NIPES - Journal of Science and Technology Research
www.nipes.org

Evaluation of Banana Leaf Powder (BLP) and Sudfloc Combinations as Coagulants for Medium Turbidity Surface Water Treatment

O. M. Ojo
Department of Civil and Environmental Engineering, the Federal University of Technology, Akure, PMB 704, Ondo State, Nigeria

Article Info

Keywords: *BLP, Sudfloc, coagulation, turbidity reduction, sustainable water treatment*

Received 3 January 2025
Revised 11 February 2025
Accepted 12 February 2025
Available online 5 March 2025

https://doi.org/10.37933/nipes/7.1.2025.10

eISSN-2682-5821, pISSN-2734-2352
© 2025 NIPES Pub. All rights reserved.

Abstract

This study evaluated the performance of banana leaf powder (BLP) in combination with Sudfloc as coagulants for the treatment of medium turbidity surface water. The research investigated the efficiency of BLP-Sudfloc blends in reducing turbidity, colour, and total dissolved solids (TDS) while maintaining pH stability. Jar tests were conducted with varying ratios of BLP and Sudfloc. The results revealed superior water quality improvements, particularly at a 25%-75% blend which achieved turbidity reductions to 0.49 NTU and colour reductions to 5 TCU. Advanced analytical techniques (SEM-EDS and XRD) revealed the porous structure and favorable elemental composition of BLP, alongside its crystalline characteristics, which contribute to its high adsorption and coagulation efficiency. The findings of this study established the synergistic potential of combining natural and chemical coagulants for sustainable water treatment.

This article is open access under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

1. Introduction

Water treatment technologies play a crucial role in ensuring access to clean and safe water, particularly in regions with limited resources [1, 2, 3]. Among these technologies, coagulation remains one of the most effective processes for reducing turbidity, colour, and suspended solids by introducing coagulants that promote particle aggregation [4, 5, 6, 7]. Conventional chemical coagulants, such as Aluminium Sulphate (Alum) and Polyaluminium Chloride (Sudfloc), have demonstrated high efficiency in water treatment applications. However, their widespread use has raised concerns regarding cost, environmental impact, and potential health risks, leading to a growing demand for more sustainable and eco-friendly alternatives [8, 9]. Sudfloc, a cationic polyelectrolyte commonly employed in water treatment, effectively forms stable flocs that enhance the removal of contaminants. Despite its effectiveness, its high cost remains a significant drawback, limiting its accessibility in low-income communities [9]. As a result, the exploration of natural coagulants derived from plants and other biodegradable materials has gained momentum as a sustainable alternative to conventional coagulants [7, 10, 11, 12]. These natural coagulants offer promising advantages such as biocompatibility, lower environmental impact, and local availability, making them an attractive option for resource-limited settings. Their integration into water treatment systems presents an opportunity to enhance cost-effectiveness while reducing the reliance on synthetic chemicals. The utilization of banana leaves, a readily available agricultural byproduct, as a natural coagulant aligns with global efforts toward resource recovery and sustainable waste recycling [13, 14, 15]. Natural coagulants offer several advantages, including biocompatibility, low toxicity, and local availability, making them particularly suitable for water treatment in resource-limited communities [16, 17, 18]. Their widespread adoption could contribute to reducing dependence on conventional chemical coagulants, which often pose environmental and health concerns. Moreover, leveraging agricultural waste for water treatment supports circular economy principles by transforming waste materials into valuable resources for environmental sustainability.

Despite their numerous benefits, natural coagulants face challenges such as dosage optimization which must be addressed to ensure their large-scale applicability [19, 20]. The innovative combination of banana leaf powder (BLP) with Sudfloc seeks to overcome these limitations by integrating the efficiency of chemical coagulants with the eco-friendly properties of natural alternatives. This synergistic approach is expected to enhance coagulation performance while reducing chemical usage and minimizing residual sludge, ultimately contributing to a more sustainable and effective water treatment process.

In this study, efficacy of BLP in combination with Sudfloc is evaluated, with focus on its potential as an eco-friendly coagulant for medium turbidity water.This research adopts a comprehensive approach to compare the performance of BLP and Sudfloc combinations against standard water quality parameters, including turbidity, pH, colour, total dissolved solids (TDS), and conductivity. By integrating advanced analytical techniques such as Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD), the study also sheds light on the microstructural properties that underpin the coagulation mechanism.

2.0 Methodology

2.1 Collection of Natural Coagulants

Fresh samples of banana leaves were obtained within the Federal University of Technology, Akure, Ondo State. The chemical coagulant Sudfloc was procured from the Lagos State Water Corporation.

