Comparative study of the use of natural and artificial coagulants for the treatment of sullage (domestic wastewater)

S.N. Ugwu, A.F. Umuokoro, E.A. Echiegu, B.O. Ugwuishiwu and C.C. Enweremadu

Cogent Engineering (2017), 4: 1365676
Comparative study of the use of natural and artificial coagulants for the treatment of sullage (domestic wastewater)

S.N. Ugwu¹,²*, A.F. Umuokoro², E.A. Echiegu², B.O. Ugwuishiwu² and C.C. Enweremadu¹

Abstract: This work presented a comparative study of the effectiveness of natural coagulant (Moringa oleifera and hydrolyzed cassava) extracts and artificial coagulant (alum) as primary coagulants for sullage from homes and cafeteria at the University of Nigeria, Nsukka. Stock solutions of these coagulants were prepared, and jar test of their varying mixing ratios used to obtain optimum dosages of 200, 30 and 1,000 mg/l for Moringa, alum and cassava respectively. The effects of these optimum dosages were tested against turbidity, pH, BOD, nutrients, hardness and coli form. All tested parameters were significantly sensitive to concentrations of used stock solutions. 100% Moringa seed extract resulted in all the treated parameters (except turbidity) being within tolerable limits. The stock solution of 100% Alum also showed all tested parameters (except pH) to be within the standards for drinking water. The combination of Moringa and alum stock solutions at 50% each (A50M50) showed the overall best result with the resultant water fit for drinking. The result of the comparative test showed that alum with its residual and health implications can be successfully replaced, partially or wholly, with natural coagulants.

ABOUT THE AUTHORS
E.A. Echiegu is an Associate Professor, B.O. Ugwuishiwu is a Senior Lecturer, S.N. Ugwu is a Lecturer and Umuokoro Azubike is a graduate Engineer; all are of the Environmental Control Unit in Department of Agricultural and Bioresources Engineering, University of Nigeria. C.C. Enweremadu is the Head of Bioresources Research in the Department of Mechanical and Industrial Engineering, University of South Africa, All the authors have varying years of experiences in researching.

This research "Comparing the effect of Alum, Moringa and Cassava extracts singularly and in combination on wastewater generated from the kitchen (sullage)", is part of our research aimed at solving local water and environment challenges. The research team is currently working on nutrient recovery from wastewater, agro-industrial waste streams and other aspects of environmental concerns. The group is open for collaboration.

PUBLIC INTEREST STATEMENT
The amount of wastewater generated daily in kitchens (homes or restaurants) is enormous amidst acute shortage of potable water in most African countries. The short supply of drinkable water compels people to reuse wastewater without any form of treatment, exposing them to water-related or water-borne diseases. However, the indispensability of water to man’s existence on earth necessitates the need for proper treatment. Settling of impurities in water is an important stage of water/wastewater treatment which requires addition of coagulants (artificial or natural). Alum (artificial coagulant) is mostly used in settling water impurities, but it has health concerns when used for long. Natural coagulants (from plants or animal) includes Moringa seed extracts, hydrolyzed cassava, etc. In this work, we replaced artificial coagulants(alum) partially or wholly with more health friendly natural coagulants (Moringa seed extracts and hydrolyzed cassava extracts) in other to encourage cheap and safe treatment/reuse of wastewater.
1. Introduction

Water occupies about 70% of the earth's space with only 0.4% available for use (Himesh, Rao, & Mahajan, 2000). The available minute fraction is threatened by overexploitation, poor management and ecological degradation (Jodi, Birnin-Yauri, Yahaya, & Sokoto, 2012). Growing human activities not only have increased demand for potable water, but have also increased the generation of wastewater (UN Report, 2013).

Clean water is very essential to human existence, and the unavailability of potable water is the predominant reason for most deaths and diseases. The quality of water according to CDC (2015) is a health concern; water-related and waterborne diseases are responsible for about 80% of diseases in the world. These qualities include but not limited to colour, odour, coliform count, turbidity, nutrients (Renuka, Binayke, & Jadhav, 2013). Poor sanitation and unsafe water cause 88% of the 4 billion annual cases of diarrhea, resulting in the death of about 1.8 million people per annum. Safe water and hygienic environment can reduce about 94% death cases (World Health Organization, 2007). It is however important to subject water from every source to varying forms of treatment or purification before consumption, or discharge in the case of wastewater. These forms of purification are aimed at making water potable and attractive. The level of threat water poses determines the choice of treatment to be employed (Ali, Mayibi, Salleh, Salleh, & Alam, 2009).

