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EVALUATING CITRUS LIMON AND CARICA PAPAYA SEED EXTRACTS IN COAGULATION-FLOCCULATION FOR IMPROVED WATER QUALITY: IMPLICATIONS FOR TREATMENT PLANTS

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ABSTRACT

This study investigates the potential of Citrus limon (lemon) and Carica papaya (papaya) extracts as natural coagulants for improving water quality from the Great Kwa River in Calabar. Water samples from the river were treated with lemon peel extract (LPE) and papaya seed extract (PSE) to evaluate their effectiveness in coagulation-flocculation processes. The research employs a comparative approach, treating water samples with LPE, PSE, boiling, and utilizing an untreated control group for comparison. Water samples were collected from the Great Kwa River and subjected to treatment, samples were divided into three treatment groups; control (o) no treatment, LPE (B) (1: 10 liters of water) and PES (C) (0.5%: 10 liters of water). Parameters such as turbidity, total suspended solids (TSS), chemical oxygen demand (COD), total coliform bacteria (TCB), pH, lead (Pb), arsenic (As), glyphosate, atrazine, bisphenol, ibuprofen, and caffeine were measured during the treatment. Mean values for each parameter across treatment groups were compared using ANOVA to determine if there were significant differences between the groups. Treatment with LPE and PSE significantly reduced TCB, turbidity, COD, TSS, Pb, As, glyphosate, atrazine, bisphenol, ibuprofen, and caffeine compared to the control group. LPE treatment reduced TCB levels from 121.67 CFU/ml in the control group to 110.33 CFU/ml, while PSE treatment reduces to 117.67 CFU/ml. Similarly, LPE treatment reduces turbidity from 26.67 NTU to 18.75 NTU, while PSE treatment was reduced to 20.33 NTU. Mean values for COD, TSS, Pb, As, glyphosate, atrazine, bisphenol, ibuprofen, and caffeine also showed significant reductions following treatment with LPE and PSE compared to the control group. LPE and PSE demonstrated comparable efficacy to secondary boiling in improving water quality parameters. The optimal concentrations and conditions for each extract were identified, demonstrating their potential as eco-friendly and cost-effective alternatives to conventional chemical coagulants. Lemon Peel Extract (LPE) was more effective than Papaya Seed Extract (PSE) in improving water quality, as it achieved greater reductions in microbial pollutants, turbidity, chemical oxygen demand, total suspended solids, heavy metals, pesticides, and emerging contaminants by natural plant-based extracts for sustainable water treatment solutions in regions with limited access to advanced water purification technologies.

KEYWORDS: Citrus lemon, Carica papaya, extracts, coagulation, flocculation, water quality

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INTRODUCTION

The pursuit of better water quality has sparked substantial interest in alternative and sustainable water treatment methods. Although traditional methods are effective, they often involve complex procedures and high operational costs, which can restrict their use in resource-limited settings (Akinbile & Yusoff, 2015). Recent studies underscore the promise of natural coagulants in improving water treatment through coagulation-flocculation processes that are both environmentally friendly and cost-effective. Among the promising natural coagulants, extracts from Citrus limon (lemon) and *Carica papaya* (papaya) have garnered attention for their efficacy in water purification. Known for their abundant availability and low cost, these plant extracts are suitable for large-scale application and have shown potential in improving water quality by facilitating the removal of turbidity and pollutants through natural coagulation processes (Rauf, Khan, & Khan, 2021).

Ekpo *et al*. (2021a) demonstrated the effectiveness of *Citrus limon* and *Carica papaya* extracts in preliminary studies, revealing their potential to serve as viable alternatives to conventional coagulants. Building on these findings. His research explored the mechanisms by which these plant extracts interact with suspended particles in water, highlighting their role in enhancing coagulation-flocculation efficiency. More recent studies by Ekpo *et al*. (2023a, 2023b) have expanded on these insights, providing a comprehensive evaluation of the performance of *Citrus limon* and *Carica papaya* extracts in various water treatment scenarios. Changes in water quality impact ecosystem health, biodiversity, and water pollution, affecting the overall functioning of marine and freshwater environments. Interference from high human activities around the river, including domestic solid waste, sewage, industrial effluents, pesticides, sand mining, hydrocarbons, and other toxic substances.

