agents are often applied before or during coagulation to increase pH and enhance the removal of color and natural organic matter [1].

1.3. Research Objective

Based on the identified research gap, this study aimed to evaluate the effectiveness of coagulation-flocculation using polyaluminum chloride (PAC) combined with burnt lime (CaO) and hydrated lime (Ca(OH)₂) for peat water treatment. Furthermore, the study compared the coagulation-flocculation performance of peat water collected from Sumatra and Kalimantan to investigate the effects of sampling location and chemical treatment on key physicochemical parameters, including pH, total dissolved solids (TDS), and electrical conductivity (EC).

2. MATERIALS AND METHODS

2.1. Study Area and Peat Water Sampling

Peat water samples were collected from two representative peatland regions in Indonesia to evaluate the influence of geographical origin on the coagulation-flocculation process. The first sampling site was located at Lubuk Babu Bridge, Riau Province, Sumatra, Indonesia, while the second site was situated at Saraswanti Agro Estate, West Kalimantan, Indonesia. We selected these locations because they represent major peatland areas with distinct physicochemical characteristics, allowing comparison of treatment performance under different raw water conditions. Water samples were collected using the grab sampling method from the surface layer and transferred into clean polyethylene containers. The samples were transported to the laboratory and stored at approximately 4 °C to minimize physicochemical changes prior to analysis. All jar test experiments and subsequent water quality analyses were performed using these stored samples under identical laboratory conditions.

2.2. Chemicals and Materials

The chemicals used in this study consisted of polyaluminum chloride (PAC) powder with an active content of 30%, burnt lime (CaO), and hydrated lime (Ca(OH)₂). PAC served as the primary coagulant, while burnt lime and hydrated lime were used as alkaline agents to adjust pH during coagulation-flocculation. Distilled water was used to prepare all stock solutions and for dilution.

The coagulation-flocculation experiments were conducted using a six-paddle jar test apparatus equipped with 1000 mL glass beakers. Supporting laboratory equipment included an analytical balance, volumetric flasks, graduated cylinders, measuring pipettes, pipette pumps, and glass stirring rods for chemical preparation and dosing. Water quality analyses were performed using a calibrated multiparameter meter to determine pH, total dissolved solids (TDS), and electrical conductivity (EC) before and after treatment.

2.3. Experimental Design

A factorial experimental design was employed to evaluate the effects of sampling location and chemical treatment on the coagulation-flocculation performance of peat water. The experiment consisted of two sampling locations (Sumatra and Kalimantan) and five treatment combinations, resulting in a 2 × 5 factorial design. Each treatment was performed in triplicate, yielding a total of 30 experimental units.

Treatment codes were assigned according to the alkaline agent and PAC dosage, where BL denotes burnt lime (CaO) and HL denotes hydrated lime (Ca(OH)₂). One treatment consisted of 100 mg L⁻¹ BL combined with 40 mg L⁻¹ PAC (BL100-PAC40), whereas the remaining treatments consisted of 200 mg L⁻¹ HL combined with PAC dosages of 20, 40, 60, and 80 mg L⁻¹, designated as HL200-PAC20, HL200-PAC40, HL200-PAC60, and HL200-PAC80, respectively.

2.4. Preparation of Stock Solutions

Stock solutions of the coagulant and alkaline agents were prepared prior to the coagulation-flocculation experiments. The polyaluminum chloride (PAC) stock solution was prepared at an

active concentration of 1000 mg L⁻¹ by dissolving 3.33 g of PAC powder (30% active content) in distilled water and adjusting the final volume to 1 L. The required PAC mass was calculated based on its active ingredient content to achieve the desired active concentration.

Separate stock solutions of burnt lime (CaO) and hydrated lime (Ca(OH)₂) were prepared by dissolving 10 g of each material in distilled water and making up the volume to 1 L, resulting in stock solutions with a concentration of 10 g L⁻¹. All stock solutions were prepared fresh before each experimental run and thoroughly mixed to ensure homogeneity before chemical dosing.

