American Journal of Applied Chemistry
2025, Vol. 13, No. 5, pp. 129-138
https://doi.org/10.11648/j.ajac.20251305.11

SciencePG
Science Publishing Group

Research Article

Comparative Efficiency of Coagulation-Flocculation and Electrocoagulation for Turbidity Removal in Surface Water Treatment: A Case Study of the Ayédjoko Dam, Benin

Akuemaho Virgile Onesime Akowanou*, Guercia-Divine Mabika-Soka, Calixte Akotegnon, Mohamed Moukorab Aremou Daouda, Martin Pepin Aina

Institut National de l'Eau, Abomey-Calavi University, Abomey-Calavi, Benin Republic

Abstract

This study provides a comparative assessment of conventional chemical coagulation-flocculation and electrocoagulation processes for the treatment of surface water from the Ayédjoko Dam, Benin. Response surface methodology (RSM) with a centered composite design (CCD) was employed to optimize operational parameters and maximize turbidity removal. The chemical coagulation-flocculation process using aluminum sulfate achieved a maximum turbidity reduction of 92.06%, while the electrocoagulation process with aluminum electrodes reached 98.23% under optimal conditions. Analyses of pH, coagulant dosage, and applied current demonstrated their strong influence on treatment performance and water quality improvements. Both processes were effective; however, electrocoagulation showed clear advantages by reducing chemical consumption and sludge generation, while maintaining compliance with local water quality standards. These benefits underscore its potential as a sustainable alternative for water treatment, particularly in resource-limited contexts. The findings not only confirm the feasibility of electrocoagulation but also highlight its suitability for integration into decentralized water treatment systems. Furthermore, the study emphasizes the importance of optimizing key parameters to enhance treatment efficiency and minimize environmental impacts. Overall, this research contributes to the growing body of evidence supporting electrocoagulation as a viable, cost-effective, and environmentally friendly technology for surface water treatment. It also provides practical insights for policymakers and water managers seeking to develop sustainable strategies for improved access to safe water in developing countries.

Keywords

Surface Water, Coagulation-Flocculation, Electrocoagulation, Response Surface Methodology

1. Introduction

Access to safe and potable water is a critical challenge faced by many regions around the world, particularly in developing countries where water resources are under increasing stress from population growth, industrialization, and agricultural practices [1-5]. In many African nations, surface water bodies such as dams, lakes, and rivers are primary

*Corresponding author: virgile.akowanou@uac.bj (Akuemaho Virgile Onésime Akowanou)

Received: 9 August 2025; **Accepted:** 18 August 2025; **Published:** 2 September 2025

sources of drinking water [6-9]. However, these sources are often subject to pollution from both natural processes and human activities, leading to high turbidity and contamination by organic and inorganic pollutants [10-15].

In Benin Republic, the Ayédjoko Dam is a crucial water supply source for local communities and is currently used by the national water treatment company, SONEB, for potable water distribution. Water from this reservoir frequently exhibits turbidity levels that exceed acceptable standards, probably due to suspended particles, colloids, and other contaminants that result from runoff, industrial discharges, and agricultural activities. Elevated turbidity not only affects the aesthetic quality of the water but also poses serious health risks, as it can harbor pathogenic microorganisms and interfere with disinfection processes [16, 17].

Traditional water treatment methods have relied heavily on chemical coagulation-flocculation, a process that destabilizes colloidal particles through the addition of coagulants such as aluminum sulfate. Although this method is widely used and generally effective, it requires doses of chemicals, which can lead to excessive sludge production and increased operational costs. Moreover, the disposal of chemically induced sludge poses environmental and logistical challenges, particularly in resource-limited settings.

In recent years, electrocoagulation has emerged again as a promising water treatment technology [18-20]. Unlike conventional methods, electrocoagulation generates coagulant species in situ through the electrolytic dissolution of sacrificial electrodes (typically made of aluminum or iron). This approach offers several advantages: it reduces the need for external chemical inputs, minimizes sludge production, and allows for a more controlled and adaptable treatment process. Furthermore, electrocoagulation has been shown to effectively remove turbidity and other contaminants, making it a viable option for improving water quality in areas where traditional methods may be less sustainable.