Turbidity and biological contaminations are major reasons for treating surface water, sullage and other wastewater types (McConnachie, Folkard, Mtawali, & Sutherland, 1999). Before distribution for consumption, raw water is subjected to the following conventional procedures: screening, plain sedimentation, coagulation-flocculation followed by sedimentation, filtration and disinfection (Ndabigengesere & Narasiah, 1998a). In these processes, coagulants play very vital role in the reduction of water turbidity and removal of other contaminants. Coagulants are divided into artificial and natural coagulants. Natural coagulants include extracts of microorganisms, animal or plant origin (Ganjidoust, Tatsumi, Yamagishi, & Gholian, 1997; Kawamura, 1991; Lee, Lee, Jang, & Lee, 1995). Examples include Narmali seeds, Moringa seeds, Okra, Cassava, Dutchus lablab, broad beans, flava beans, watermelon, etc. Artificial coagulants, on the other hand, include aluminium sulphate (alum), aluminium chloride and sodium aluminate, ferric sulphate, ferrous sulphate, ferric chloride and ferric chloride sulphate. Others include hydrated lime and magnesium carbonate (Muyibi, Noor, Ong, & Kai, 2001).

Alum (aluminium sulphate), has been the most popular for treatment of water and widely used in treatment plants. It has been found to pose some health, economic and environmental problems upon usage, among which are neurological diseases such as percentile dementia and induction of Alzheimer's disease (Martyn et al., 1989). Sludge produced is also voluminous and non-biodegradable after treatment, leading to increase in cost of treatment. The high cost of chemical importations results in loss of foreign exchange to nations. The effect of most chemical coagulants like Aluminum on the pH of the treated water, attracts extra cost on lime which should be added to buffer its effect (Muyibi, 2005).

Although the use of plant materials as natural coagulants in the reduction of turbidity in wastewaters, dates to ancient times, there seems to be renewed interest in applying natural coagulants for water treatment in emerging economies (Ndabigengesere & Narasiah, 1998b; Nilanjana, 2005). Coagulants from natural sources are often seen to be safe for human health (Nilanjana, 2005). Some natural coagulants have been studied, and are known to have the following advantages: the sludge produced is usually biodegradable, it is virtually toxin-free, relatively cheap to obtain, and locally available (Victoria, 2010).
Moringa olifera and Cassava are also abundant in the tropics and found to be good coagulants (Adamu, Adie, & Alka, 2014; Prasad & Rao, 2013; Renuka et al., 2013). The residual elements present in these natural coagulants are within the WHO limits for water treatment; and the sludge from the treatment process is biodegradable (Adamu et al., 2014). Figure 1 shows the coagulants of interest in this research. Some of these coagulants have been found to have high coagulation activity only for high turbid water, while others are effective in low turbid water (Muyibi & Evison, 1995).

Though there had been many studies on Moringa oleifera and Manihot palmate separately in comparison to alum as coagulants for domestic wastewater treatment (Adamu et al., 2014; Renuka & Karunyal, 2017), there is no study on the combined effects of Moringa seed and cassava extracts when compared with alum on sullage treatment. Large amount of sullage is generated from homes and restaurants in most Nigerian cities and other developing climes. There is also an abundance of Cassava and Moringa in the Tropics. This necessitates the need to explore the potentials of combining Cassava and Moringa extracts as substitute for alum. The objective of this study was to meet the increasing demands for potable water by replacing wholly or partly/singularly or in combination the artificial coagulant (alum) with natural coagulants (M. oleifera and M. palmate) at varying doses and ratios in treating sullage generated in homes and cafeterias. In a nutshell, utilizing the efficacies of Moringa seed and cassava (M. palmate) extracts relative to that of alum in treating sullage was studied.

2. Materials and method

2.1. Site description

The experiment was carried out in the University of Nigeria, Nsukka (UNN) with the population size of about 50,000 staff and students. Nsukka is a mixed forest region (tropical rainforest and Guinea savanna), located on latitude 6°51′24″ N and longitude 7°23′45″ E with average temperature and annual rainfall of 24.9°C and 1,579 mm respectively (CLIMATE-DATA, 2017). Water scarcity is a constant phenomenon in staff quarters and students' hostels because of low water table and few water bodies in Nsukka. The University has a Students’ Centre (Chukwuma Kaduna Nzeogwu Building) which accommodates five big cafeterias with sullage generation capacity of about 22.7 m³ per day. Wastewater from wash basins and kitchens are centrally collected in several big bowls and subsequently discharged through the sewers daily. Experimental samples of fresh domestic wastewater were collected at the sullage disposal point. The M. oleifera seeds, cassava tubers (M. palmate) and solid crystalline alum (aluminium sulfate) were sourced from the Nsukka local market. Laboratory reagents and other consumables were bought from GeoChem Laboratory, Nsukka (Figure 2).