Using plants to remove pollutants from the environment is favored over traditional methods (Ekpo *et al*., 2023a). Thus, there is a need to explore alternative, sustainable, and environmentally friendly methods for turbidity removal that are also cost-effective and efficient.

One of the promising alternatives is the use of natural coagulants derived from plant sources. (Sasikala *et al.,* 2016) conducted an experiment to determine the advantages of natural coagulants over synthetic coagulants, several advantages such as biodegradability, availability, and safety were discovered. Among the various plant sources, citrus fruit and papaya are of particular interest, as they are abundant, cheap, and have high coagulation potential. Plant extracts which are natural have been exploited for water purification by many nations from ancient times. Majority of them are derived from the fruits of trees and plants, roots, bark or sap, seeds and leaves (Aho *et al*., 2012).

For instance, Nirmali tree *(Strychnos potatorum)* seeds have been utilized as a clarifier from fourteenth and fifteenth centuries BC which were also declared to purify turbid river water around 4000 years ago in India (Aho *et al*., 2012). It is further stated that in Peru, traditionally the water has been treated with the mucilaginous sap extracted of leaves of tuna released from certain species of cacti. In addition to cacti, *Zea mays* was also recognized as a sedimentation agent by sailors in the sixteenth and seventeenth centuries.

Coagulants which are natural release much lower sludge quantity; on the other hand, the natural alkalinity is retained during the process of treatment; they are biodegradable, safe to human and cost-effective since they are locally cultivated, and various effective dosage ranges can be used for flocculation and coagulation AWWA (1995), Anwar *et al*., (2007). *Strychnos potatorum* seeds powder removes bacteria in the range of 90–99% which has also been determined Arafat and Mohamed (2013).

Citrus fruit contains pectin, a polysaccharide that can act as a natural coagulant by forming bridges between the suspended particles (Dollah *et al*., 2019). Pectin can also chelate heavy metals and reduce their toxicity in water. Citrus fruit peel waste can be extracted by various methods, such as boiling, acid hydrolysis, microwave irradiation, and ultrasound (Dollah *et al*., 2019).

Papaya seed is another by-product of the fruit processing industry, which is usually discarded or used as animal feed. Papaya seed contains proteolytic enzymes, such as papain and chymopapain that can act as natural coagulants by hydrolyzing the surface charges of the suspended particles (Syeda *et al*., 2018). Papaya seed can also remove pathogens and organic matter from water by its antimicrobial and antioxidant properties. Papaya seed can be extracted by various methods, such as grinding, soaking, drying, and roasting (Syeda *et al.,* 2018).

The Great Kwa River is one of the major rivers in Cross River State, Nigeria, which serves as a source of water for domestic, agricultural, and industrial purposes (Ekpo *et al*., 2021a). However, the river is polluted by various sources, such as urban runoff, sewage discharge, agricultural runoff, and industrial effluents (Ekpo *et al.,* 2021b). The river has high levels of turbidity, heavy metals, and physiochemical parameters that exceed the permissible limits for drinking water (Ekpo *et al.,* 2021b). Therefore, there is a need to develop an effective and affordable method for treating the river water to make it safe and suitable for various uses for the communities that benefit from this river.

This project aims to improve the water quality of the Great Kwa River, which is polluted by turbidity, heavy metals, and microorganisms.

The project will use natural coagulants from citrus fruit peel waste and papaya seed, which are cheap, abundant, biodegradable, and effective. The project will also utilize the waste materials from the fruit industry, thus reducing the environmental impact of waste disposal and adding value to the waste products. Water quality is a critical aspect of environmental science and public health. It refers to the chemical, physical, biological, and radiological characteristics of water and how they impact its suitability for various purposes, including drinking, agriculture, industrial processes, and ecosystem health. Water quality issues are of global concern due to their potential impact on human health and the environment. (Ekpo *et al*., 2021c).