This study aims to conduct a comparative evaluation of chemical coagulation-flocculation and electrocoagulation for the treatment of surface water from the Ayédjoko Dam. By employing response surface methodology (RSM) with a centered composite design (CCD), the research systematically optimizes key operational parameters to maximize turbidity removal. Ultimately, the findings are expected to contribute valuable insights into the development of more sustainable and cost-effective water treatment strategies, particularly for regions with limited resources and growing water quality challenges.

The broader implications of this work extend to environmental management and public health, underscoring the importance of adopting innovative technologies to ensure a reliable supply of safe drinking water in developing regions.

2. Materials and Methods

2.1. Study Area and Sample Collection

2.1.1. Study Area

The research was conducted using the raw water from Gobé drinking water treatment plant. The water comes from the Ayédjoko Dam, located in Savè region, Benin Republic. The dam is located between 2°10' and 2°48' East longitude and between 7°42' and 8°45' North latitude. This dam is a crucial water supply source for local communities and is known to exhibit high turbidity levels due to natural runoff, agricultural discharge, and other anthropogenic influences.

2.1.2. Sample Collection

Surface water samples were collected from a designated intake point on the dam where water is drawn for treatment. Collection followed standard protocols to ensure representativeness:

Samples were taken during early morning hours to minimize diurnal variations.

Pre-cleaned, high-density polyethylene bottles were used to collect samples. Bottles were rinsed with the sample water before collection.

Samples were transported in insulated coolers to the laboratory for immediate analysis to prevent any changes in water quality parameters.

2.2. Experimental Design and Setup

To compare the two treatment processes, experiments were conducted in parallel under controlled laboratory conditions. A detailed optimization was performed on classical coagulation-flocculation and electrocoagulation, using response surface methodology (RSM) specially a central composite design (CCD).

A central composite design (CCD) comprising 13 experimental runs was applied to optimize the processes. The design matrix was generated in The Minitab® 17.1 software using a full three-level factorial scheme. The key factors affecting the performance of chemical coagulation and electrocoagulation were identified and are summarized in the tables belows:

Table 1. Experimental ranges and levels of the independent variables used during coagulation - flocculation experiments.

Variables (Factors)	Levels and ranges		
	Low (-1)	Middle (0)	High (+1)
Coagulant dose (mg/L)	20	50	120
pH	5.5	6.5	7.5

Table 2. Experimental ranges and levels of the independent variables used during electrocoagulation experiments.

Variables (Factors)	Levels and ranges		
	Low (-1)	Middle (0)	High (+1)
Coagulant dose (mg/L)	13.2	33.01	79.2
Electrolysis time (min)	2	5	10

Turbidity was used as key parameter to compare the efficiency of classic coagulation versus coagulation - flocculation.

2.2.1. Chemical Coagulation-Flocculation (CC)

Coagulant: Aluminum sulfate ($Al_2(SO_4)_3$ 18H_2O) was chosen based on its widespread use in water treatment. The reagent was prepared in a stock solution and diluted to the required concentrations.

Experimental Setup:

Batch Tests: A series of batch tests were conducted in 1-liter glass beakers. Flocculator Stuart Flocculator SW6 was used during the experimentations.

Mixing: Rapid mixing was initiated immediately upon addition of the coagulant to ensure even dispersion. This was achieved using a mechanical stirrer at 150 rpm for 5 minutes.

Flocculation: After rapid mixing, the stirring speed was reduced at 30 rpm for 15 minutes.

Sedimentation: Following flocculation, the mixtures were allowed to settle undisturbed for 30 minutes. Samples were then collected from the supernatant for turbidity and chemical analysis.

Parameter Optimization:

Variables: Coagulant dosage and pH were systematically varied. The pH was adjusted using dilute hydrochloric acid or sodium hydroxide.

2.2.2. Electrocoagulation (EC)

Reactor Configuration:

A bench-scale electrocoagulation reactor was constructed using a pair of aluminum electrodes arranged in a parallel configuration. The electrocoagulation (EC) pilot unit used in this study consisted of (Figure 1):

A power generator capable of delivering a maximum current of 3.26 A at a voltage of 30 V.

A magnetic stirrer

A batch-type reactor

Two aluminum electrodes

The reactor consisted of a plexiglass tank with a thikness of 4 mm and a working volume of 1 L, equipped with two electrode holders. An overflow of 5 cm was designed to facilitate the retention of less dense sludge. The treatment was carried out using two identical electrodes. The surface of the electrodes was 0.8 dm^2. The electrodes were positioned at 2 cm from the bottom of the reactor to ensure proper mixing of the effluent in the reactor. The reactor used is designed to allow variation of the inter-electrode distance from 1 cm to 3 cm.