2.5. Jar Test Procedure

Jar test experiments were conducted using a six-paddle jar test apparatus equipped with 1000 mL glass beakers. For each experimental run, 500 mL of peat water was transferred into a glass beaker, after which the predetermined dosages of PAC and the corresponding alkaline agent were added according to the experimental design.

The coagulation-flocculation process consisted of three sequential stages. During the coagulation stage, the suspension was rapidly mixed at 120 rpm for 1 min to ensure rapid dispersion of the chemicals and destabilization of colloidal particles. This was followed by the flocculation stage, in which the mixing speed was reduced to 45 rpm for 15 min to promote particle collision and form larger, settleable flocs. Subsequently, the suspension was allowed to undergo sedimentation for 30 min under quiescent conditions to facilitate gravitational settling of the formed flocs.

After sedimentation, the clarified supernatant was carefully withdrawn from approximately 2 cm below the water surface using a pipette to avoid disturbing the settled sludge. The collected supernatant was subsequently analyzed for pH, total dissolved solids (TDS), and electrical conductivity (EC).

2.6. Statistical Analysis

All experiments were performed in triplicate, and the results are presented as mean ± standard deviation (SD). Statistical analyses were performed using Minitab Statistical Software version 22 (Minitab LLC, State College, PA, USA). We conducted a two-way analysis of variance (ANOVA) to evaluate the effects of sampling location, chemical treatment, and their interaction on pH, total dissolved solids (TDS), and electrical conductivity (EC). When significant differences were detected ($p < 0.05$), Tukey's honestly significant difference (HSD) test was performed to compare treatment means. Interaction plots were generated to visualize the combined effects of sampling location and treatment on each response variable.

3. RESULT AND DISCUSSION

3.1 Raw Peat Water Baseline Characteristics

Prior to the coagulation-flocculation experiments, the initial physicochemical characteristics of the raw peat water were

analyzed in triplicate to establish a baseline for evaluation. As shown in Table 1, the untreated peat water exhibited strongly acidic conditions and low background ionic strength typical of natural peatland aquatic systems. This strongly acidic baseline underscores the operational need to add alkali before coagulation to achieve the optimal pH window for polyaluminium chloride precipitation.

Table 1. Initial Physicochemical Characteristics of Raw Peat Water

Location	Parameter	Run 1	Run 2	Run 3
Kalimantan	pH	3.5	3.62	3.66
	Total Dissolved Solids (ppm)	38	38	38
	Electrical Conductivity (μS/cm)	95.6	95.7	95.8
Sumatera	pH	3.9	4.05	4.01
	Total Dissolved Solids (ppm)	46	45	45
	Electrical Conductivity (μS/cm)	99.8	100.1	99.9

These baseline measurements reveal clear regional differences in raw water quality between the two sampling locations. Peat water from Sumatera showed slightly higher baseline values for pH, total dissolved solids, and electrical conductivity than that from Kalimantan. These inherent variations in initial water chemistry reflect distinct regional peatland characteristics and organic composition, which ultimately influence the required coagulant dosage and chemical interactions during subsequent treatment stages.

3.2 Water Quality Parameters After Coagulation-Flocculation

The coagulation-flocculation experiments evaluated the influence of sampling location and chemical treatment on the physicochemical characteristics of peat water. Following each treatment, pH, total dissolved solids (TDS), and electrical conductivity (EC) were measured as indicators of treatment performance. To ensure experimental reliability, we conducted each treatment combination in triplicate ($n = 3$), yielding 30 individual observations for statistical evaluation.

Table 1 presents the individual observations obtained from the triplicate coagulation-flocculation experiments. The results indicate noticeable differences in pH, total dissolved solids (TDS), and electrical conductivity (EC) among the treatment combinations as well as between peat water collected from Sumatera and Kalimantan. These observations suggest that both sampling location and chemical dosage influenced treatment response. The following sections present

Table 2. Individual observations of pH, total dissolved solids (TDS), and electrical conductivity (EC) for each treatment combination.

