



Comparative Studies on the Performance Evaluation of Synthetic and Phytochemical-Coagulants in Water Purification and Production—A Case Study of New Fabricated Pilot Plant

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Abstract

In this work, the comparative studies on the performance evaluation of synthetic and phytochemical coagulants in water treatment and purification plant (WTPP) was investigated in a newly fabricated pilot plant at the Department of Chemical Engineering, Ahmadu Bello University Zaria. The effectiveness of three (3) synthetic coagulants, namely: polyacryl amide, sodium aluminate, and aluminium sulphate were examined together with water extracts of the cake for *Moringa oleifera* seeds, a phytochemical-based coagulant. The raw water was sourced from Kubanni Dam and supplied by Ahmadu Bello University Water Works (ABUWW). The analysis of the water quality performance indicators was conducted according to comprehensive performance evaluation (CPE), and analytical hierarchy process (AHP) methods, and the results were compared with the standards of World Health Organizations (WHO). The indicators used in the assessments are turbidity, pH level, conductivity, hardness, alkalinity, nitrates, and total coliform counts. The turbidity and pH level of the extracts of the cake for *Moringa oleifera* seeds, polyacryl amide, sodium aluminate, and aluminium sulphate were found to be 2, 5, 1, and 2 NTU; 6.9, 9.2, 8.2, and 5.9, respectively. On the other hand, the conductivity, hardness, alkalinity, nitrates of the extracts of the cake for *Moringa oleifera* seeds, polyacryl amide, sodium aluminate, and aluminium sulphate were estimated to be 4, 17, 4.8, and 3 ppm; 42, 80, 72, and 71 mg/L; 70, 77, 75, and 48 mg/L; 10, 51, 22, and 24 mg/L, respectively. The phytochemical coagulant appeared to be the best and the second best in the nitrates, conductivity, and hardness removal, lowest number of coliform counts and turbidity removal, respectively. The results of the water quality parameters are in conformity with the WHO standards.

Keywords: *Moringa oleifera*-based phytochemical, polyacryl amide, sodium aluminate, aluminium sulphate, pilot plant.

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1. Introduction

The high increased in the demand of potable water for drinking purposes resulted in the process development of high throughput rapid sand filtration (RSF) technology that somehow compromised the quality of the drinking water produced by the older slow sand filtration (SSF) system but called for the search of the safe, efficient, and effective coagulants in the water treatment and purification processes. Many researchers have been devoted their time and other resources in the investigation for the harmless and cost-effective coagulants to enhance the quality and efficiency of coagulation-flocculation process [1-17], one of the crucial unit processes in today's modern municipal water treatment and purification plants (WTPPs) [9,11,14].

Coagulants can be generally classified into synthetic-based chemicals and phyto-based or animal-based chemicals that are added to the raw water to enhance the destabilization and agglomeration of slow and difficult to settle particulate species or materials in the modern water treatment and purification plants (WTPPs) [5,10-12,15]. Basically, the synthetic chemical coagulants are categorized into the polyelectrolytes (aminoethyl polyacrylamides, polyamines polyethyleneimines, polydiallyldimethyl ammonium chloride, etc) [17-20], the hydrolysing metallic salts (ferric chloride, aluminium sulphate (alum), ferric sulphate, magnesium chloride, etc) [1,5,6,10,20-25], and pre-hydrolysing metallic salts (polyferric chloride, polyferric sulphate, poly aluminium chloride, polyaluminium sulphate, etc) [5,8,26-29]. The second classification is the group for phyto-based chemicals (i.e., derived from plant materials) or referred as phytochemicals (water extracts of the cake for *Moringa oleifera* seeds, extracts of tannins from Acacia, or cassava peels, etc) [30-50], and animal-based chemicals (chitin, chitosan, Xanthan gum, etc) that possess many excellent intrinsic features like nontoxicity, biodegradability, and good chelating properties [15].

Hydrolysing metallic salts based synthetic chemical coagulants have been utilized in the water treatment and purification plants for more than 120 years [1,1,5,6,10,20-25]. A lot of research investigations have been reported on the use of aluminium sulphate (alum), ferric sulphate, and magnesium chloride [1,5,6,10,20-25]. Similarly, there are many studies on the pre-hydrolysing metallic salts such polyaluminium sulphate, polyferric chloride, etc [5,8,26-29]; and more recently focused studies on polyelectrolyte like aminoethyl polyacrylamides, polyamines polyethyleneimines. On the other hand, one of the groundbreaking studies that reported the application of phytochemical based coagulants for water treatments and purification were the works of Jahn and Dirar [33], and Jahn [34-37]. Jahn and Dirar [33] sourced the samples of the raw water from the Hafir of Wad Hassuna in the Butana, Khartoum Province, East of the White Nile, and the Hafir El Qirabin, a mountainous area of the Blue Nile, South of the Sinnar and West of the Blue Nile for the potable water purification