The electrode used was an aluminum alloy AGS/6060 from Euralliage, which exhibits excellent corrosion resistance.

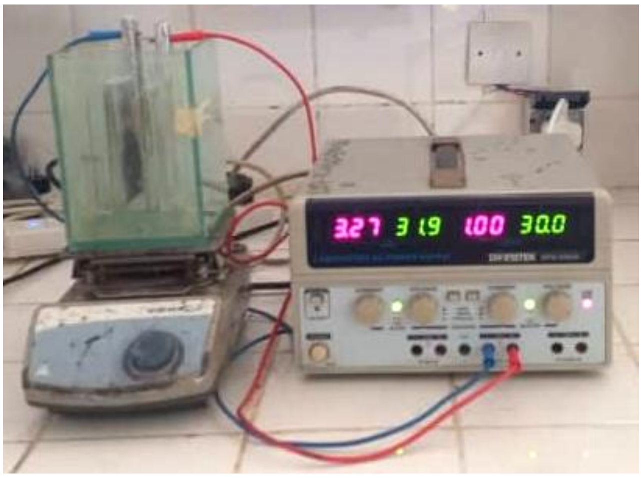

Figure 1. Electrocoagulation setup.

Table 3. Average composition of AGS aluminum alloy according to the supplier Euralliage.

Metal	Al	Si	Fe	Cu	Mn	Mg	Cr
Proportion (%)	98.22	0.45	0.20	0.10	0.10	0.48	0.05

Operational Parameters:

The operational parameters used are as follow:

Current Intensity: Experiments were conducted at various current intensities to determine the optimal amperage for efficient coagulation.

Electrolysis Duration: The treatment time was varied (ranging from 10 to 30 minutes) to optimize the generation of coagulant species.

The electrodes were positioned at a fixed distance initially, with electrode spacing later optimized through the CCD.

The determination of the actual dose of dissolved coagulant was based on the Faraday's law, according to the formula:

$$R_a = \frac{m_{exp}}{m_{th}} \quad (1)$$

With:

1) Ra: anodic efficiency
2) $m_{th:}$ Theoretical mass dissolved according to Faraday's law
3) m_{exp}: Experimental dissolved mass

The theorical mass dissolved according to Faraday is obtained based on the following formula:

$$m_{th} = \frac{I.t.M}{n.F} \quad (2)$$

With:

1) M: Molar mass of aluminum (g/mol)
2) I: Current applied to the electrode terminals (A)
3) n: Number of electrons involved in the considered reaction
4) F: Faraday constant (C/mol)
5) t: Electrolysis duration (s)

The anodic efficiency of the electrodes was determined as 1.18 in a previous experiment.

3. Results

This section presents the experimental outcomes for both treatment processes and interprets the findings through a detailed comparative analysis.

3.1. Optimization of Coagulation-Flocculation

The results obtained after implementing the experimental design for coagulation-flocculation are presented in Table 4.

Table 4. Result from surface response design implementation.

Standard runs	Factor A: Dose (mg/l)	Factor B: pH	Response Turbidity removal (%)
1	-1	-1	79.50
2	0	-1	83.99
3	-1	+1	87.30
4	+1	-1	82.10
5	+1	1	87.50
6	-1	-1	82.03
7	+1	+1	87.48
8	0	-1	86.30
9	-1	1	87.40
10	-1	0	90.11
11	0	0	92.06
12	+1	0	90.40

Standard runs	Factor A: Dose (mg/l)	Factor B: pH	Response Turbidity removal (%)
13	0	+1	92.06

The polynomial equation resulting from the implementation of the experimental design is as follow:

Turb (%) = $-152.5 + 69.97X_1 + 0.2513X_2 - 5.143X_1^2 - 0.001755X_2^2$

With:

X_1: pH

X_2: Coagulant dose

Figures 2 and 3 present respectively the response surface and contour plots of turbidity removal percentage as a function of coagulant dose and pH.