Location	Treatment	pH (Average)	TDS (Average, ppm)	Conductivity (Average, $\mu\text{S/cm}$)
Sumatera	Burnt Lime 100 mg/L + PAC 40 mg/L	6.69	87	218
Sumatera	Hydrated Lime 200 mg/L + PAC 20 mg/L	11.08	116.7	292
Sumatera	Hydrated Lime 200 mg/L + PAC 40 mg/L	11.64	160.7	401
Sumatera	Hydrated Lime 200 mg/L + PAC 60 mg/L	8.23	114	284
Sumatera	Hydrated Lime 200 mg/L + PAC 80 mg/L	6.5	138.3	346.7
Kalimantan	Burnt Lime 100 mg/L + PAC 40 mg/L	4.8	68	169.5
Kalimantan	Hydrated Lime 200 mg/L + PAC 20 mg/L	6.5	45.7	115.9
Kalimantan	Hydrated Lime 200 mg/L + PAC 40 mg/L	6.2	70.3	175.4
Kalimantan	Hydrated Lime 200 mg/L + PAC 60 mg/L	5.5	81.3	204.7
Kalimantan	Hydrated Lime 200 mg/L + PAC 80 mg/L	6.6	117.3	293.7

a detailed evaluation of each water quality parameter.

3.3 Effect of Coagulation-Flocculation on pH

The two-way analysis of variance (ANOVA) revealed that both sampling location and treatment significantly influenced the pH of peat water ($p < 0.001$). Moreover, a highly significant interaction between location and treatment was observed ($F = 434.04$; $p < 0.001$), indicating that the effectiveness of the coagulant-alkalinity combination depended on the peat water's geographical origin. The statistical model showed excellent explanatory power, with a coefficient of determination (R^2) of 99.76%, indicating that the experimental factors and their interaction explained nearly all variation in pH.

Table 3. Two-Way ANOVA Results for Peat Water pH

Source of Variation	DF	F-value	p-value
Sampling Location	1	3820.58	<0.001
Treatment	4	723.74	<0.001
Sampling Location $\times$ Treatment	4	434.04	<0.001
Error	20	-	-

The significant effect of sampling location suggests that peat waters collected from Sumatera and Kalimantan possessed distinct physicochemical characteristics that influenced their response to coagulation-flocculation. Tropical peat waters are known to differ in the composition of natural organic matter (NOM), particularly humic and fulvic substances, as well as in alkalinity and buffering capacity. These variations may influence hydroxyl ion (OH^-) consumption during lime addition, thereby affecting the equilibrium pH achieved after treatment. Consequently, identical chemical dosages may produce different pH responses depending on the raw peat water's intrinsic properties.

Table 4. Comparison of Mean pH Using Tukey HSD Test

Sampling Location	Treatment	Mean pH $\pm$ SD	Tukey Group*
Sumatra	HL200-PAC40	11.64 $\pm$ 0.04	A
Sumatra	HL200-PAC20	11.08 $\pm$ 0.05	B
Sumatra	HL200-PAC60	8.23 $\pm$ 0.07	C
Sumatra	BL100-PAC40	6.69 $\pm$ 0.29	D
Kalimantan	HL200-PAC80	6.60 $\pm$ 0.12	D
Kalimantan	HL200-PAC20	6.51 $\pm$ 0.04	D E
Sumatra	HL200-PAC80	6.50 $\pm$ 0.12	D E
Kalimantan	HL200-PAC40	6.19 $\pm$ 0.02	E
Kalimantan	HL200-PAC60	5.51 $\pm$ 0.09	F
Kalimantan	BL100-PAC40	4.77 $\pm$ 0.21	G

Treatment also significantly influenced pH. Among all treatment combinations, HL200-PAC40 applied to Sumatera peat water produced the highest mean pH (11.64 $\pm$ 0.04), followed by HL200-PAC20 (11.08 $\pm$ 0.05). In contrast, BL100-PAC40 applied to Kalimantan peat water resulted in the lowest pH (4.77 $\pm$ 0.21). The Tukey honestly significant difference (HSD) test further classified these treatment combinations into distinct significance groups (Groups A-G), confirming that several location-treatment combinations differed significantly in their effects on pH.