utilizing *Moringa oleifera* seeds phytochemicals as coagulant. The investigation of Adinolfi *et al.* [38], and the later works of Muyibi [39], Muyibi and Evison [40], Muyibi and Okuofu [41], Muyibi [43], Muyibi *et al.* [45], Muyibi and Alfugara [46], and Muyibi [45-47]. Likewise, there are several reported studies on the combination of hydrolysing metallic salts with polyelectrolytes or pre-hydrolysing metallic salts or phytochemical or animal-based as hybrid or composite coagulants [8,27,29,46,49-51,53]. There have been also many reported research investigations for the process improvements, intensifications, and performance evaluations of WTPPs deploying synthetic chemical coagulants [54-62] and the ones trying to employ the use of phytochemical based coagulants [18-22,33,46,49,51]. In this paper, the research was focused on the comparative studies on the comprehensive performance assessments of phyto-based and synthetic-based chemical coagulants in water treatment and purification plant (WTPP). The effectiveness of three (3) synthetic coagulants, namely: polyacryl amide, sodium aluminate, and aluminium sulphate and the water extracts of the cake for *Moringa oleifera* seeds, a phytochemical-based coagulant were examined in a newly fabricated pilot plant at the Department of Chemical Engineering, Ahmadu Bello University Zaria.

2. Materials and methods

2.1 Materials

20,000 L of the surface raw water sourced from Kubanni dam Zaria was supplied by Ahmadu Bello University Water Works (ABUWW) for the research studies. Figure 1 is the map of our studies areas, the Kubanni Dam and ABUWW, respectively.

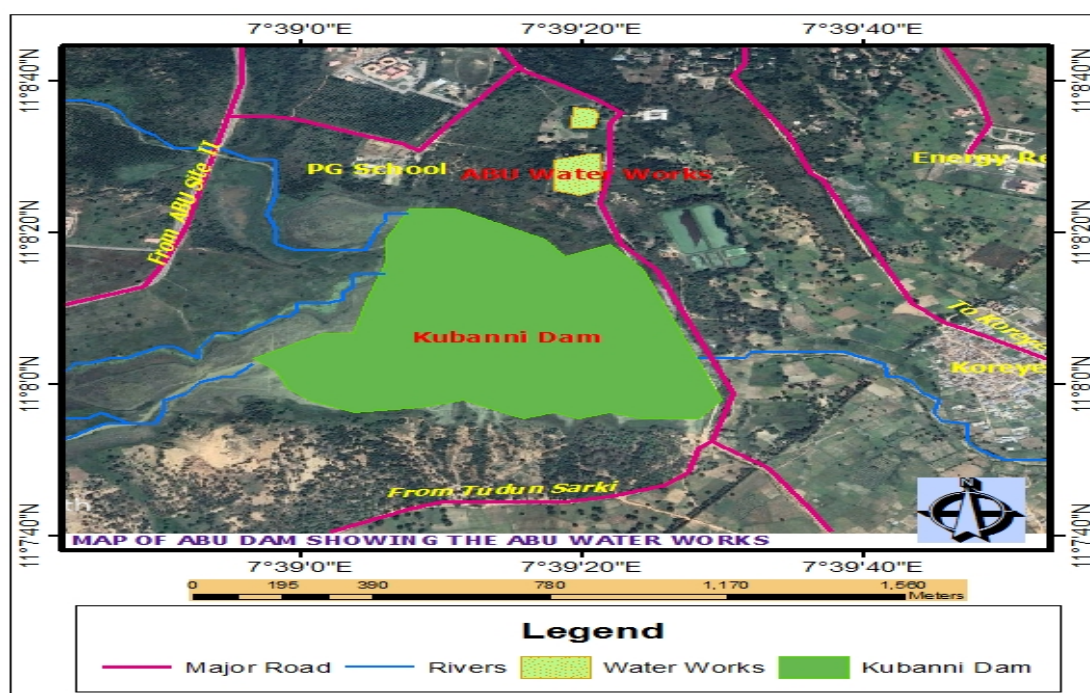


Figure 1. Map of Kubanni Dam, Zaria, Kaduna State-Nigeria

The facilities employed in the investigation include a new fabricated pilot plant for water purification and potable water production at the Department of Chemical Engineering, Ahmadu Bello University (ABU) as shown in Figures 2 and 3, a Stuart flocculator Jar test apparatus, a turbidimeter model of HACH 2100P, a Crison pH meter, a conductivity meter, test tubes, and cylinders. 200 L of distilled water, analytical grades of lactose broth, 20 mL Eriochrome black T and other important chemical reagents were used in the analysis. Phytochemical constituents of the water extracts from the cake of the dried *Moringa oleifera* seeds were used after extracting the oil as the phytochemical coagulant.