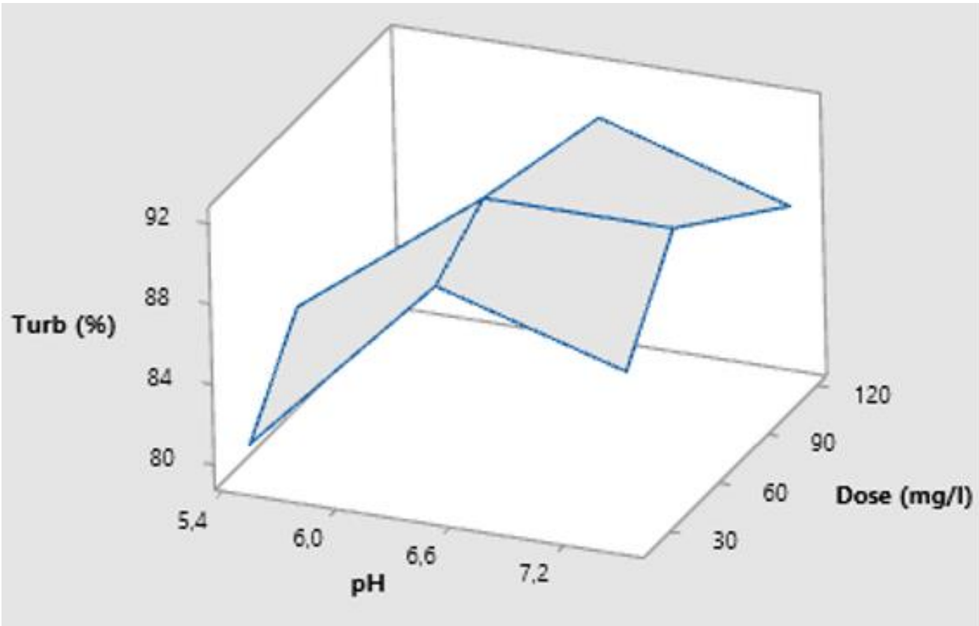

Figure 2. *Response surface of plot of turbidity removal percentage as a function of coagulant dose and pH.*

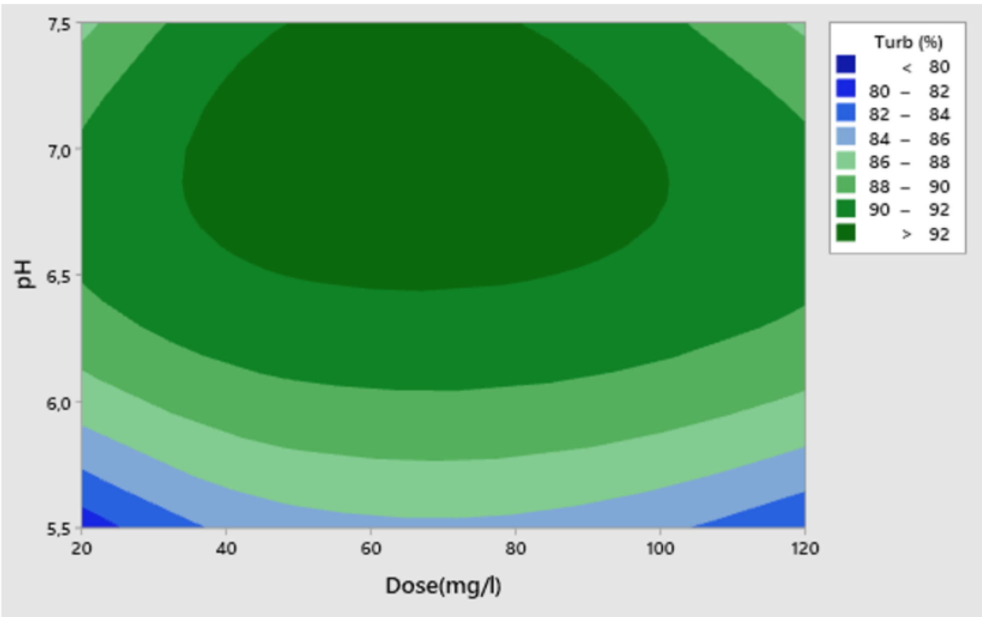

Figure 3. *Contour plot of turbidity removal percentage as a function of coagulant dose and pH.*

According to the results, a turbidity removal efficiency above 92% can be achieved at coagulant doses ranging from 40 mg/L to 100 mg/L and a pH between 6.5 and 7.5. In contrast, the efficiency does not exceed 80% at doses of 20-40 mg/L with a pH of 5.5, as well as for coagulant doses above 100 mg/L with a pH of 5.5.