The elevated pH observed in treatments containing hydrated lime ($\text{Ca}(\text{OH})_2$) is consistent with its strong alkaline nature. Upon dissolution, $\text{Ca}(\text{OH})_2$ releases hydroxyl ions that neutralize acidic functional groups, particularly carboxylic ($-\text{COOH}$) and phenolic ($-\text{OH}$) groups associated with dissolved humic substances in peat water. Under the 200 mg L^{-1} hydrated lime dosage, increasing the PAC concentration from 20 to 40 mg L^{-1} slightly increased the

pH of Sumatra peat water from 11.08 to 11.64. This response may be associated with improved destabilization of colloidal organic matter and more efficient neutralization of acidic constituents. However, increasing the PAC dosage to 60 and 80 mg L⁻¹ substantially decreased pH to approximately 6.5. This decline is consistent with the hydrolysis of polyaluminium chloride, which is commonly accompanied by proton release during the formation of amorphous Al(OH)₃ flocs, thereby consuming part of the alkalinity generated by hydrated lime.

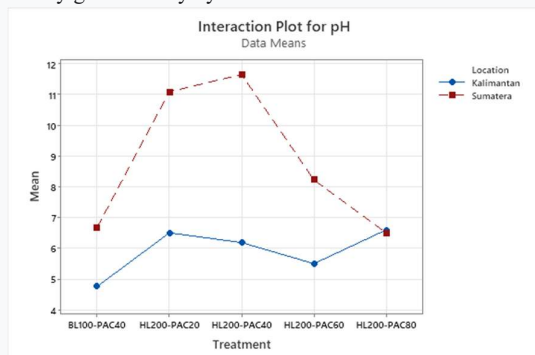


Fig 1. Interaction Plot of Sampling Location and Treatment on Peat Water pH

The interaction plot further supports the ANOVA results by illustrating a pronounced location-dependent treatment response. The response curves for Sumatra and Kalimantan were clearly non-parallel and converged under the HL200-PAC80 treatment, confirming a significant interaction between the two experimental factors. While hydrated lime combined with lower PAC dosages substantially increased the pH of Sumatra peat water (pH > 11), the corresponding increase in Kalimantan peat water remained considerably lower (approximately pH 6.2–6.5). This observation suggests that Kalimantan peat water exhibited greater resistance to alkalization, possibly because of differences in dissolved organic matter composition and buffering capacity. Therefore, the response of peat water to identical chemical dosages cannot be assumed to be uniform across different peatland regions.

From a practical perspective, the results indicate that the optimal chemical combination for pH adjustment is site-specific rather than universal. Although HL200-PAC40 produced the highest pH in Sumatra peat water, the resulting pH exceeded the recommended drinking water range of 6.5–8.5 established by the Indonesian Ministry of Health (Permenkes No. 2/2023). Conversely, BL100-PAC40 (mean pH = 6.69) and HL200-PAC80 (mean pH = 6.50) produced pH values closer to the regulatory standard for Sumatra peat water, whereas HL200-PAC80 generated the most suitable pH (mean pH = 6.60) for Kalimantan peat water. These findings highlight the importance of optimizing coagulation-flocculation conditions according to the specific physicochemical characteristics of regional peat water sources rather than applying a single treatment strategy across all locations.

3.4 Effect of Coagulation-Flocculation on Total Dissolved Solid (TDS)

The two-way analysis of variance (ANOVA) demonstrated that both sampling location and treatment significantly affected the total dissolved solids (TDS) of peat water ($p < 0.001$). Furthermore, a highly significant interaction between location

and treatment was identified ($F = 7755.58$; $p < 0.001$), indicating that the effectiveness of the coagulation-flocculation process in modifying TDS depended on the peat water's geographical origin. The statistical model showed excellent goodness-of-fit, with a coefficient of determination (R^2) of 99.99%, indicating that the experimental factors and their interaction explained almost all variability in TDS.