Figure 2. A Pilot Plant for Water Treatment showing the Major Unit Processes and Operations



Figure 3. A Pilot Plant for Water Treatment showing the Coagulation, Flocculation, and Sedimentation Processes

On the other hand, 20 kg of aluminium sulphate, 1.5 kg of sodium aluminate, and 400 g of polyacryl amide synthetic coagulants were utilized for the research comprehensive performance assessments.

2.2 Process description of the new fabricated pilot plant

The pilot plant consists of six major sections: the raw water storage tank, leaching tank, coagulant storage tank, coagulation-flocculation chamber, sedimentation tank, sand filtration, and treated water subsections. Raw water was pumped from the raw water storage tank into the coagulation-flocculation chamber, where either phytochemical or synthetic coagulants of interest coming from the coagulant storage tank were dosed, and rapid mixing took place. The resulting mixture was then transferred into the settling chamber for slow mixing. Afterwards, the sedimented water was passed through the sand filter for filtration, and then subsequently to the treated water storage tank. The samples of sedimented and filtered water were collected for analysis, respectively.

2.3 Preparation of the coagulants

The preparation of each of the coagulants was done separately and used immediately for the raw water treatment and purification.

2.3.1 Preparation of the Phytochemical constituents of the cake from the *Moringa oleifera* seeds

4 kg of the dried *Moringa oleifera* seeds were dehusked and ground. The powdered of the nuts were poured in the mechanical press oil extractor, where the oil was extracted. 1.2 kg of the residual cake was put in a plastic container and 40 L of distilled water added. The mixture was poured into a leaching tank and stirred at 170 rpm by the 1 HP for 17 minutes to produce the phytochemical coagulants from the residual cake. It was filtered out and then pumped into the coagulant storage tank to be used for the raw water purification. This technique was a slight modification for the method of Folkard and Sutherland [44]. The stock solution was made based on the demand for the treatment to avoid the deterioration of the protein-based water-soluble phytochemical constituents of the coagulants if kept beyond three (3) days at room temperature [36].

2.3.2 Preparation of the aluminium sulphate

2 kg of the alum flakes were dissolved in 40 L of distilled water in a leaching tank incorporated in the pilot plant and stirred at 170 rpm by the 1 HP motor for 15 minutes to ensure complete dissolution to produce 20% strength of aluminium sulphate. The solution was then pumped into the coagulant storage tank.

2.3.3 Preparation of the sodium aluminate

1.2 kg of the sodium aluminate powder in 40 L of distilled water in a leaching tank and stirred at 170 rpm by the 1 HP motor for 15 minutes to ensure complete dissolution to produce 15% strength of sodium aluminate. The solution was then pumped into the coagulant storage tank.

2.3.4 Preparation of the polyacryl amide

0.05 kg of the polyacryl amide granules in 40 L of distilled water in a leaching tank and stirred at 170 rpm by the 1 HP motor for 15 minutes to ensure complete dissolution to produce 0.1% strength of polyacryl amide. The solution was then pumped into the coagulant storage tank.

2.4 Methodology for Jar test

A standard Jar test procedure used in the United Kingdom was deployed for this study based on the rapid mixing for 2 minutes at 200 rpm to achieve homogeneity of the coagulant and then followed by slow mixing for 20 minutes at 20 rpm to have good flocculation [43]. A six place, Stuart flocculator SW 6 model Jar test apparatus was used. 1, 2, 3, 4, 5, and 6 mL of both phytochemical and synthetic coagulants were measured into 6 beakers: the first, second, third, fourth, fifth, and sixth beaker, respectively containing 500 mL of raw water. The beakers were placed inside the Jar test apparatus and the paddles were inserted for each beaker. Rapid and slow mixing were set according to the above-mentioned procedure. The beakers were removed from the apparatus, and then the supernatant solutions were allowed to settle for 2 hours.

2.5 Water Quality Performance Indicators

2.5.1 Turbidity measurement

The samples of the raw, sedimented and filtered water were put into the test tubes, and the turbidity was determined using a multipurpose turbidimeter according to the standard method such as comprehensive performance evaluation (CPE) and analytical hierarchy process (AHP) methods.

2.5.2 pH level measurement

The measurement of pH level for the raw, sedimented and filtered water were conducted using Crison pH meter Basic C20, and the results were observed and recorded according to the standard method such as comprehensive performance evaluation (CPE) and analytical hierarchy process (AHP) techniques.

2.5.3 Conductivity measurement

The measurement of electrical conductivity of the raw, sedimented and filtered water were carried out using Crison Conductivity meter Basic C30, and the results were observed and recorded according to the standard method such as comprehensive performance evaluation (CPE) and analytical hierarchy process (AHP) techniques.

2.5.4 Nitrate measurement

The samples of the raw, sedimented and filtered water for nitrates estimation were determined using cadmium reduction technique according to the standard method such as comprehensive performance evaluation (CPE) and analytical hierarchy process (AHP) methods.