2.2 Processing of Natural Coagulants

The collected leaves were cut into small pieces, washed with distilled water and sun-dried for seven days to a fine brown colour and crunchy texture. The drying of the leaves was done as suggested by [21]. The dried leaves were further oven-dried for 24 hours at 100°C to completely remove moisture. Plates 1 and 2 shows sun-drying and oven-drying of the banana leaves. Pulverization of the dried leaves into fine powder was carried out using a ball mill, with the resulting powder sieved through a 425 μm mesh. The fine powders were stored in airtight containers for subsequent experimental use.

Plate 1: Sun drying of leaves

Plate 2: Oven drying

2.3 Preparation of Coagulant Solutions

A stock solution of 10 mg/L was prepared by dissolving 2.5 g of the BLP in 250 mL of distilled water. The mixture was stirred vigorously for 20 minutes and then filtered through 110 mm filter paper. The filtrates were stored in clean, capped bottles for jar testing and water quality analysis. Sudfloc mixture was prepared by diluting 1 mL of concentrated Sudfloc in 1 L of distilled water and allowing it to rest for 24 hours.

2.4 Raw Water Sample Collection

Raw water samples were sourced from the Ogun River tributary in Lagos State, representing medium turbidity conditions (45-50 NTU). Five liters of water were drawn directly from the raw water inlet chamber of the Lagos State Water Corporation's Iju Waterworks. Samples were transported to the laboratory immediately and analyzed for initial water quality parameters, including pH, turbidity, colour, total dissolved solids (TDS), and conductivity.

2.5 Water Quality Analysis

2.5.1 pH Measurement

The pH was determined using the Bromothymol Blue Indicator method. Five milliliters of sample were mixed with three drops of indicator, and the resulting colour was compared using a Lovibond comparator with a bromothymol blue disc.

2.5.2 Colour Measurement

Water colour was assessed using the American Public Health Association (APHA) colour scale with a Lovibond Nessleriser. Samples were matched against a comparator disc to determine colour intensity in true colour units (TCU).

2.5.3 Turbidity

A Nephelometric turbidity meter was used to measure turbidity. After calibrating the instrument with distilled water, raw and treated water samples were analyzed, and turbidity readings were recorded.

2.5.4 Total Dissolved Solids (TDS) and Conductivity

TDS and conductivity were measured using an Adwa AD-31 EC/TDS meter. The probe was immersed in the water sample, and the readings were recorded for different coagulant dosages.

2.6 Jar Testing

Jar tests were conducted to determine the optimum dosages of coagulants. Five 1 L jars, labeled A through E, were prepared with varying ratios of natural coagulants to Sudfloc:

- **Jar A:** 100% BLP (50 ppm) + 0% Sudfloc
- **Jar B:** 75% BLP (37.5 ppm) + 25% Sudfloc (5 ppm)
- **Jar C:** 50% BLP (25 ppm) + 50% Sudfloc (10 ppm)
- **Jar D:** 25% BLP (12.5 ppm) + 75% Sudfloc (15 ppm)
- **Jar E:** 0% BLP + 100% Sudfloc (20 ppm)

Each jar was filled with 1 L of raw water, and the coagulants were added according to the predefined ratios. The mixtures were stirred at 100 rpm for 1 minute (rapid mixing) and at 40 rpm for 15 minutes (slow mixing). The samples were then allowed to settle for 30 minutes before the supernatant was collected for post-treatment analysis.

2.7 Advanced Analytical Techniques

2.7.1 Scanning Electron Microscopy (SEM)

SEM analysis was conducted to examine the morphological properties of the BLP coagulant. The sample was mounted on metal stubs using adhesive tape, coated with gold, and analyzed under a scanning electron microscope at an accelerating voltage of 15 kV. Energy Dispersive Spectroscopy (EDS) was used in conjunction with SEM to determine the elemental composition of the BLP sample.

2.7.2 X-Ray Diffraction (XRD)

XRD analysis was performed to investigate the crystalline structure of the coagulant. Diffraction patterns were analyzed to correlate structural properties with coagulation performance.

2.8 Statistical Analysis

The experimental results were systematically analyzed and presented in graphical form using Microsoft Excel. The graphical representations enabled a clear visualization of trends and variations in the data thereby enhancing the comparative assessment of treatment efficiency. These analyses provided a robust evaluation of the efficiency of BLP-Sudfloc combinations in water treatment.