Table 5. Two-Way ANOVA Results for Total Dissolved Solids (TDS)

Source of Variation	DF	F-value	p-value
Sampling Location	1	81900.17	<0.001
Treatment	4	14040.25	<0.001
Sampling Location × Treatment	4	7755.58	<0.001
Error	20	-	-

The significant effect of sampling location suggests that peat waters collected from Sumatra and Kalimantan differed in their dissolved constituents and their response to chemical treatment. Peat water generally contains various dissolved inorganic ions together with humic and fulvic substances that contribute substantially to TDS. Differences in the composition and concentration of these dissolved materials between peatlands may influence the coagulation-flocculation process, resulting in different residual TDS values following treatment. Consequently, identical chemical dosages may produce different TDS responses depending on the source water's physicochemical characteristics.

To further identify differences among treatment combinations, we performed a Tukey honestly significant difference (HSD) post-hoc test. The results demonstrated significant differences among the location–treatment combinations. The highest mean TDS was obtained from HL200-PAC40 applied to Sumatra peat water (160.67 ± 0.58 mg L⁻¹), followed by HL200-PAC80 (138.00 ± 0.00 mg L⁻¹). Conversely, the lowest mean TDS was observed for HL200-PAC20 applied to Kalimantan peat water (45.67 ± 0.58 mg L⁻¹). The Tukey HSD test classified these location–treatment combinations into distinct statistical groups (A–I), confirming that several treatment combinations produced significantly different TDS responses. The increase in TDS observed under several hydrated lime treatments likely reflects the dissolution of calcium hydroxide and the addition of polyaluminium chloride (PAC), both of which contribute dissolved ionic species to the aqueous phase. While coagulation removes suspended and colloidal particles through charge neutralization and floc formation, the simultaneous addition of chemical reagents also introduces calcium, aluminium, chloride, and hydroxyl ions into solution. Consequently, when the amount of dissolved ions introduced exceeds the quantity removed through precipitation, the measured TDS may increase rather than decrease. This trend was particularly evident for the HL200-PAC40 treatment applied to Sumatra peat water, which produced the highest residual TDS. These findings indicate that TDS changes are governed not only by contaminant removal but also by the balance between ion dissolution and precipitation during the coagulation-flocculation process.

Table 6. Comparison of Mean TDS Using Tukey HSD Test

Sampling Location	Treatment	Mean TDS (mg L ⁻¹) ± SD	Tukey Group*
Sumatra	HL200-PAC40	160.67 ± 0.58	A
Sumatra	HL200-PAC80	138.00 ± 0.00	B
Kalimantan	HL200-PAC80	117.33 ± 0.58	C
Sumatra	HL200-PAC20	116.67 ± 0.58	C
Sumatra	HL200-PAC60	114.00 ± 0.00	D
Sumatra	BL100-PAC40	87.00 ± 0.00	E
Kalimantan	HL200-PAC60	81.33 ± 0.58	F
Kalimantan	HL200-PAC40	70.33 ± 0.58	G
Kalimantan	BL100-PAC40	68.00 ± 0.00	H
Kalimantan	HL200-PAC20	45.67 ± 0.58	I

The interaction plot (Figure 2) further supports the ANOVA results by illustrating a pronounced location-dependent treatment response. The response curves for Sumatra and Kalimantan were clearly non-parallel, confirming a significant interaction between sampling location and treatment. Sumatra peat water consistently exhibited higher TDS values than Kalimantan peat water across most treatment combinations, although both locations displayed a similar response pattern characterized by an increase in TDS from HL200-PAC20 to HL200-PAC40, followed by a decrease at HL200-PAC60. However, the magnitude of these changes differed substantially between locations, suggesting that the physicochemical characteristics of peat water influenced dissolution, hydrolysis, and precipitation during coagulation–flocculation. Therefore, identical treatment dosages are unlikely to produce equivalent TDS responses in peat waters from different peatland regions.