The optimum obtained using minitab software is presented as follows:

Table 5. Result from surface response design implementation.

Optimal pH	Optimal dose	Measured response (turbidity removal)
6.8	75.5 mg/l	92.06%

3.2. Optimization of Electrocoagulation

The results obtained after implementing the experimental design for electrocoagulation are presented in Table 6.

Table 6. Result from surface response design implementation.

Standard runs	Factor A: Dose (mg/l)	Factor B: pH	Response Turbidity removal (%)
1	+1	1	78.35
2	-1	-1	87.68
3	+1	-1	80.50
4	0	+1	89.66
5	-1	+1	83.25
6	0	-1	87.45
7	0	0	98.23
8	+1	0	92.10
9	+1	-1	80.35
10	-1	0	96.35
11	+1	+1	78.35
12	-1	-1	87.77
13	-1	+1	85.87

The polynomial equation resulting from the implementation of the experimental design is as follow:

$$Turb\ (\%) = 67.22 + 8.765X_1 + 0.419X_2 + 0.7468X_1^2 - 0.000664X_2^2$$

X_1: Electrolysis time

X_2: Coagulant dose

Figures 4 and 5 present respectively the response surface and contour plots of turbidity removal percentage as a function of coagulant dose and Electrolysis time.

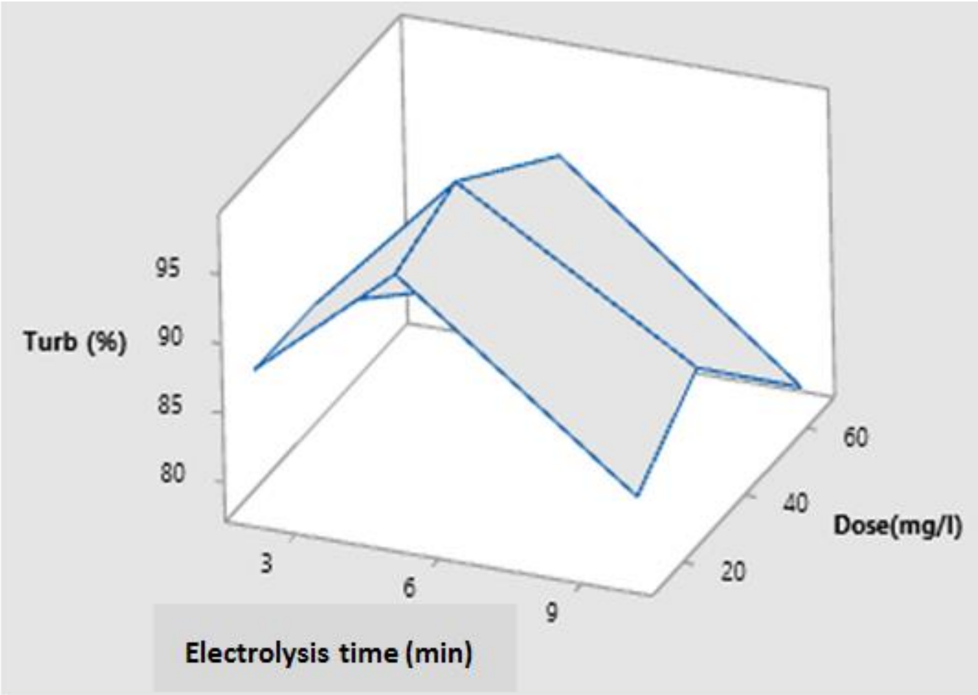

Figure 4. Response surface of plot of turbidity removal percentage as a function of coagulant dose and Electrolysis time.