2.5.5 Hardness measurement

The analysis for total hardness of the raw, sedimented and filtered water were carried out using EDTA titrimetric method, the results were observed and recorded according to the standard method such as comprehensive performance evaluation (CPE) and analytical hierarchy process (AHP) techniques.

2.5.6 Alkalinity measurement

The samples of the raw, sedimented and filtered water for total alkalinity determination were estimated using H₂SO₄ technique according to the standard method such as comprehensive performance evaluation (CPE) and analytical hierarchy process (AHP) methods.

2.5.7 Microbial load measurement

The analysis for the microbial load measurement for determining the most probable number of coliforms that were present in the raw, sedimented and filtered water were carried out using the multiple tube fermentation method, the results were observed and recorded according to the standard method such as comprehensive performance evaluation (CPE) and analytical hierarchy process (AHP) techniques.

3. Results and discussion

3.1 Jar test results for coagulants dosages per residual turbidity

Jar test is one of the powerful tools utilized for developing design criteria for the existing and new commissioned water treatment and purification plants (WTPPs), monitoring the performance

assessments, and controlling the coagulation process, as well as optimizing the operating conditions of the plant. The Jar test results for coagulants dosages per residual turbidity are shown in Table 1.

Table 1. Jar Test Results showing coagulants dosages and residual turbidity.

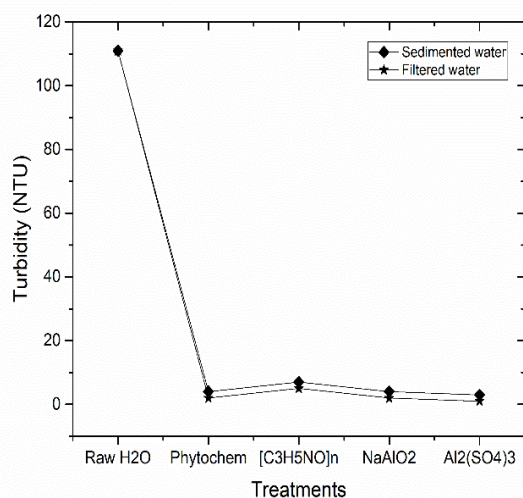
Type	Coagulants	Dosage (mL)/Residual Turbidity (NTU)					
		1 st	2 nd	3 rd	4 th	5 th	6 th
1. Phytochemical	1. <i>Moringa olifera</i>	5	4	4	2	5	3
2. Synthetic	1. [C ₃ H ₅ NO] _n	5	3	4	4	3	6
	2. NaAlO ₂	6	5	4	4	5	3
	3. Al ₂ (SO ₄) ₃	5	3	2	3	2	4

From Table 1, the turbidity values ranged from 2 to 6 NTU for all the treatments. The raw water is used as the control with the highest turbidity of 111 NTU as shown in Figure 4 (a). At a phytochemical coagulant dosage of 1, 2, 3, 4, 5, and 6 mL, the residual turbidity of the treated water was 5, 4, 4, 2, 5, and 3 NTU, respectively. This shows that the optimum dosage is 4 mL per 500 L of the raw water, which was used to set the flow rate for phytochemical based coagulant treatment. At the aluminium sulphate dosage of 1, 2, 3, 4, 5, and 6 mL, the residual turbidity of the treated water was 5, 3, 2, 3, 2, and 4 NTU, respectively. This shows that the optimum dosage is 3 mL per 500 L of the raw water, which was used to set the flow rate for aluminium sulphate treatment. Similarly, at the sodium aluminate dosage of 1, 2, 3, 4, 5, and 6 mL, the residual turbidity of the treated water was 6, 5, 4, 4, 5, and 3 NTU, respectively. This indicates that the optimum dosage should be 6 mL per 500 L of the raw water, but 3 mL per 500 mL is more suitable in terms of financial implications, thus, it was considered as the optimum dosage, which was used to set the flow rate for sodium aluminate treatment. Lastly, at the polyacryl amide dosage of 1, 2, 3, 4, 5, and 6 mL, the residual turbidity of the treated water was 5, 3, 4, 4, 3, and 6 NTU, respectively. This shows that the optimum dosage is 2 mL per 500 L of the raw water, and this was used to set the flow rate for polyacryl amide treatment.