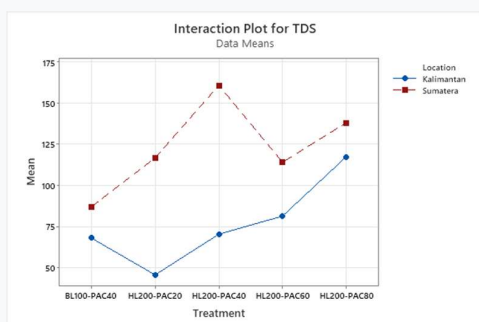


Fig 2. Interaction Plot of Sampling Location and Treatment on Total Dissolved Solids (TDS)

From a practical perspective, the results indicate that optimization of coagulation–flocculation for peat water treatment should consider not only pH adjustment but also changes in dissolved solids. Although hydrated lime combined with PAC effectively modified water chemistry, excessive chemical addition may

increase residual dissolved ions, thereby elevating TDS. Nevertheless, all evaluated treatment combinations maintained residual TDS levels well below the maximum allowable limit of 300 mg L⁻¹ specified by the Indonesian Ministry of Health (Permenkes No. 2 of 2023). Among the evaluated treatments, HL200-PAC20 applied to Kalimantan peat water produced the lowest residual TDS, whereas HL200-PAC40 applied to Sumatra peat water generated the highest. These findings demonstrate that the optimal treatment for minimizing TDS is site-specific and should be selected according to the physicochemical characteristics of the source water. Furthermore, optimization of peat water treatment should simultaneously consider TDS together with other key water quality parameters, particularly pH and electrical conductivity, to achieve overall treatment performance.

The non-linear, complex fluctuations observed in TDS across varying PAC dosages specifically the sharp increase at HL200-PAC40 followed by a distinct drop at HL200-PAC60 can be attributed to the dynamic equilibrium between chemical dissolution, aluminium hydrolytic speciation, and organic co-precipitation mechanisms [23]. At intermediate dosages such as HL200-PAC40, the heavy addition of hydrated lime (Ca(OH)₂) and PAC introduces a high concentration of free dissolved ions (Ca²⁺, Cl⁻, and mobile monomeric/oligomeric Al species) that temporarily exceed the quantity of precipitate formed, resulting in peak residual TDS levels [23]. However, as the PAC dosage increases to HL200-PAC60, the chemical environment favors the formation of highly charged polymeric hydrolytic species, such as Al₁₃ tridecameric polycations. These polymeric species possess high positive charge density and efficiently neutralize the negatively charged functional groups (carboxyl and phenolic) of dissolved humic and fulvic macromolecules. This charge neutralization triggers strong interparticle bridging and sweep flocculation, forming heavy, insoluble humic aluminium complexes (Al_n(OH)_m–humate) that rapidly precipitate out of solution. The physical removal of these dissolved organic–inorganic complexed ions from the aqueous phase effectively decreases the total concentration of residual mobile charge carriers, thereby explaining the sudden decline in TDS at the HL200-PAC60 configuration.

3.5 Effect of Coagulation–Flocculation on Conductivity

Two-way analysis of variance (ANOVA) showed that sampling location, chemical treatment, and their interaction significantly influenced the electrical conductivity (EC) of treated peat water ($p < 0.001$). Among the investigated factors, sampling location showed the greatest statistical effect ($F = 163196.51$), followed by treatment ($F = 28137.82$), while the location–treatment interaction was also highly significant ($F = 15321.49$; $p < 0.001$). These results indicate that both the geographical origin of the peat water and the applied chemical dosage jointly governed the electrical conductivity response during coagulation–flocculation. Furthermore, the statistical model showed excellent explanatory performance, with a coefficient of determination (R^2) of 99.99%, indicating that the experimental factors and their interaction explained virtually all observed variability in electrical conductivity.

Table 7. Two-Way ANOVA Results for Electrical Conductivity

Source of Variation	DF	F-value	p-value
Sampling Location	1	163196.51	<0.001
Treatment	4	28137.82	<0.001
Sampling Location × Treatment	4	15321.49	<0.001
Error	20	-	-

The dominant effect of sampling location suggests that peat waters collected from Sumatra and Kalimantan differed in their physicochemical characteristics before treatment, resulting in distinct conductivity responses following identical chemical additions. Electrical conductivity is primarily determined by the concentration and mobility of dissolved ions present in the aqueous phase. Therefore, regional differences in dissolved inorganic constituents, along with naturally occurring dissolved organic matter, may influence the residual ionic environment after coagulation–flocculation. Consequently, identical coagulant and alkaline dosages cannot be expected to produce equivalent conductivity values in peat waters originating from different peatland regions.