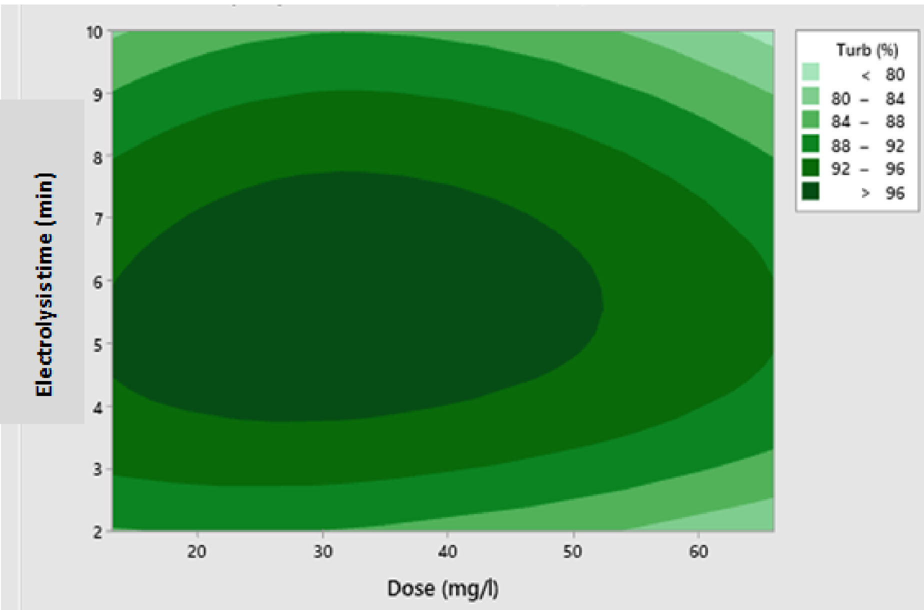

Figure 5. Contour plot of turbidity removal percentage as a function of coagulant dose and Electrolysis time.

The optimum obtained using minitab software is presented as follows:

Table 7. Result from surface response design implementation.

Optimal Electrolysis time (min)	Optimal dose	Measured response (turbidity removal)
5	33.01 mg/l	98.23%

3.3. Comparison Between Coagulation - Flocculation and Electrocoagulation

Table 8 present the comparative results between coagulation - flocculation and electrocoagulation. Under the optimized conditions determined by the CCD-based RSM, the chemical coagulation-flocculation process achieved significant reductions in turbidity, but electrocoagulation was relatively better.

Table 8. Comparison between Coagulation - flocculation and electrocoagulation.

Parameters	Raw water	Coagulation - Floculation	Electrocoagulation
Coagulant dose (mg/L)	-	50	33.01
pH	7.4	6.5	7.32
Temperature (℃)	25.57	26.5	26.9
Turbidity Removal (%)	14.5	92.06	98.23

4. Discussion

Under the optimized conditions determined by the CCD-based RSM, the chemical coagulation-flocculation process achieved significant reductions in turbidity. Specifically, the maximum turbidity removal reached approximately 92.06%. The optimal performance was observed at a pH range between 5 and 7, which is consistent with the known precipitation behavior of aluminum hydroxide. At this pH range, aluminum sulfate undergoes hydrolysis to form insoluble flocs that efficiently adsorb and remove colloidal particles.
Experiments demonstrated that even small variations in coagulant dosage significantly affected the turbidity removal efficiency. Figure 3 illustrates the relationship between aluminum sulfate dosage and turbidity reduction. Although higher dosages improved removal efficiency, they also resulted in an increased volume of sludge. So careful dosage control is necessary to avoid exceeding safe residual aluminum levels in treated water.

In contrast to chemical coagulation, the electrocoagulation process demonstrated superior performance, with a maximum turbidity reduction of up to 98.23%. The experimental design allowed for precise control of electrical parameters, and the optimization revealed that:

1) A specific combination of current intensity and electrolysis time was critical for optimal coagulant generation. These parameters directly influenced the rate of aluminum dissolution at the anode and, consequently, the in-situ production of coagulant species.
2) Reduced spacing between electrodes enhanced the electric field strength, promoting more efficient coagulant generation and rapid floc formation.
3) When comparing the two processes, several critical distinctions emerge:
4) Electrocoagulation consistently outperformed chemical coagulation-flocculation in turbidity removal. The higher efficiency observed with EC (98.23% vs. 92.06%) is attributed to the continuous and controlled generation of coagulant species, as well as enhanced interaction with suspended particles.
5) The coagulation floculation process required high dosages of aluminum sulfate, leading to increased operational costs and significant sludge production. Conversely, the EC process minimized external chemical inputs, reducing both chemical consumption and sludge handling costs.

The findings from this study underscore the potential of electrocoagulation as an effective alternative to conventional chemical coagulation-flocculation. With its superior turbidity removal efficiency and reduced chemical and sludge management requirements, electrocoagulation is particularly advantageous in regions where resource constraints and environmental impacts are significant considerations. Additionally, the ability to fine-tune process parameters in response to fluctuating water quality makes electrocoagulation an adaptable solution for field applications.