3. Results and Discussion

3.1 Effect of Coagulant Dosages on Water Quality

3.1.1 Turbidity Reduction

The BLP-Sudfloc coagulation on the surface water is shown in Figure 1. The BLP demonstrated significant turbidity reduction, with its best performance observed at the 25%-75% banana-to-Sudfloc ratio (Jar D). Turbidity decreased from an initial value of 44.9 NTU to 0.49 NTU, surpassing the efficiency of the pure chemical coagulant (Jar E). This reduction highlights the synergistic effect of combining natural and chemical coagulants. The performance of BLP as a natural coagulant, particularly when combined with Sudfloc, aligns with findings from similar studies on natural coagulants. [22] reported turbidity removal efficiency of 74.5%, which is lower than the 93.1% efficiency achieved with alum in the same study. [23] demonstrated that plant-based coagulants such as *Moringa oleifera* and aloe vera effectively reduce turbidity and colour in water. However, the turbidity reduction achieved in this study—from 44.9 NTU to 0.49 NTU at optimal dosage—is superior to the 2-5 NTU range commonly reported in the literature for Moringa-based coagulants. This highlights the enhanced efficiency of BLP when combined with a chemical coagulant.

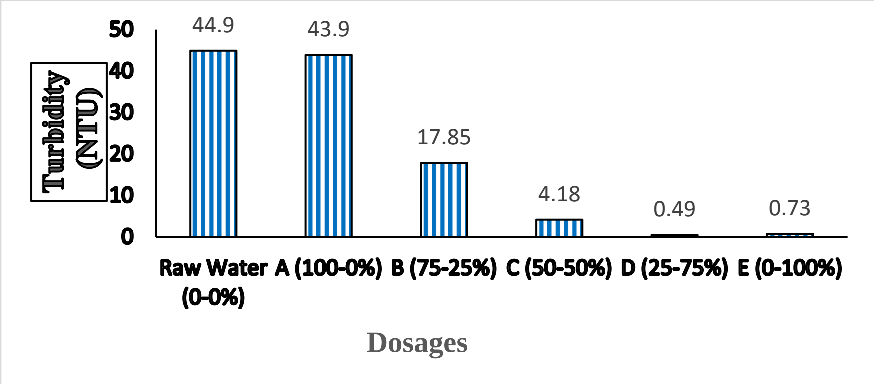


Figure 1: Coagulation effect on turbidity

3.1.2 Colour Removal

Figure 2 shows the effect of coagulation on the colour of the surface water samples. Colour intensity reduction followed a similar trend, with the combination in Jar D achieving a reduction from 225 TCU to 5 TCU. The results emphasize the effectiveness of the banana-Sudfloc combination in addressing colour-related impurities in water, likely due to enhanced floc formation. The study's findings on colour reduction compare favorably with existing literature. [24] reported a colour reduction of up to 88.7% using different natural coagulants. This suggest that BLP, as a natural coagulant, has a distinct advantage in addressing colour-related impurities. Also, [25] reported that the use of Linseed demonstrated high removal of colour, up to 97.76 %, thus suggesting that BLP could have similar colour removing potentials.

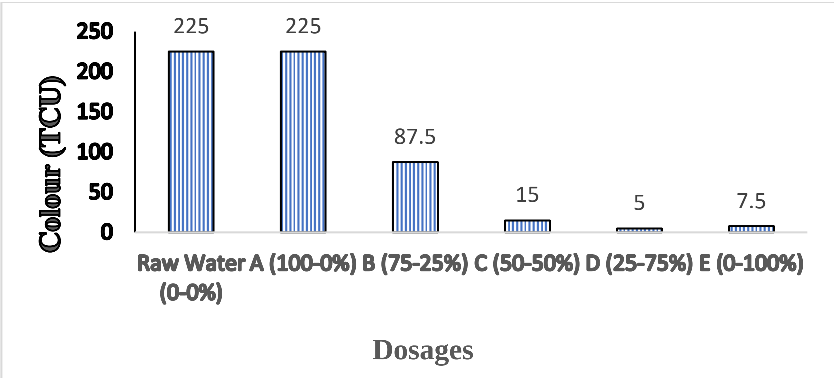


Figure 2: Coagulation effects on colour

3.1.3 pH Stability

Figure 3 presents the effects of coagulation on pH of the water. The pH values remained stable across all dosages, with slight variations between 7.0 and 7.2. This stability is critical, as it indicates that the coagulants do not significantly alter the natural water chemistry, making them suitable for practical applications. The pH stability observed in this study (7.0-7.2) is consistent with findings by [26], who noted minimal pH variations during water treatment with Sudfloc. The synergy between BLP and Sudfloc appears to further stabilize pH, contrasting with some natural coagulants that tend to lower pH values due to acidic components.