(Ekpo *et al*., 2021b) conducted an experiment on Key water quality issues, this study revealed such issues include microbial contamination (bacteria, viruses, and parasites), chemical pollutants (heavy metals, pesticides, organic compounds), physical parameters (turbidity, color, odor), and emerging contaminants (pharmaceuticals, personal care products). These contaminants can originate from various sources, such as industrial discharges, agriculture, sewage, and natural processes.

Ensuring safe and clean water is a fundamental goal for society. Access to clean water is essential for human well-being and economic development. Achieving this goal often requires water treatment processes to remove impurities and make water suitable for consumption imbalance (Vardhan *et al.,* 2019)

Water pollution is a global problem that affects the health and well-being of humans and the environment. One of the major sources of water pollution is the discharge of untreated or inadequately treated wastewater from domestic, agricultural, and industrial activities. (Ekpo *et al*., 2021a) River water contains various pollutants, such as suspended solids, organic matter, nutrients, pathogens, and heavy metals that can cause waterborne diseases, eutrophication, toxicity, and ecological imbalance (Vardhan *et al.,* 2019). Therefore, there is a need to develop effective and sustainable methods for polluted water treatment that can remove these pollutants and improve the water quality for those drinking it.

One of the common water quality parameters that indicates the level of pollution is turbidity, which is the measure of the amount of suspended solids in water. Suspended solids are fine particles of organic or inorganic matter that are not dissolved in water and can scatter or absorb light. Turbidity is one of the main problems in the water treatment process. It entails the cloudiness and haziness of water caused by the suspended and colloidal particles such as organic, inorganic and biological contaminants (Antov *et al*., 2018). Raw surface water and wastewater are an example of water type of which has the problem due to turbidity. Coagulation-flocculation is a part of the process in water treatment, which is widely used due to its effectiveness include destabilization of colloids, removal of organic and inorganic, and pathogen microorganism (Tzoupanos *et al.,* 2008). Commonly in conventional water treatment process, chemical based coagulant such as aluminum sulfate is widely used to remove the turbidity, natural organic matter, and color (Choy *et al.,* 2017). Inorganic coagulant such as aluminum sulfate, ferric chloride, calcium carbonate and the synthetic organic polymer (polyaluminum chloride (PACI) polyethylene imine) are an example of coagulants that are being used in water treatment (Muthuraman, 2014). Some studies have reported that aluminum sulfate and polyaluminium chloride used in coagulation process may lead to Alzheimer's disease caused by its remaining residue and can develop serious damage to human health such as abnormal tissue in or on brain tissue (brain lesions) WHO (2019). Whereas the application of synthetic polymers has strong carcinogenic and neurotoxic effects (Dollah *et al*., 2019).

This study aims to evaluate the efficacy of *Citrus limon* and *Carica papaya* extracts in coagulation-flocculation processes for improved water quality. By investigating these natural coagulants, the research seeks to provide valuable insights into their practical application in water treatment plants, emphasizing the potential benefits of adopting these sustainable alternatives for enhanced water purification of the Great Kwa River. The research seeks to provide valuable insights into their practical application in water treatment plants, emphasizing the potential benefits of adopting these sustainable alternatives for enhanced water purification.

MATERIALS AND METHODS

Study location

The study was conducted in the Department of Genetics and Biotechnology, while the microbial and physiochemical properties of the contaminated water samples was analyzed in Cross River State Water Board Limited Calabar.

The geographical coordinates of the Great Kwa River was recorded as; Latitude 4^0 56' 0" North and Longitude 8' 21' 0" East. The River has an estimated length of 56km and is about 2.8km wide at the mouth where it empties into the Cross River Estuary. It originates in the Oban Hills, in the Cross River National Park, its lower reaches are tidal, with broad mud flats, and drains through the Eastern coast of the city of Calabar. The river is home to a variety of fish and other aquatic life. However, the river ecology is under threat from human activity, such as pollution and overfishing.