While the laboratory-scale results are promising, the challenges of scaling up electrocoagulation—such as ensuring a stable power supply and managing initial capital costs—must be addressed in future research. Pilot-scale studies and long-term evaluations will be crucial in establishing the full economic and environmental benefits of this technology.

Moreover, despite these promising outcomes, several challenges remain. The initial capital investment for electrocoagulation systems and the requirement for a stable power supply can present barriers to widespread implementation. Addressing these limitations will require further pilot-scale studies and the exploration of alternative energy sources, such as solar power, to enhance system sustainability and economic viability.

5. Conclusions

This study provides a comprehensive comparative evaluation of chemical coagulation-flocculation and electrocoagulation for treating surface water from the Ayédjoko Dam, Benin Republic. The optimized experiments, based on a robust CCD-driven response surface methodology, revealed that both treatment processes are capable of achieving significant turbidity removal, with electrocoagulation consistently outperforming the conventional chemical approach. Specifically, the chemical coagulation-flocculation process achieved a maximum turbidity reduction of approximately 92.06%, while electrocoagulation reached up to 98.23% under optimal conditions.

The superior performance of the electrocoagulation process can be attributed to its unique mechanism of in situ coagulant generation. This method not only enhances the destabilization of colloidal particles but also reduces the need for external chemical dosing, thereby lowering operating costs and minimizing sludge production. Such advantages are particularly critical in resource-constrained environments where efficient water treatment is paramount.

Abbreviations

CDD	Central Composite Design
DOE	Design of Experiment
NTU	Nephelometric Turbidity Unit
RSM	Response Surface Methodology

Author Contributions

Akuemaho Virgile Onesime Akowanou: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing

Guercia-Divine Mabika-Soka: Data curation, Formal Analysis

Calixte Akotegnon: Resources, Validation

Mohamed Moukorab Aremou Daouda: Methodology

Martin Pepin Aina: Supervision

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] D. Lee, J. M. D. Gibson, J. Brown, J. Habtewold, H. M. Murphy, Burden of disease from contaminated drinking water in countries with high access to safely managed water: A systematic review, Water Res 242 (2023). https://doi.org/10.1016/j.watres.2023.120244

[2] S. Mbiankeu Nguea, Uncovering the linkage between sustainable development goals for access to electricity and access to safely managed drinking water and sanitation services, Soc Sci Med 345 (2024). https://doi.org/10.1016/j.socscimed.2024.116687

[3] T. P. Maluleke, S. Dube, E. D. Sunkari, A. A. Ambushe, Assessment of borehole water quality in Nwadzekudzeku village, Giyani, Limpopo Province, South Africa: Implication for potential human health risks, Journal of Trace Elements and Minerals 11 (2025). https://doi.org/10.1016/j.jtemin.2024.100206

[4] A. R. Yang, J. M. Bowling, C. E. Morgan, J. Bartram, G. L. Kayser, Predictors of household drinking water E. coli contamination: Population-based results from rural areas of Ghana, Malawi, Mozambique, Niger, Rwanda, Uganda, and Zambia, Int J Hyg Environ Health 264 (2025). https://doi.org/10.1016/j.ijheh.2024.114507

[5] K. H. Nguyen, D. J. Operario, M. E. Nyathi, C. L. Hill, J. A. Smith, R. L. Guerrant, A. Samie, R. A. Dillingham, P. O. Bessong, E. T. Rogawski McQuade, Seasonality of drinking water sources and the impact of drinking water source on enteric infections among children in Limpopo, South Africa, Int J Hyg Environ Health 231 (2021). https://doi.org/10.1016/j.ijheh.2020.113640

[6] A. Adewuyi, Q. Li, Emergence of microplastics in African environmental drinking water sources: A review on sources, analysis and treatment strategies, Journal of Hazardous Materials Advances 16 (2024) 100465. https://doi.org/10.1016/j.hazadv.2024.100465

[7] M. W. Lema, Contamination of urban waterways: A mini-review of water pollution in the rivers of East Africa's major cities, HydroResearch 8 (2025) 307-315. https://doi.org/10.1016/j.hydres.2024.11.004

[8] A. V. O. Akowanou, M. P. Aina, Ceramic Water Filter as a Household Water Treatment System, in: Encyclopedia of the UN Sustainable Development Goals, 2022: pp. 61-71. https://doi.org/10.1007/978-3-319-95846-0_189

[9] A. V. O. Akowanou, M. P. Aina, L. Groendijk, B. K. Yao, Household Water Treatment in Benin: Current / Local Practices, European Journal of Scientific Research 142 (2016) 246-256.