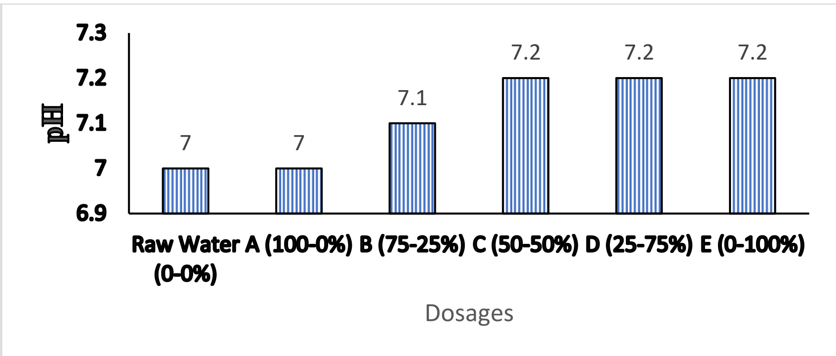


Figure 3: Coagulation effects on pH

3.1.4 Total Dissolved Solids and Conductivity: TDS and conductivity measurements (as presented in Figures 4 and 5) showed minimal variation across different dosages, indicating that the coagulants did not introduce significant ionic loads into the water. This behaviour is advantageous for maintaining overall water quality.

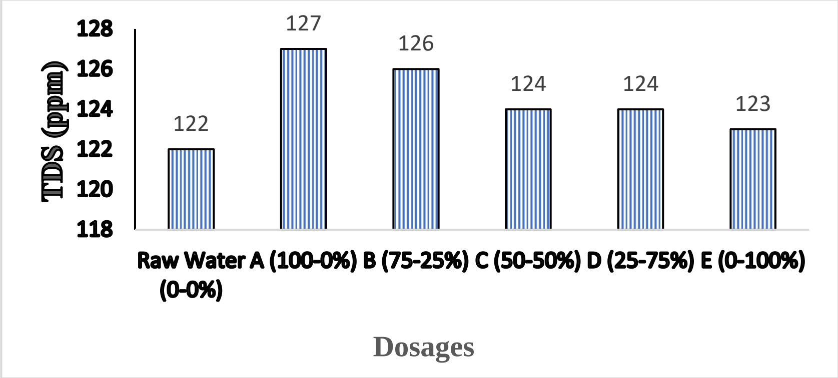


Figure 4: Coagulation effect on TDS

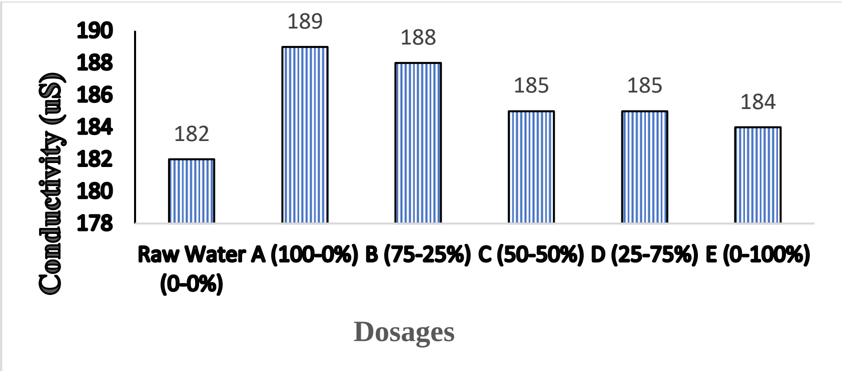
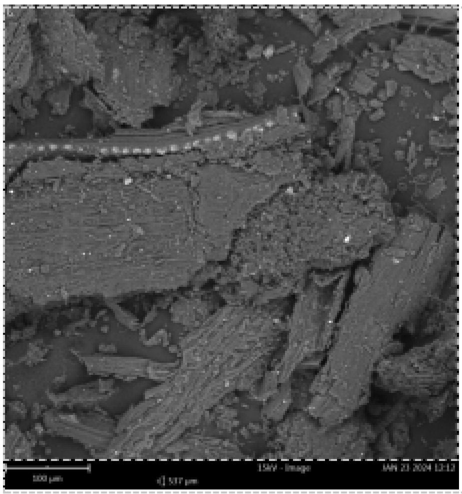