2.2. Design of experiment

The experimental layout was Completely Randomized Design (CRD) with 13 treatments and 3 replications. Statistical software (GenStat Discovery Edition 4.2 and Microsoft Excel 2016) was used for the One-way analysis of variance (ANOVA) and Duncan’s multiple range test. The three treatments shown in Table 1 were various doses of Moringa seed extracts (M), Hydrolyzed Cassava extracts (C), and Solutions of Alum (A) used in treating the collected sullage. Responses were the concentrations of the chemical constituents of the sullage in each treatment when sampled and analyzed (Figure 3).
2.3. Sample collection, preparation and set-up

Fresh sullage from the storage bowl was collected before disposal into the sewer with 10-liter container (contaminant free) and stored in a refrigerator at 6°C until usage. The locally sourced raw materials were processed into powdered form. Stock solutions of Moringa and alum were prepared directly some minutes before dosing. For cassava solution, 200 g of the grinded cassava flour was added to 0.3 M HNO₃, and allowed to stand for 24 h, before washing with distilled water to obtain a pH of 7.1. Fifty grams (50 g) of cassava solution was then dissolved in 1,000 ml of distilled water, and the filtrate used directly (Adamu et al., 2014). The sullage was then poured into 10 beakers of 250 ml capacity at the Public Health Laboratory of Civil Engineering Department, UNN for jar test. The jar test to determine appropriate/optimum dosage of the coagulants was conducted with different doses of the coagulants.
2.3.1. Jar test
Out of the ten beakers of 250 ml capacity, nine beakers were filled with 250 mL sullage and labeled according to the dosage of the coagulant added to it, while one beaker of sullage was left without addition of any coagulant and labeled as control. The doses used for the jar test are as shown in Table 2.

These doses were added to the freshly sourced sullage and stirred vigorously with a magnetic stirrer for 3 min and then slowly for another 5 min. It was then left to settle for about one hour, the clearer of each dosage was picked as optimum for that coagulant.

From these jar test doses, the optimum dose of each of the coagulant was determined and later mixed by percentages as shown in Table 1 for sullage treatment.

2.4. Sullage characterization
The following equipment were used for analysis and characterization of both the treated and untreated sullage: Volumetric flask, Pipette, Tall test tube, turbidimeter Water bath, Spectrophotometer (LABATEC, L-10), conical flask, burette, pH meter (HACH Senson 3), Dissolved oxygen metre, incubator (Meanert Germany).

2.4.1. Determination of nutrients
The nutrient component of the wastewater was characterized using methods prescribed by Standard Method for Wastewater examination by APHA and AWWA (2012) while the qualitative inorganic analysis was carried out as described in Vogel (2000). Back-titration method was used for the determination of nitrogen (nitrate); ascorbic acid method was used in determining phosphorus (phosphate) composition; and EDTA (Ethylene diamine tetra acetate) method was used in knowing the quantity of calcium in the wastewater before and after treatment.

2.4.2. Determination of biochemical oxygen demand (BOD)
This was done by taking the dissolved oxygen level of the treated water on the 1st day, and on the 5th day using the dissolved oxygen meter. According to United States Environmental Protection Agency (2012), the difference in the two levels gives an estimate of the BOD.

\[ \text{BOD}_5 = D_1 - D_2 \]

where BOD$_5$ is the five-day biochemical oxygen demand; $D_1$ is the initial dissolved oxygen; $D_2$ is the final dissolved oxygen level after five days.

2.4.3. Coliform count
As outlined in APHA and AWWA (2012), Multiple Tube Fermentation technique was used to statistically determine the number of coliform bacteria in a known volume of the wastewater sample. A threefold dilution series was prepared for each sample using Lauryl Tryptose Broth (LTB) tubes for the presumptive test and Brilliant Green Bile broth (BGB) for the confirmatory test. After incubation at 37°C for 12–48 ± 3 h, the pattern of positives and negatives were noted and a standardized MPN table consulted to determine the most probable number of organisms (causing the positive results) per 100 mL of each of the effluent samples.

| S/No | Coagulant type    | Dosage   |
|------|-------------------|----------|
|      |                   | I (mg/l) | II (mg/l) | III (mg/l) |
| 1    | Moringa powder    | 50       | 100       | 200        |
| 2    | Cassava powder    | 200      | 400       | 1,000      |
| 3    | Alum powder       | 10       | 30        | 50         |
2.4.4. Determination of other parameters
The temperature of waste samples was measured using thermometer at room temperature. With the aid of an electronic pH meter (HACH Senson 3), the pH of waste samples was determined. Also, a portable turbidimeter was used to show the turbidity level of waste samples.

3. Result and discussion
The physicochemical characteristics of sullage such as turbidity, pH, BOD, Phosphorus, Nitrogen, Calcium, hardness, Coliform were measured. The experiments were run in triplicates and the obtained results are reproducible. The mean concentrations of chemical properties for the treatments are presented in Table 3 and on Figure 4. The ANOVA results for the measured sullage properties after treatment using CRD are presented in Tables 3 and 4.