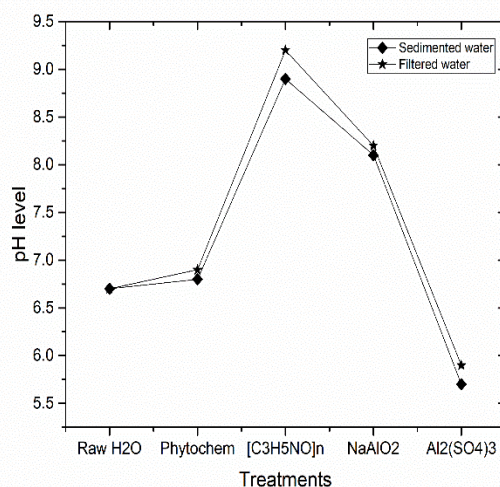
3.1 Influence of phytochemical and synthetic coagulants on water quality performance indicators

3.1.1 Influence of phytochemical and synthetic coagulants on turbidity and pH levels

Figure 4 (a) and (b) depicts the profiles of water extracts of the cake for *Moringa oleifera* seeds phytochemical based coagulants, and polyacryl amide, sodium aluminate, and aluminium sulphate synthetic coagulants on the turbidity removal and pH levels.



(a)



(b)

Figure 4. Effect of Phytochemical and Synthetic Coagulants on the Turbidity and pH Levels.

From Figure 4 (a), the values of turbidity ranged from 1 to 111 NTU for the raw water considered as the control with the initial highest value of the turbidity before the treatments. Each of the coagulants gave results that were acceptable according to the standards of WHO after sedimentation and filtration except for polyacryl amide treatment which showed 7 and 5 NTU, respectively. The maximum allowable value for turbidity for safe drinking water set by WHO guideline is 5 NTU [63]. The treatment with water extracts of the cake for *Moringa oleifera* seeds phytochemical based coagulants, polyacryl amide, sodium aluminate, and aluminium sulphate synthetic coagulants reduced the turbidity from 111 to 4, and 2; 7 and 5; 4 and 2; 3 and 1 NTU after sedimentation and filtration, respectively. It is clearly seen that the treatment with phytochemical based coagulants gives similar results in comparison with aluminium sulphate and sodium aluminate and performed better than that of polyacryl amide. This shows that *Moringa oleifera* phytochemical based coagulants has the potentials to compete and replace some of the synthetic coagulants for water purification and potable water production. This can lead to the cost reduction in the conventional water treatment using aluminium sulphate, sodium aluminate, polyacryl amide, etc, without any risk or threat to human life due to the overdose of synthetic chemical coagulants as stated by Crapper *et.al.* [29], Kaggwa *et. al.* [26], and Martenson *et. al.* [32].

Likewise, from Figure 4 (b), it can be observed that the values of pH levels range from 5.9 to 9.2. The pH values of sedimented and filtered water for aluminium sulphate was 5.7 and 5.9, respectively, which falls outside the WHO [63] recommended standards. The recommended acceptable

range of pH for the safe drinking water specified by WHO [63] is between 6.0 and 8.0. This could be explained by the fact that the solutions were becoming more acidic. This could be attributed to the fact that the treatment with aluminium sulphate produces sulphuric acid which lowered the pH levels. The increase in acidity could be due to the trivalent cation aluminium which serves as a Lewis acid. Hence, it can accept a lone pair of electrons. This calls for the pH adjustment with coagulation aids such as lime in order to control the coagulation process in the feasible region of maximum efficiency. The reverse of the case was observed with the treatments of *Moringa*, sodium aluminate, and polyacryl amide. The pH levels increased slightly from 6.7 to 6.8 and to 6.9 after sedimentation and filtration, respectively. Ndabigengesere et. al. [16] stated the action of *Moringa oleifera* phytochemical-based coagulant lies in the presence of water-soluble cationic proteins in the residual cake. This suggests that the basic amino acids present in the protein of *Moringa oleifera* based coagulant would accept a proton from water resulting in the release of a hydroxyl group making the solution basic. This accounted for the values of basic pH levels observed for the treatments with phytochemical based coagulants compared with that of aluminium sulphate. However, it is less basic when compared with sodium aluminate.

3.1.2 Influence of phytochemical and synthetic coagulants on conductivity and hardness

The response for the conductivity and hardness are exhibited in Figure 5 (a) and (b). For the conductivity profile, it can be seen that the conductivity performance indicator ranged from 3 to 21 for both the phytochemical and synthetic coagulants except in the case of the raw water (i.e., control), where the highest value of 158 ppm was observed and recorded. Conductivity is a measure of total dissolved solids (TDS) in water. In other words, is a measure of the ability of water to conduct an electrical current. The treatments of raw water with water extracts of the cake for *Moringa oleifera* seeds phytochemical based coagulants, polyacryl amide, sodium aluminate, and aluminium sulphate synthetic coagulants reduced the conductivity from 158 to 18, and 4; 21 and 17; 17.5 and 4.8; and 16 and 3 ppm, after sedimentation and filtration, respectively. It can be observed that aluminium sulphate showed the best efficiency with 16 and 3 ppm, and closely followed by *Moringa oleifera* based phytochemical coagulants with 18 and 4 ppm, respectively. Thus, it is clearly seen that the phytochemical coagulants can be adopted to decrease the turbidity and dissolved impurities in rural areas and can serve as replacement for aluminium sulphate, sodium aluminate, or polyacryl amide in existing and new treatment plants.