The Tukey honestly significant difference (HSD) test further confirmed significant differences among the location–treatment combinations. The highest mean electrical conductivity was obtained from HL200-PAC40 applied to Sumatra peat water ($401.00 \pm 1.00 \mu\text{S cm}^{-1}$), whereas the lowest value was observed for HL200-PAC20 applied to Kalimantan peat water ($115.93 \pm 0.25 \mu\text{S cm}^{-1}$). The remaining treatment combinations fell into distinct statistical groups (A-I), showing that changes in chemical dosage produced significantly different conductivity responses depending on the sampling location.

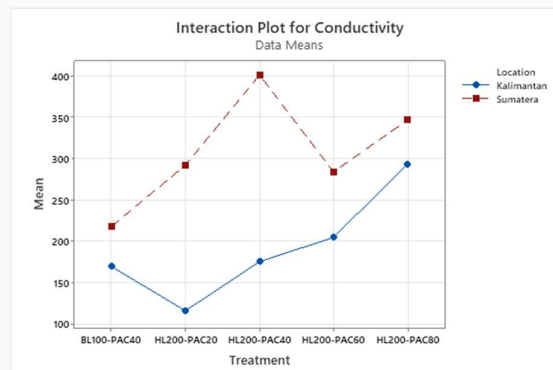
Table 8. Mean Electrical Conductivity ($\pm$ SD) and Tukey HSD Grouping for Each Sampling Location-Treatment Combination

Sampling Location	Treatment	Mean Conductivity ($\mu\text{S cm}^{-1}$) $\pm$ SD	Tukey Group*
Sumatra	HL200-PAC40	401.00 ± 1.00	A
Sumatra	HL200-PAC80	346.67 ± 0.58	B
Kalimantan	HL200-PAC80	293.67 ± 0.58	C
Sumatra	HL200-PAC20	292.00 ± 0.00	C
Sumatra	HL200-PAC60	284.00 ± 0.00	D
Sumatra	BL100-PAC40	218.00 ± 0.00	E
Kalimantan	HL200-PAC60	204.33 ± 0.58	F
Kalimantan	HL200-PAC40	175.43 ± 0.21	G
Kalimantan	BL100-PAC40	169.50 ± 0.50	H
Kalimantan	HL200-PAC20	115.93 ± 0.25	I

The observed conductivity changes are consistent with the chemical reactions occurring during coagulation–flocculation. Hydrated lime ($\text{Ca}(\text{OH})_2$) dissociates to release calcium (Ca^{2+}) and hydroxyl (OH^-) ions, whereas polyaluminium chloride (PAC) contributes aluminium hydrolysis species together with accompanying chloride ions to the solution. Adding these electrolytes generally increases the number of charge carriers available for electrical conduction. However, precipitation reactions during floc formation simultaneously influence conductivity, as dissolved ionic species become incorporated into aluminium hydroxide flocs or are otherwise removed from the aqueous phase. As a result, the final conductivity reflects a dynamic balance between the introduction of dissolved ions through chemical addition and their partial removal during coagulation and flocculation.

This behaviour was clearly observed in the treatment response patterns. In Sumatra peat water, electrical conductivity increased markedly from $292.00 \mu\text{S cm}^{-1}$ under HL200-PAC20 to $401.00 \mu\text{S cm}^{-1}$ under HL200-PAC40, followed by a substantial decrease to $284.00 \mu\text{S cm}^{-1}$ at HL200-PAC60 before increasing again to $346.67 \mu\text{S cm}^{-1}$ at HL200-PAC80. In contrast, Kalimantan peat water exhibited a more gradual increase in conductivity with increasing PAC dosage, rising from $115.93 \mu\text{S cm}^{-1}$ to $293.67 \mu\text{S cm}^{-1}$ across the same treatment range. These contrasting trends suggest that the balance between ion release and ion removal during coagulation-flocculation differed between the two peat water sources, most likely because of differences in their initial water chemistry and buffering characteristics.