[10] A. Nkwasa, C. James Chawanda, M. Theresa Nakkazi, T. Tang, S. J. Eisenreich, S. Warner, A. van Griensven, One third of African rivers fail to meet the 'good ambient water quality' nutrient targets, Ecol Indic 166 (2024). https://doi.org/10.1016/j.ecolind.2024.112544

[11] M. Hossein, A. S. Ripanda, Pollution by Antimicrobials and Antibiotic Resistance Genes in East Africa: Occurrence, Sources, and Potential Environmental Implications, Toxicol Rep (2025) 101969. https://doi.org/10.1016/j.toxrep.2025.101969

[12] E. S. Okeke, C. E. I. Nwankwo, T. P. C. Ezeorba, M. O. Ogugofor, C. O. Nwuche, Antibiotic residues and antibiotic resistance genes in African water systems: Implications for safe drinking water, aquatic ecosystems, and Sustainable Development Goals, Journal of Water Process Engineering 69 (2025). https://doi.org/10.1016/j.jwpe.2024.106636

[13] W. Samuels, A. Awe, C. Sparks, Microplastic pollution and risk assessment in surface water and sediments of the Zandvlei Catchment and estuary, Cape Town, South Africa, Environmental Pollution 342 (2024). https://doi.org/10.1016/j.envpol.2023.122987

[14] A. Ripanda, M. Hossein, M. J. Rwiza, E. C. Nyanza, J. R. Selemani, S. Nkrumah, R. Bakari, M. S. Alfred, R. L. Machunda, S. A. H. Vuai, Combatting toxic chemical elements pollution for Sub-Saharan Africa’s ecological health, Environmental Pollution and Management 2 (2025) 42-62. https://doi.org/10.1016/j.epm.2025.01.003

[15] M. Hossein, M. J. Rwiza, E. C. Nyanza, R. Bakari, A. Ripanda, S. Nkrumah, J. R. Selemani, R. L. Machunda, Fluoride contamination a silent global water crisis: A Case of Africa, Sci Afr 26 (2024). https://doi.org/10.1016/j.sciaf.2024.e02485

[16] Z. Yu, Y. Xie, X. Li, W. Liu, J. L. Han, C. Zheng, Q. Zheng, X. Zhao, A. Wang, Why the disinfection efficiency of ultraviolet radiation may become unsatisfactory at low suspended solid concentrations: The mechanism of extracellular polymeric substances secretion induced by different particles, Water Res 274 (2025). https://doi.org/10.1016/j.watres.2025.123122

[17] U. Alkan, B. Şengül Topaç, N. Denizli, Efficiencies of solar light, solar/H_2O_2 and solar photo-fenton processes for disinfection of turbid wastewaters, Desalination Water Treat 80 (2017) 149-155. https://doi.org/10.5004/dwt.2017.21003

[18] N. Abdul Rahman, C. Jose Jol, A. Albania Linus, S. N. L. Taib, A. Parabi, C. Kwong Ming, A. S. L. Parabi, A. James, N. S. Samsol, S. B. John, A. A. Jitai, D. F. A. Abang Abdul Hamid, Unveiling challenges of aluminium electrode fouling and passivation in electrocoagulation treatment system for sustainable water management of coastal Borneo peatlands: A focused review, Environ Res 270 (2025). https://doi.org/10.1016/j.envres.2025.121005

[19] M. Bharti, P. P. Das, M. K. Purkait, A review on the treatment of water and wastewater by electrocoagulation process: Advances and emerging applications, J Environ Chem Eng 11 (2023). https://doi.org/10.1016/j.jece.2023.111558

[20] I. García, L. F. Castañeda, J. L. Nava, O. Coreño, Continuous electrocoagulation-flocculation-sedimentation process to remove arsenic, fluoride, and hydrated silica from drinking water, Journal of Water Process Engineering 69 (2025). https://doi.org/10.1016/j.jwpe.2024.106571