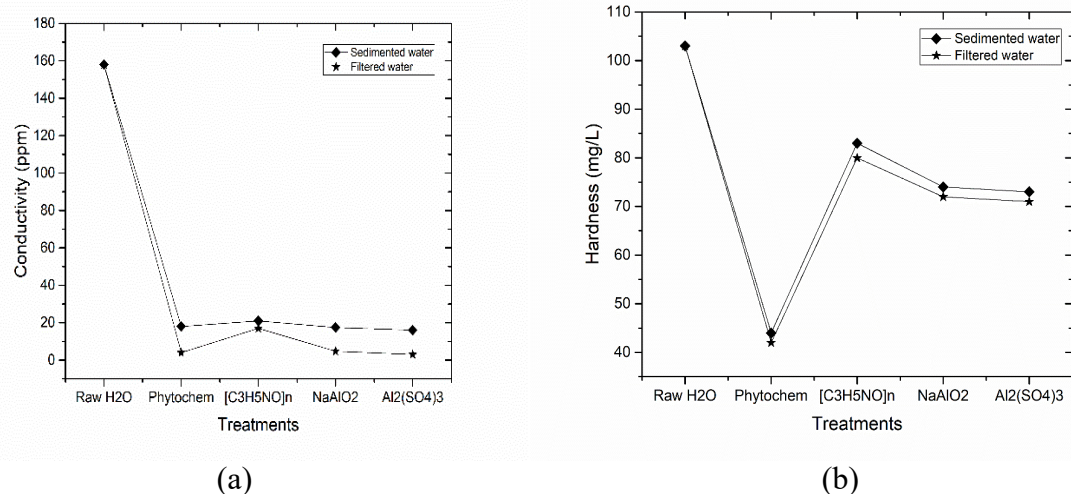


Figure 5. Effect of Phytochemical and Synthetic Coagulants on the Conductivity and Hardness.

In the case of hardness water quality parameter, the treatments of the raw water with the extracts of the cake for *Moringa oleifera* seeds phytochemical based coagulants, polyacryl amide, sodium aluminate, and aluminium sulphate synthetic coagulants reduced the hardness of the raw water from 103 to 44, and 42; 83 and 80; 74 and 72; and 73 and 71 mg/L, after sedimentation and filtration, respectively. It can be observed from Figure 5 (b) that the *Moringa oleifera* based coagulum had the lowest hardness of 44 and 42 mg/L after sedimentation and filtration, respectively. However, the treatment with alum and sodium aluminate can achieve only the reduction of hardness from 103 mg/L to 73 and 70 mg/L; 74 and 71 mg/L after sedimentation and filtration, respectively. Polyacryl amide had the least performance reduction of hardness from 103 mg/L to 82 and 80 mg/L after sedimentation and filtration respectively. According to WHO [63], the maximum permissible level of drinking water hardness as CaCO_3 is 150 mg/L and 200 mg/L respectively. Although all the values observed for both synthetic and phytochemical coagulants fall within the recommended values, it can be clearly seen that the three (3) synthetic chemical coagulants do not possess the effective softening properties. Nevertheless, *Moringa oleifera* based phytochemical coagulum appears to have the best softening features. It was observed that *Moringa oleifera* coagulum removed 46.99 – 49.4 % hardness in water which lends support to earlier findings of Muyibi and Evison [40], and Muyibi [63].

3.1.3 Influence of phytochemical and synthetic coagulants on conductivity and hardness

Figure 6 (a), and (b), shows the profiles for nitrates and alkalinity in the initial raw water (control), and the residual treated water after sedimentation and filtration.