Figure 5: Coagulation effect on conductivity

3.2 Morphological and Structural Analysis

3.2.1 SEM-EDS Analysis

The results of the SEM-EDS analysis are presented in Figure 6. The SEM image shows the surface morphology and elemental composition of the banana leaf coagulant powder. The SEM images revealed the porous microstructure of the BLP, which contributes to its high adsorption capacity and ability to trap suspended particles during coagulation. The EDS data indicates a high carbon content (60.18%), highlighting the organic nature of the material, along with significant amounts of nitrogen (19.84%) and potassium (5.82%), which are known to enhance coagulation properties. These structural and elemental characteristics align with the coagulant's ability to effectively reduce turbidity, as observed in this study. The porous structure increases the surface area available for interaction with suspended particles, while the elemental composition, particularly potassium and nitrogen, contributes to destabilizing colloids. This finding is consistent with the excellent performance of BLP in achieving turbidity reductions below 1 NTU, demonstrating its potential as a sustainable alternative to chemical coagulants. The morphological analysis using SEM also corroborates findings by [27, 28], which highlighted the significance of porous and rough surfaces in enhancing adsorption capacity. The porous structure of BLP observed in this study likely contributes to its superior performance in trapping suspended particles, a feature similarly noted in neem and tamarind-based coagulants.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	60.18	43.98
7	N	Nitrogen	19.84	16.91
19	K	Potassium	5.82	13.86
13	Al	Aluminium	3.46	5.67
14	Si	Silicon	2.28	3.90
12	Mg	Magnesium	2.27	3.36
17	Cl	Chlorine	1.34	2.90
20	Ca	Calcium	0.99	2.42
11	Na	Sodium	1.62	2.27
15	P	Phosphorus	0.91	1.72
16	S	Sulfur	0.86	1.68
26	Fe	Iron	0.28	0.96
22	Ti	Titanium	0.13	0.37

FOV: 537 µm, Mode: 15kV - Image, Detector: BSD Full, Time: JAN 23 2024 12:12

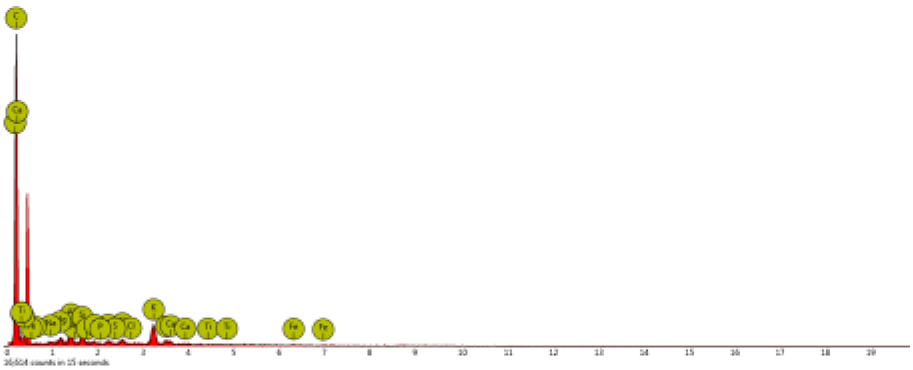


Figure 6: SEM-EDS results

3.2.2 XRD Analysis

The XRD result of the BLP is presented in Figure 7. The XRD results reveal a crystalline structure for the BLP, with prominent peaks that suggest the presence of graphite, cristobalite, and other identified phases like urea syn and dawine. The presence of crystalline structures in the BLP play a role in its coagulation efficacy. The major peak at around 20° indicates significant crystalline properties, which may contribute to the effective coagulation observed in this study. The presence of graphite is particularly noteworthy, as it is associated with improved adsorption capabilities, enhancing the removal of suspended particles and impurities from water. The identified phases correlate with the functionality of the BLP as a natural coagulant. Cristobalite and other silica-based compounds can contribute to the destabilization of colloidal particles, while organic compounds like those linked to the urea syn phase may enhance surface reactivity. These structural attributes likely explain the observed reductions in turbidity, colour, and other water quality parameters during the jar tests. The crystalline phases in BLP enhance its effectiveness as a natural coagulant. [29, 30, 31] identified the role of crystalline structures in other plant-based coagulants, where enhanced adsorption and particle destabilization were linked to specific crystalline phases. The results of this study provide further evidence of the utility of BLP as a sustainable and efficient water treatment agent.