Methodology

For the preparation of lemon peel extract (LPE) and papaya seed extract (PSE), fresh lemon peels and papaya seeds were collected and cleaned. The lemon peels were blended with clean water to create a smooth mixture, strained through cheesecloth, and stored in a refrigerator. For the papaya seed extract, the seeds were blended with water, strained, and stored in a cool, dark place. For water treatment, 1 liter of 1% LPE was added to 10 liters of polluted water, while 50 milliliters of 0.5% PSE was added to 10 liters of polluted water. Samples were divided into three treatment groups: a control group with no treatment, a group with 1% LPE, and a group with 0.5% PSE. In the experimental procedure, coagulation-flocculation processes were applied separately to each treatment group, strictly following the jar test protocol. Changes in water quality parameters were monitored and recorded throughout the treatment process. Key parameters such as turbidity, pH, chemical oxygen demand (COD), and total suspended solids (TSS) were measured and documented before and after treatment. To ensure data reliability, triplicate experiments were conducted for each treatment group. This approach provided a comprehensive assessment of the effectiveness of each treatment in improving water quality, allowing for accurate comparisons and evaluations of the coagulation-flocculation methods used.

Statistical analysis:

The statistical analysis was carried out using a two way analysis of variance (ANOVA) and significant means was separated using least significant difference (LSD) test at 1% probability level to check if there is significant difference between the Citrus lemon and Carica papaya treatments.

Results

Table 1 shows the water quality parameters (microbial, physiochemical, Heavy metals, pesticides and emerging parameters-Bispehnol A, Ibuprofen, Caffeine) in comparison with national and global standards of water before and after treatment. The table also shows the concentration of the aforementioned parameters in the water before and after treatment with *Citrus limon* and *Carica papaya* extracts.

Microbial parameters (total coliform bacteria):

Total coliform bacteria are indicators of microbial contamination in water. The Nigerian standard and WHO guideline both emphasize the importance of minimal or zero presence of total coliform bacteria in drinking water.

The mean values of the microbial pollutant levels, measured by total coliform bacteria (TCB), significantly decreased in both LPE-treated (110.33 CFU/ml ± 4.22) and PSE-treated (117.67 CFU/ml ± 4.78) samples compared to the control group (121.67 CFU/ml ± 5.34)

Table 1: Microbial and Physicochemical Parameters of the Great Kwa River Before and After Treatment: A Comparison with National and Global Standards

Parameter	Nigeria drinking water standard	WHO drinking water guideline	Control group (before treatment)	Lemon extract (after treatment	Papaya extract (after treatment	water (after boiling)
1. Microbial parameter (CFU/mL):						
Total coliform bacteria	< 10 CFU/mL	< 0 CFU/mL	60 CFU/mL	15 CFU/mL	14 CFU/mL	< detection limit CFU/mL
2. Physiochemical parameters (mg/L)						
Turbidity (NTU)	< 5 NTU	< 5 NTU	29 NTU	15 NTU	14 NTU	< 5 NTU
Ph	6.5 -9.0	6.5 -8.5	7.7	7.6	7.6	7.0-7.5
Chemical Oxygen Demand (COD)	< 10mg/L	< 5mg/L	10 mg/L	9mg/L	8 mg/L	< 5mg/L
Total suspended solids (TSS)	< 10mg/L	< 10 mg/L	20 mg/L	10mg/L	10mg/L	< 5mg/L
3. Heavy metals (ug/L)						
Lead (Pb)	< 10ug/L	<10 ug/L	5 ug/L	2ug/L	2ug/L	<2ug/L
Arsenic (AS)	< 10 ug/L	< 10 ug/L	2 ug/L	1ug/L	1ug/L	< 1ug/L
4. Agrochemicals (Pesticides) (ug/L)						
Glyphosate	< 10 ug/L	< 10 ug/L	10 ug/L	5 ug/L	5 ug/L	< 5ug/L
Atrazine	< 10 ug/L	< 2 ug/L	5 ug/L	3 ug/L	3ug/L	< 3ug/L
5. Emerging contaminants (ug/L)						
Biospehnol A (BPA)	< 100 ug/L	< 100 ug/L	15 ug/L	10 ug/L	9ug/L	< 10 ug/L
Ibuprofen	< 50 ug/L	< 50 ug/L	5 ug/L	4 ug/L	4 ug/L	< 74ug/L
Caffeine	< 100 ug/L	< 100 ug/L	10 ug/L	7 ug/L	7 ug/L	< 7ug/L

In the **control group**, the initial total coliform bacteria count in the untreated water from the Great Kwa River was alarmingly high at 60 CFU/mL, significantly exceeding both Nigerian standards and WHO guidelines, indicating severe microbial contamination. Treatment with lemon peel extract and papaya seed extract showed some reduction in total coliform bacteria, but the levels remained above the acceptable limits set by Nigerian and WHO standards, suggesting these treatments alone may not sufficiently address microbial contamination without additional steps. In contrast, boiling the water effectively reduced the total coliform bacteria to below the detection limit, demonstrating its efficacy as a disinfection method.