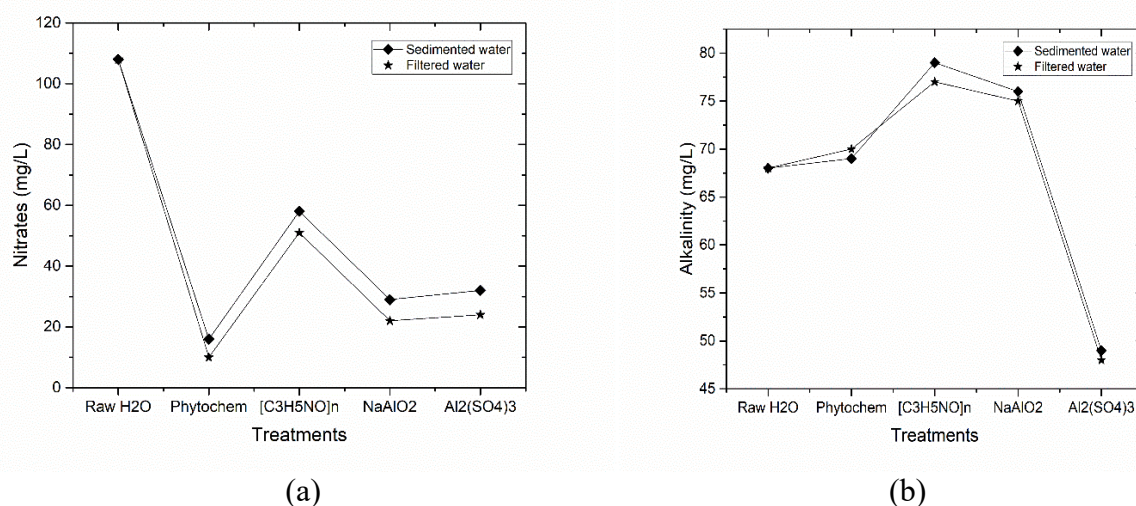


Figure 6. Effect of Phytochemical and Synthetic Coagulants on the Nitrates and Alkalinity.

From Figure 6 (a), the profile displays nitrates residual concentration as a function of different types of treatments for both synthetic and phytochemical coagulants with the initial concentration of raw water of 103 mg/L. The treatments of the raw water with the extracts of the cake for *Moringa oleifera* seeds phytochemical based coagulants, polyacryl amide, sodium aluminate, and aluminium sulphate synthetic coagulants reduced the hardness of the raw water from 108 to 16, and 10; 58 and 51; 29 and 22; and 32 and 24 mg/L, after sedimentation and filtration, respectively. It can be observed from the results that *Moringa oleifera* seeds phytochemical based coagulants was the most effective coagulant in terms nitrates reduction, then followed by sodium aluminate, aluminium sulphate and lastly polyacryl amide. It was noted that the higher nitrates values obtained from the treatment with polyacryl amide were not in conformity with WHO [63] standards. On the other hand, the profiles for alkalinity residual concentration as a function of different types of synthetic and phytochemical coagulants are depicted in Figure 6 (b). The treatments of raw water with *Moringa oleifera* based phytochemical coagulants, polyacryl amide, sodium aluminate, and aluminium sulphate synthetic coagulants adjusted the alkalinity of the raw water from 68 to 69 and 70; 79 and 77; 76 and 75; and 49 and 48 mg/L, after sedimentation and filtration, respectively. It was observed that *Moringa oleifera* based phytochemical

coagulants slightly increased the alkalinity from 68 to 69 and 70 mg/L after sedimentation and after filtration. That slight increase in alkalinity may be due to the precipitation of insoluble products of the reaction between the *Moringa oleifera* based phytochemical coagulant and the hardness property of the raw water causing ions alike to softening by precipitation using coagulation aids. This indicates that the phytochemical-coagulant does not react with natural alkalinity before coagulation is achieved. It is quite different for the synthetic chemical coagulants. The treatment of the raw water with aluminium sulphate was the only one that led to the reduction in alkalinity from 68 to 49 and 48 mg/L after sedimentation and filtration. With sodium aluminate treatment, an increase in alkalinity was observed from 68 to 76 mg/L after sedimentation, followed by a slight reduction to 75 mg/L after filtration. This corresponds to 11.76 % increment and 1.32 % decrease, respectively. The highest alkalinity change was observed with the polyacryl amide treatment; sedimented and filtered water from 68 to 79 and 77 mg/L, which corresponds to 16.17 % increase and 2.53 % decrease, respectively.

3.1.4 Total coliform counts

The total coliform counts per 100 mL recorded for the sedimented and filtered water for the *Moringa oleifera* based phytochemical coagulant; polyacryl amide, sodium aluminate, and aluminium sulphate (alum) synthetic chemical coagulants was observed to be 2 and 2; 9 and 7, 10 and 8, and 13 and 11, respectively. It can be observed that phytochemical coagulant from *Moringa oleifera* seeds gave the lowest count of 2 for both the sedimented and filtered water corresponding to 89.47 % of the most probable number (MPN) for the total coliform per 100 mL. According to Eirlert *et. al.* [31], *Moringa oleifera* seeds contain active antimicrobial agents and when isolated was found to be 4- α L-rhamnosyloxy-benzyl isothiocynate. Therefore, the wonderful performance of *Moringa oleifera* based phytochemical coagulant 89.47 % and 94.74 reductions in the microbial load after sedimentation and filtration, respectively may be attributed to antimicrobial active ingredients. These results show a wonderful performance in getting rid of the bacteria and oppose the ones that exaggerate the claims on flocculation process alone in the removal of bacteria which are normally attached to the solid particles when synthetic chemical coagulants are used. The raw water (i.e., the control) had the highest counts of coliform (20/100 mL). This affirms the earlier mentioned recommendation that raw water without treatment is not safe for drinking, thus if consumed may lead to water borne disease.