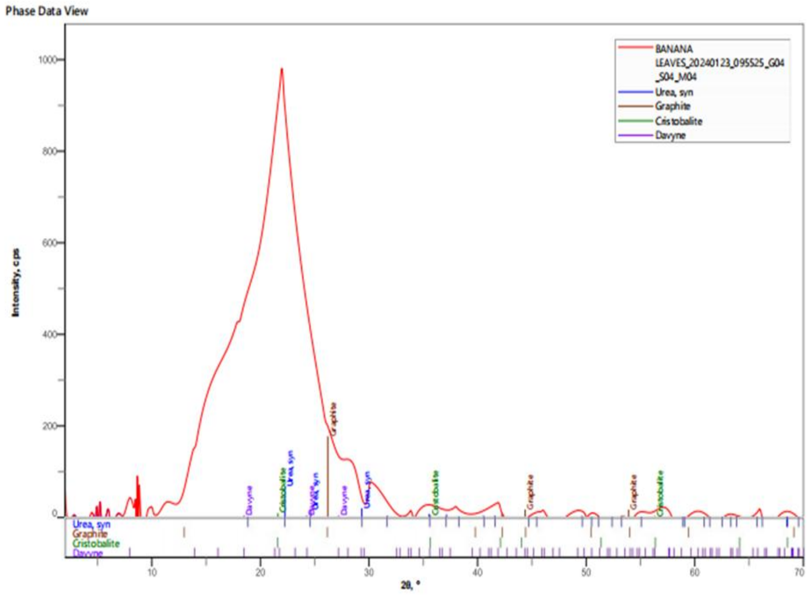


Figure 7: XRD result

4.0 Conclusion

The findings of this study demonstrate the efficacy of BLP as a natural coagulant for water treatment, particularly when used in combination with Sudfloc. The results show significant reductions in turbidity, colour, TDS, and conductivity, with values surpassing those reported in existing literature for other natural coagulants. This is attributed to the unique morphological and crystalline characteristics of BLP, as revealed through SEM and XRD analyses, which enhance its coagulation ability. Incorporating BLP as a coagulant would reduce the dependency on expensive chemical coagulants, making the treatment process more cost-effective for communities in resource-limited settings. Additionally, the potential for sourcing banana leaves locally further supports its feasibility in decentralized water treatment applications.

Acknowledgment

The author expresses gratitude for the support provided by Taiwo Olabanji, Jamiu Basola, and Ariyo Peter in conducting this research.

References

[1] O. V. Obayomi, D. C. Olawoyin, O. Oguntimehin, L. S. Mustapha, S. O. Kolade, P. O. Oladoye, S. Oh, and K. S. Obayomi, "Exploring emerging water treatment technologies for the removal of microbial pathogens," *Current Research in Biotechnology*, vol. 8, p. 100252, 2024. [Online]. Available: https://doi.org/10.1016/j.crbiot.2024.100252.

[2] J. A. Silva, "Wastewater Treatment and Reuse for Sustainable Water Resources Management: A Systematic Literature Review," *Sustainability*, vol. 15, no. 14, p. 10940, 2023. [Online]. Available: https://doi.org/10.3390/su151410940.

[3] E. Ojomo, M. Elliott, L. Goodyear, M. Forson, and J. Bartram, "Sustainability and scale-up of household water treatment and safe storage practices: Enablers and barriers to effective implementation," *International Journal of Hygiene and Environmental Health*, vol. 218, no. 8, pp. 704-713, 2015. [Online]. Available: https://doi.org/10.1016/j.ijheh.2015.03.002.

[4] M. Getahun, A. Befekadu, and E. Alemayehu, "Coagulation process for the removal of colour and turbidity from wet coffee processing industry wastewater using bio-coagulant: Optimization through central composite design," *Heliyon*, vol. 10, no. 7, p. e27584, 2024. [Online]. Available: https://doi.org/10.1016/j.heliyon.2024.e27584.

[5] R. M. El-taweel, N. Mohamed, K. A. Alrefaey, S. Husien, A. B. Abdel-Aziz, A. I. Salim, N. G. Mostafa, L. A. Said, I. S. Fahim, and A. G. Radwan, "A review of coagulation explaining its definition, mechanism, coagulant types, and optimization models; RSM, and ANN," *Current Research in Green and Sustainable Chemistry*, vol. 6, p. 100358, 2023. [Online]. Available: https://doi.org/10.1016/j.crgsc.2023.100358.

[6] A. K. Badawi, R. S. Salama, and M. M. M. Mostafa, "Natural-based coagulants/flocculants as sustainable market-valued products for industrial wastewater treatment: a review of recent developments," *RSC Advances*, vol. 13, no. 28, pp. 19335–19355, 2023. [Online]. Available: https://doi.org/10.1039/d3ra01999c.

[7] B. Koul, N. Bhat, M. Abubakar, M. Mishra, A. P. Arukha, and D. Yadav, "Application of natural coagulants in water treatment: A sustainable alternative to chemicals," *Water*, vol. 14, no. 22, p. 3751, 2022. [Online]. Available: https://doi.org/10.3390/w14223751.