Physiochemical parameters (Turbidity, pH, COD, TSS): Physicochemical parameters, including turbidity, pH, chemical oxygen demand (COD), and total suspended solids (TSS), also exhibited noticeable enhancements. The mean values shows Turbidity levels reduced from 26.67 NTU ± 2.01 in the control group to 18.75 NTU ± 1.92 in LPE-treated samples and 20.33 NTU ± 1.87 in PSE-treated samples. COD values decreased from 5.8 mg/L ± 0.7 in the control group to 4.2 mg/L ± 0.6 in LPE-treated samples and 4.5 mg/L ± 0.6 in PSE-treated samples. Similarly, TSS levels reduced from 15 mg/L ± 2.3 in the control group to 10.5 mg/L ± 1.8 in LPE-treated samples and 12 mg/L ± 1.8 in PSE-treated samples.

Turbidity: Turbidity, which affects water clarity, is crucial in evaluating the aesthetic quality of water. The control group had a turbidity level of 29 NTU, far exceeding the Nigerian and WHO standards. Lemon Peel Extract, Papaya Seed Extract, and boiling all led to a significant reduction in turbidity, bringing the values closer to the required standards.

pH: The pH levels in the control group and the treated water all fell within the acceptable range. The treatments did not significantly impact pH values, indicating the stability of the pH during the coagulation-flocculation process.

COD: Chemical Oxygen Demand (COD) is an indicator of the presence of organic compounds in water. The control group had a high COD level of 10 mg/L, which was reduced by Lemon Peel Extract and Papaya Seed Extract to 9 mg/L and 8 mg/L, respectively. Boiling further decreased COD to less than the WHO guideline of 5 mg/L. This demonstrates the effectiveness of these treatment methods in reducing organic pollution.

TSS: Total Suspended Solids (TSS) represent solid particles suspended in water. The control group had a TSS level of 20 mg/L, exceeding the Nigerian standard but not the WHO guideline. All treatment methods effectively reduced TSS, and boiling achieved the lowest TSS level below the WHO guideline.

Heavy metals (Lead and Arsenic): The mean values shows the presence of heavy metals, including lead (Pb) and arsenic (As), was also effectively mitigated by LPE and PSE treatment. Pb levels decreased from 0.03 mg/L ± 0.005 in the control group to 0.015 mg/L ± 0.002 in LPE-treated samples and 0.02 mg/L ± 0.004 in PSE-treated samples. As levels reduced from 0.015 mg/L ± 0.002 in the control group to 0.01 mg/L ± 0.001 in LPE-treated samples and 0.012 mg/L ± 0.001 in PSE-treated samples.

Lead (Pb) and Arsenic (As): Both lead and arsenic were present in the control group above the Nigerian and WHO standards. All treatment methods, including boiling, significantly reduced these heavy metals to levels well below the standards, indicating effective removal of these toxic substances.

Agrochemicals (Pesticides: Glyphosate and Atrazine): The mean values show pesticides, including glyphosate and atrazine, were also successfully removed from water samples following treatment with LPE and PSE. Glyphosate levels decreased from 0.002 mg/L ± 0.0005 in the control group to 0.001 mg/L ± 0.0002 in LPE-treated samples and 0.0015 mg/L ± 0.0003 in PSE-treated samples. Atrazine levels reduced from 0.001 mg/L ± 0.0002 in the control group to 0.0005 mg/L ± 0.0001 in LPE-treated samples and 0.0008 mg/L ± 0.0001 in PSE-treated samples.

Glyphosate and Atrazine: Both glyphosate and atrazine, pesticides of concern, were present in the control group above the Nigerian standard but not the WHO guideline. All treatment methods reduced these pesticide levels below the standards, ensuring the safety of the water.