4. Conclusion

In a nutshell, the comprehensive performance assessments of the water extracts of the cake for *Moringa oleifera* seeds phytochemical coagulant and three (3) synthetic chemical coagulants: polyacryl amide, sodium aluminate, and aluminium sulphate in quality drinking water treatment and purification plant (WTPP) were successfully examined. The four (4) coagulants were subjected to Jar test and the outcome for the experiments were utilized in the operation of a new fabricated pilot plant. The water quality parameters used include turbidity, pH level, conductivity, hardness, nitrates, alkalinity, and microbial load performance indicators, and their values were found in conformity with the standards of the Nigerian Standard Drinking Water Quality (NSDWQ) and that of the World Health Organization (WHO). Based on the research findings, the following conclusions can be drawn:

1. It was observed that the effectiveness of the water extracts of the cake for *Moringa oleifera* seeds phytochemical coagulant was found to be higher than that of polyacryl amide and similar to those of aluminium sulphate and sodium aluminate synthetic chemical coagulants.
2. *Moringa oleifera* seeds based phytochemical coagulant has an added advantage of stronger softening features and anti-microbial properties over aluminium sulphate, sodium aluminate, and polyacryl amide synthetic chemical coagulants.
3. For raw water (i.e., the control) with turbidity of 111 NTU, the optimum doses of aluminium sulphate, sodium aluminate, polyacryl amide synthetic chemical coagulants, and *Moringa oleifera* based phytochemical coagulant were found to be, 2 mL/500 mL, 3 mL/500 mL, 3 mL/500 mL, and 2 mL/500 mL, respectively.
4. It was noted that the treatments with *Moringa oleifera* based phytochemical coagulant, aluminium sulphate, sodium aluminate, and polyacryl amide synthetic chemical coagulants gave a reduction in turbidity of 98.2, 99.1, 99.1, and 95.5%, respectively after filtration. The observed turbidity values met the NSDWQ, and WHO/ISO standards.
5. It was observed that the treatment with *Moringa oleifera* seeds based phytochemical coagulant does not affect the values of the pH levels during coagulation, while the treatments with synthetic chemical coagulants were significantly affected by the pH levels. It was noted to be only between 6.7 and 6.9 after filtration for *Moringa oleifera* seeds based phytochemical coagulant. However, the pH levels of aluminium sulphate reduced from 6.7 to 5.9, while sodium aluminate and polyacryl amide synthetic chemical coagulants increased from 6.7 to 8.2 and 9.2, respectively.
6. The reduction in conductivity was observed to be 97.47, 98.1, 96.96, and 89.24% for the *Moringa oleifera* based phytochemical coagulant, aluminium sulphate, sodium aluminate,

- and polyacryl amide synthetic chemical coagulants, corresponding to electrical conductivity value of 4, 3, 4.8, and 17 ppm respectively which indicated low dissolve solids.
7. It was noted that the treatments with *Moringa oleifera* seeds based phytochemical coagulant, aluminium sulphate, sodium aluminate, and polyacryl amide synthetic chemical coagulants reduced the hardness of the raw water from 103 mg/L to 61, 71, 72, and 80 mg/L, respectively after filtration, in which all the coagulants met the WHO/ISO standards of having values below 200 mg/L. Hence, *Moringa oleifera* based phytochemical coagulant appears to be the most effective coagulant, followed by aluminium sulphate, sodium aluminate, and lastly polyacryl amide synthetic chemical coagulants.
 8. It was observed that the treatments with *Moringa oleifera* seeds based phytochemical coagulant, aluminium sulphate, sodium aluminate, and polyacryl amide synthetic chemical coagulants gave nitrates reduction of 98.2, 99.1, 99.1, and 95.5%, respectively after filtration. The observed nitrates values were all below 50 mg/L, which are in conformity with the WHO/ISO standards.
 9. It was observed that the synthetic chemical coagulants aluminium sulphate, sodium aluminate and polyacryl amide reacted quickly with the associated alkalinities present in the raw water before achieving effective coagulation while *Moringa oleifera* seeds based phytochemical coagulant does not.
 10. The most probable number (MPN) of coliform bacteria was observed to reduce from initial raw water (i.e., the control) of 20/100 mL to 2, 7, 8, and 11 with treatments of *Moringa oleifera* seeds based phytochemical coagulant, aluminium sulphate, sodium aluminate, and polyacryl amide synthetic chemical coagulants after filtration, corresponding to 90, 65, 60, and 19.45% reduction in microbial load, respectively. Therefore, *Moringa oleifera* seeds based phytochemical coagulant appears to be the most effective coagulant, followed by aluminium sulphate, sodium aluminate, and lastly polyacryl amide synthetic chemical coagulants.

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Conflict of Interest

The authors declare that there is no known conflict of interest in this research paper.

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