[8] A. Daryabeigi Zand and H. Hoveidi, "Comparing Aluminium Sulfate and Poly-Aluminium Chloride (PAC) Performance in Turbidity Removal from Synthetic Water," *J. Appl. Biotechnol. Rep.*, vol. 2, no. 3, pp. 287-292, Summer 2015.

[9] O. M. Ojo, A. S. Adewuyi, T. O. Olabanji, M. A. Ogidi, J. O. Basola, and A. S. Peter, "Evaluation of Mango Leaves Powder-Sudfloc Dosage Ratios for Enhanced Coagulation-Flocculation in Surface Water Treatment," *Nigerian Research Journal of Engineering and Environmental Sciences*, vol. 9, no. 2, pp. 757-763, 2024.

[10] K. Zaman, N., R. Rohani, I. Izni Yusoff, M. A. Kamsol, S. A. Basiron, and A. I. Abd Rashid, "Eco-Friendly Coagulant versus Industrially Used Coagulants: Identification of Their Coagulation Performance, Mechanism and Optimization in Water Treatment Process," *Int. J. Environ. Res. Public Health*, vol. 18, no. 17, p. 9164, 2021, doi: 10.3390/ijerph18179164.

[11] H. Tahraoui, S. Toumi, M. Boudoukhani, N. Touzout, A. N. E. H. Sid, A. Amrane, A.-E. Belhadj, M. Hadjadj, Y. Laichi, M. Aboumustapha, et al., "Evaluating the effectiveness of coagulation–flocculation treatment using aluminum sulfate on a polluted surface water source: A year-long study," *Water*, vol. 16, p. 400, 2024. [Online]. Available: https://doi.org/10.3390/w16030400.
[12] S. Nimesha, C. Hewawasam, D. J. Jayasanka, Y. Murakami, N. Araki, and N. Maharjan, "Effectiveness of natural coagulants in water and wastewater treatment," *Global J. Environ. Sci. Manage.*, vol. 8, no. 1, pp. 101-116, 2022, doi: 10.22034/gjesm.2022.01.08.
[13] B. S. Padam, H. S. Tin, F. Y. Chye, and M. I. Abdullah, "Banana by-products: An under-utilized renewable food biomass with great potential," *Journal of Food Science and Technology*, vol. 51, no. 12, pp. 3527–3545, 2014. [Online]. Available: https://doi.org/10.1007/s13197-012-0861-2.
[14] S. Alzate Acevedo, Á. J. Díaz Carrillo, E. Flórez-López, and C. D. Grande-Tovar, "Recovery of banana waste-loss from production and processing: A contribution to a circular economy," *Molecules*, vol. 26, no. 17, p. 5282, 2021. [Online]. Available: https://doi.org/10.3390/molecules26175282.
[15] G. Gupta, M. Baranwal, S. Saxena, and M. S. Reddy, "Utilization of banana waste as a resource material for biofuels and other value-added products," *Biomass Conversion and Biorefinery*, vol. 13, no. 14, pp. 12717–12736, Sep. 2023. [Online]. Available: https://doi.org/10.1007/s13399-022-02306-6.
[16] A. Michael, S. Patrick, N. C. Betty, H. Matovu, N. Prossie, K. Isa, and A. Zziwa, "Potential of natural coagulants for bioremediation of persistent organic pollutants in wastewater in sub-Saharan Africa: A review," *Archives of Agriculture and Environmental Science*, vol. 9, no. 2, pp. 385-403, 2024. [Online]. Available: https://doi.org/10.26832/24566632.2024.0902026.
[17] W. El Bouaidi, G. Libralato, Z. Tazart, G. Enaime, M. Douma, A. Ounas, A. Yaacoubi, G. Lofrano, M. Carotenuto, L. Saviano, A. Siciliano, V. Romano Spica, M. Guida, and M. Loudiki, "Nature-based coagulants for drinking water treatment: An ecotoxicological overview," *Water Environment Research*, vol. 94, no. 8, p. e10782, 2022. [Online]. Available: https://doi.org/10.1002/wer.10782.
[18] W. L. Ang and A. W. Mohammad, "State of the art and sustainability of natural coagulants in water and wastewater treatment," *Journal of Cleaner Production*, vol. 262, p. 121267, 2020. [Online]. Available: https://doi.org/10.1016/j.jclepro.2020.121267.
[19] N. S. Zaidi, W. Chin Ting, Z. Zhan Loh, M. Burhanuddin Bahrodin, N. Azimatolakma Awang, and A. Kadier, "Assessment and optimization of a natural coagulant (*Musa paradisiaca*) peels for domestic wastewater treatment," *Environmental and Toxicology Management*, vol. 2, no. 1, pp. 7–13, 2022. [Online]. Available: https://doi.org/10.33086/etm.v2i1.2901.