The interaction plot (Figure 3) further supports the ANOVA findings by showing clearly non-parallel response curves for Sumatra and Kalimantan, confirming a significant interaction between sampling location and treatment. Sumatra peat water consistently exhibited higher conductivity than Kalimantan peat water across all treatment combinations, although both locations displayed a similar overall response pattern characterised by increasing conductivity at lower PAC dosages followed by changes at higher dosages. These findings indicate that the effectiveness of chemical treatment cannot be generalized across different peatland regions, as the same coagulant-alkalinity combination produced substantially different conductivity responses depending on the characteristics of the raw water.

**Fig 3.** Interaction Plot of Sampling Location and Treatment on Electrical Conductivity of Peat Water

From a practical perspective, evaluate electrical conductivity alongside pH and total dissolved solids when selecting optimum

coagulation-flocculation conditions for peat water treatment. Although increasing chemical dosage enhanced the ionic content of the treated water, all measured conductivity values remained within the range commonly reported for treated freshwater intended for potable water production. Overall, the findings demonstrate that optimization of coagulation-flocculation should be based on the specific physicochemical characteristics of the source water rather than applying a single chemical dosage universally across different peatland regions.

The conductivity profile closely followed the TDS trend because both parameters are governed by the concentration of dissolved ionic species remaining in solution after coagulation-flocculation. This strong correspondence indicates that changes in ionic composition resulting from chemical addition directly influenced both TDS and electrical conductivity.

From an operational perspective, the transient spikes in electrical conductivity under configurations such as HL200-PAC40 require careful evaluation regarding the long-term integrity of drinking water distribution infrastructure. Polyaluminium chloride contributes residual chloride ions (Cl^-), while lime dissolution adds calcium ions (Ca^{2+}) to the aqueous phase. Although the overall conductivity values (115.93 to 401.00 $\mu\text{S}/\text{cm}$) remain well within acceptable potable water guidelines, elevated concentrations of residual Cl^- and Ca^{2+} can increase the corrosive potential of the treated water, leading to localized pitting corrosion in metallic piping networks or scaling problems in distribution systems [24]. Therefore, optimizing the coagulant and lime dosage is critical not only to minimize chemical consumption and achieve proper pH levels, but also to prevent residual ionic accumulation that could jeopardize pipeline infrastructure over time [24].

4. CONCLUSION

This study demonstrated that the coagulation-flocculation performance of peat water treatment was significantly influenced by both sampling location and chemical treatment. Two-way analysis of variance confirmed that sampling location, treatment, and their interaction significantly affected pH, total dissolved solids (TDS), and electrical conductivity (EC), indicating that peat water from different geographical regions responded differently to identical treatment conditions. These findings emphasize that regional variations in peat water characteristics play an important role in determining coagulation performance and should therefore be considered during process optimization.

Among the evaluated treatment combinations, HL200-PAC80 produced pH values closest to the Indonesian drinking water standard (Permenkes No. 2 of 2023) for both Sumatra and Kalimantan peat water, whereas HL200-PAC20 applied to Kalimantan peat water resulted in the lowest residual TDS and EC. Conversely, higher chemical dosages tended to increase residual dissolved ions despite providing more favorable pH conditions, indicating that optimization should balance pH adjustment with the control of TDS and electrical conductivity rather than maximizing a single parameter. Overall, no single treatment combination simultaneously optimized all measured water quality parameters.

As a preliminary optimization phase, these findings provide essential foundational insights for tailoring coagulation-flocculation processes based on initial ionic responses and pH buffering dynamics, demonstrating that treatment strategies must adapt to source water chemistry rather than applying a universal dosage. A limitation of this study is that aggregate organic metrics specifically natural organic matter (NOM/DOC), color, and turbidity removal were not directly evaluated. Therefore, future research should build upon these baseline dosage configurations to systematically evaluate NOM and color removal efficiency, monitor residual aluminum levels, and test performance in pilot- or full-scale operations to support practical water treatment implementation across Indonesian peatlands.

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