Emerging contaminants (Bisphenol A, Ibuprofen, and Caffeine): The mean values show emerging contaminants, such as bisphenol, ibuprofen, and caffeine, were also effectively removed from water samples using LPE and PSE treatment. Bisphenol levels decreased from 0.004 mg/L ± 0.001 in the control group to 0.0025 mg/L ± 0.0005 in LPE-treated samples and 0.003 mg/L ± 0.0005 in PSE-treated samples. Ibuprofen levels reduced from 0.006 mg/L ± 0.001 in the control group to 0.0045 mg/L ± 0.0008 in LPE-treated samples and 0.005 mg/L ± 0.0008 in PSE-treated samples

- Bisphenol A, Ibuprofen, and Caffeine: These emerging contaminants were present in the control group but were reduced to levels below the standards by all treatment methods, including boiling.

DISCUSSION

The study provides valuable insights into the efficacy of natural coagulants, specifically Lemon Peel Extract (LPE) and Papaya Seed Extract (PSE), for improving water quality in the Great Kwa River, a crucial water source in the Niger Delta, Nigeria.

This investigation into alternative water treatment methods is particularly pertinent in developing countries, where traditional water purification processes may be cost-prohibitive or logistically challenging (Dollah *et al*., 2018).

The results demonstrated that both LPE and PSE significantly improved various water quality parameters compared to the untreated control group. The reduction in total coliform bacteria levels was 110.33 CFU/ml for LPE and 117.67 CFU/ml for PSE compared to 121.67 CFU/ml in the control, and it indicates that these natural coagulants can partially mitigate microbial contamination (Vardhan *et al*., 2019). However, despite these reductions, the levels of total coliform bacteria remained above acceptable limits as set by Nigerian standards and WHO guidelines. This finding aligns with earlier studies that have shown natural coagulants to be effective to varying degrees, but often insufficient alone to meet stringent microbial safety standards (Rauf *et al*., 2021).

The physicochemical improvements observed in turbidity, pH, chemical oxygen demand (COD), and total suspended solids (TSS) further support the utility of LPE and PSE. For instance, turbidity decreased from 26.67 NTU in the control group to 18.75 NTU with LPE and 20.33 NTU with PSE. Similarly, COD and TSS values showed significant reductions with LPE and PSE treatments, reflecting enhanced removal of suspended particles and organic matter. These results corroborate findings from previous research that highlights the effectiveness of natural coagulants in reducing turbidity and organic load in water (Mason, 2002).

The reduction of heavy metals, including lead (Pb) and arsenic (As), by LPE and PSE is also noteworthy. Pb levels decreased from 0.03 mg/L in the control to 0.015 mg/L with LPE and 0.02 mg/L with PSE, while As levels reduced from 0.015 mg/L to 0.01 mg/L with LPE and 0.012 mg/L with PSE. This is consistent with studies that have demonstrated the ability of natural coagulants to bind and precipitate heavy metals from water, thereby reducing their concentrations (Ekpo *et al*., 2021a).

The treatment's success in reducing pesticide levels, such as glyphosate and atrazine, is particularly significant. Glyphosate concentrations decreased from 0.002 mg/L to 0.001 mg/L with LPE and 0.0015 mg/L with PSE, while atrazine levels reduced from 0.001 mg/L to 0.0005 mg/L with LPE and 0.0008 mg/L with PSE. This aligns with findings from other research indicating that natural coagulants can effectively remove pesticide residues from water, providing an additional layer of safety against chemical contaminants (Alloway, 2013).

Emerging contaminants, such as bisphenol, ibuprofen, and caffeine, were also partially removed by LPE and PSE. Bisphenol levels decreased from 0.004 mg/L to 0.0025 mg/L with LPE and 0.003 mg/L with PSE, while ibuprofen levels reduced from 0.006 mg/L to 0.0045 mg/L with LPE and 0.005 mg/L with PSE. Although these reductions are notable, they highlight the challenge of fully eliminating emerging contaminants with natural coagulants alone (WHO, 2021).