[20] A. A. Azamzam, M. Rafatullah, E. B. Yahya, M. I. Ahmad, J. Lalung, M. Alam, and M. R. Siddiqui, "Enhancing the efficiency of banana peel bio-coagulant in turbid and river water treatment applications," *Water*, vol. 14, no. 16, p. 2473, 2022. [Online]. Available: https://doi.org/10.3390/w14162473.
[21] A. Ramsumair, V. Mlambo, and C. H. O. Lallo, "Effect of drying method on the chemical composition of leaves from four tropical tree species," *Trop. Agric. (Trinidad)*, vol. 91, no. 3, pp. 179–186, Jul. 2014.
[22] O. M. Ojo, "Efficiency of *Carica papaya* seeds in the coagulation of moderately turbid wastewater," *Advances in Science and Technology Switzerland*, vol. 154, pp. 139–145, 2024.
[23] D. Kenea, T. Denekew, R. Bulti, B. Olani, D. Temesgen, D. Sefiw, D. Beyene, M. Ebba, and W. Mekonin, "Investigation on surface water treatment using blended moringa oleifera seed and aloe vera plants as natural coagulants," *South African Journal of Chemical Engineering*, vol. 45, pp. 294-304, 2023. [Online]. Available: https://doi.org/10.1016/j.sajce.2023.06.005.
[24] C. de Oliveira Cardoso Nascimento, M. T. Veit, S. M. Palácio, and G. da Cunha Gonçalves, "Use of natural coagulants in the removal of color and turbidity from laundry wastewater," Water, Air, & Soil Pollution, vol. 232, no. 7, p. 300, Jul. 2021. [Online]. Available: https://doi.org/10.1007/s11270-021-
[25] A. K. Husen, F. Bidira, W. M. Desta, and P. Asaithambi, "COD, color, and turbidity reduction from surface water using natural coagulants: Investigation and optimization," *Progress in Engineering Science*, vol. 1, no. 2–3, p. 100007, 2024. doi: 10.1016/j.pes.2024.100007. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2950425224000070.
[26] O. M. Ojo and A. S. Adewuyi, "Removal of bacteriological contaminants from household wastewater using activated carbon derived from sawdust," *NIPES-Journal of Science and Technology Research*, vol. 6, no. 4, pp. 44–54, 2024. doi: 10.5281/zenodo.1430381.
[27] M. A. Ahsan, V. Jabbari, M. T. Islam, R. S. Turley, N. Dominguez, H. Kim, E. Castro, J. A. Hernandez-Viezcas, M. L. Curry, J. Lopez, J. L. Gardea-Torresdey, and J. C. Noveron, "Sustainable synthesis and remarkable adsorption capacity of MOF/graphene oxide and MOF/CNT based hybrid nanocomposites for the removal of Bisphenol A from water," *Science of The Total Environment*, vol. 673, pp. 306–317, 2019, doi: 10.1016/j.scitotenv.2019.03.219.
[28] R. K. Bharali and K. G. Bhattacharyya, "Biosorption of fluoride on Neem (Azadirachta indica) leaf powder," *Journal of Environmental Chemical Engineering*, vol. 3, no. 2, pp. 662–669, 2015, doi: 10.1016/j.jece.2015.02.007.
[29] M. K. Karnena and V. Saritha, "Phytochemical and physicochemical screening of plant-based materials as coagulants for turbidity removal – An unprecedented approach," *Watershed Ecology and the Environment*, vol. 4, pp. 188–201, 2022, doi: 10.1016/j.wsee.2022.11.006.
[30] B. I. Okolo, O. Adeyi, E. O. Oke, C. M. Agu, P. C. Nnaji, K. N. Akatobi, and D. O. Onukwuli, "Coagulation kinetic study and optimization using response surface methodology for effective removal of turbidity from paint wastewater using natural coagulants," *Scientific African*, vol. 14, e00959, 2021, doi: 10.1016/j.sciaf.2021.e00959.
[31] T. Usman, I. M. Ho, L. Baloo, M. K. Lam, P. L. Show, and W. Sujarwo, "Comprehensive Review of Modification, Optimisation, and Characterisation Methods Applied to Plant-Based Natural Coagulants (PBNCs) for Water and Wastewater Treatment," *Sustainability*, vol. 15, no. 5, p. 4484, 2023, doi: 10.3390/su15054484.