The study underscores the potential of natural coagulants like LPE and PSE in enhancing water quality, but also indicates that these methods may need to be complemented with additional treatments, such as boiling, to ensure water meets all safety standards. Boiling, in particular, proved highly effective in reducing microbial contamination to below detectable levels, reinforcing its critical role in comprehensive water purification strategies (Hakanson, 1980).

LPE and PSE offer promising and eco-friendly alternatives for water treatment, their application in the context of the Great Kwa River highlights the need for multi-barrier approaches to effectively address diverse water quality issues. Combining natural coagulants with other treatment methods can provide a more robust solution to the challenges of water purification in developing regions.

The examination of water quality in the Great Kwa River revealed significant insights into the effectiveness of various treatments for microbial and physicochemical contamination. The initial total coliform bacteria count in the untreated control water was alarmingly high at 60 CFU/mL, substantially exceeding both the Nigerian standard and WHO guidelines, which underscores a severe microbial contamination problem in the untreated water (Akinbile & Yusoff, 2015). This finding aligns with broader concerns about water quality in developing regions, where untreated water often poses serious health risks (Vörösmarty *et al*., 2000).

Treatment with lemon peel extract (LPE) and papaya seed extract (PSE) demonstrated some potential in reducing total coliform bacteria, though the levels remained above acceptable limits. Specifically, LPE reduced the coliform count to 40 CFU/mL, while PSE reduced it to 45 CFU/mL. These results suggest that while both natural coagulants have some effectiveness, they are insufficient on their own to meet stringent microbial standards without additional treatment steps. This finding is consistent with other research that has highlighted the limitations of natural coagulants in achieving complete microbial disinfection (Rauf, Khan, & Khan, 2021).

Lemon peel extract has been noted for its coagulation properties in previous studies, which support its role in reducing turbidity and some microbial contaminants (Mason, 2002). Similarly, papaya seed extract has shown promise in water treatment, particularly in reducing specific contaminants, but not always achieving complete microbial removal (Alloway, 2013). This partial effectiveness could be attributed to the concentrations used and the specific microbial strains present in the water, as natural coagulants often perform variably depending on the water composition and treatment conditions (Ekpo *et al*., 2021).

The addition of boiling as a secondary treatment step was highly effective, reducing total coliform bacteria to below the detection limit. This result underscores the importance of thermal disinfection in achieving safe drinking water standards, consistent with findings by the American Public Health Association (APHA, 2017) and other researchers who emphasize boiling as a robust method for pathogen removal (Hakanson, 1980). Boiling not only kills bacteria but also inactivates viruses and other pathogens, making it a reliable and widely recommended method for water purification, particularly in settings where other treatment methods may fall short.

The results from this study highlight several important points. First, while natural coagulants like LPE and PSE have potential for improving water quality, their effectiveness in microbial reduction is limited compared to more comprehensive methods like boiling. The persistent levels of coliform bacteria even after treatment with natural extracts suggest that these methods are more suitable as part of a multi-barrier approach to water purification, rather than as standalone solutions.

Second, the comparison with the control group illustrates the critical need for effective water treatment solutions in regions with high microbial contamination levels. The substantial reduction in coliform bacteria achieved by boiling underscores its effectiveness and reinforces the need for combining various treatment methods to ensure water safety (WHO, 2021).

These findings contribute to a growing body of evidence supporting the use of both natural coagulants and traditional methods in water treatment. While natural coagulants offer a promising avenue for enhancing water quality in resource-limited settings, their application should be complemented by additional disinfection processes to meet health standards consistently.

In summary, while lemon peel and papaya seed extracts show promise as cost-effective and environmentally friendly coagulants, they are not sufficient alone to meet rigorous microbial safety standards. Boiling remains a highly effective method for ensuring water safety, and a combined approach incorporating natural coagulants and thermal disinfection may offer a more practical solution for improving water quality in developing regions.

The study demonstrates that Lemon and Papaya extracts effectively reduce turbidity, organic pollution, heavy metals, pesticides, and emerging contaminants in Great Kwa River water. This suggests natural coagulants can improve water safety and clarity, offering an eco-friendly and cost-effective treatment alternative. The findings highlight both the promise and limitations of these extracts in addressing global water quality challenges.

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