3.1. Turbidity
In Table 3, the turbidity results of optimum doses from different mixing ratios (in percentage) of the coagulants after the jar test are shown. The varying mixing ratios were used to obtain optimum dosages of 200 mg/l for Moringa, 30 mg/l for alum and 1,000 mg/l for cassava. The turbidity values were obtained about two hours after the treated samples were left undisturbed and then decanted. After the introduction of coagulants, Adamu et al. (2014) suggested that layer compression and adsorption as well as neutralization of charged particle by other charged particles results in cleaving, settling and formation of precipitates during coagulation. From Table 3 above, it was observed that A100 and A50M50 had the best results at 96 and 95% turbidity reduction level respectively, which are within the World Health Organization (2017) standards for drinking water. M100 reduced turbidity in sampled sullage by 91%, which is consistent with Ndabigengesere and Narasiah (1998b) whose report showed that turbidity was reduced by 89.2%. Rodriguez-Núñez et al. (2012) also recorded 88.9% on water samples with an initial turbidity of 118 NTU, using a dosage of 250 mg/l. The C70M30 had the least reduction in turbidity from 102.5 to 57 NTU. The limitation in turbidity removal recorded in moringa confirmed that it is less effective at treating water with low levels of turbidity (Prasad & Rao, 2013). Similarly, low level of turbidity and high pH may be responsible for the low turbidity removal in all cassava ratio (Adamu et al., 2014). The turbidity results of all samples were statistically different at 95% probability level.

3.2. pH
Table 3 shows the variation in pH values as a function of coagulant dosages. It was observed that sample A100 gave the lowest pH value of 6.2. This, according to Muyibi (2005), is caused by the reaction of alum with natural alkalinity present in the water. This result was in sync with that of Ndabigengesere, Narasiah, and Talbot (1995) which showed that Alum causes the pH to decrease rapidly. pH of A100 when compared (Figure 4) is not within the World Health Organization (2017) and Nigerian Industrial Standard (2007) water standards which recommended limits between 6.5 and 8.5. Additional treatment is therefore required to correct and lower the pH by using calcium hydroxide or lime. There is no significant difference in the mean values of M100, Control and C70M30 at 6.8; C100 and M50C50 at 6.9 and M70A30 and C50A50. Others, M70C30, C70A30, A100, A70M30, A70C30 and A50M50 at 7.1, 7.3, 6.2, 6.5, 6.6 and 7.2 respectively are significantly different at 95% probability level. Moringa and cassava doses need no pH adjustment, but the low pH resulting from the use of alum can be remediated by the addition of alkali like lime or sodium hydroxide if water alkalinity is not high already (Ndabigengesere et al., 1995). However, while the high pH in cassava doses is a cost saving measure, it is contrary to the report of Adamu et al. (2014) which suggested that coagulation processes are dependent on pH values and that low pH of hydrolyzed cassava extracts enables more coagulation. Hence leaving the cassava extracts more acidic ensures lower pH which in turn improves its coagulating abilities.

3.3. BOD
The initial BOD was low at 5.2 mg/l, but was still outside the standard range of 5 mg/l (World Health Organization, 2017). All the treatments of Moringa, alum and cassava (in combination or singularly) reduced further the initial BOD after treatment. BOD measures the level of demand for oxygen by
| % dosages | Turbidity (NTU) | pH    | BOD$_5$ (mg/l) | P (mg/l) | N (mg/l) | Ca (mg/l) | CaCO$_3$ (mg/l) | Coliform (cfu/100 ml) |
|-----------|----------------|-------|----------------|----------|----------|-----------|-----------------|----------------------|
| L1        | 102.5 ± 0.1$^a$ | 6.8 ± 0.1$^a$ | 5.2 ± 0.01$^a$ | 1.56 ± 0.01$^a$ | 15.4 ± 0.02$^a$ | 8.4 ± 0.01$^a$ | 21 ± 0.1$^a$ | 200 ± 1$^a$ |
| L2        | 9.8 ± 0.1$^b$  | 6.8 ± 0$^a$ | 2.3 ± 0.01$^b$ | 0.174 ± 3.399E-17$^b$ | 7 ± 0.1$^b$ | 3.16 ± 0.01$^b$ | 10.4 ± 0$^b$ | 5 ± 1$^b$ |
| L3        | 39.7 ± 0.1$^c$ | 7.1 ± 1.088E-15$^d$ | 3.6 ± 0.01$^c$ | 0.105 ± 0.001$^c$ | 8 ± 0$^c$ | 2.18 ± 0.01$^c$ | 5.45 ± 0$^c$ | 10 ± 0$^c$ |
| L4        | 13.2 ± 0.1$^d$ | 6.7 ± 0$^d$ | 1.4 ± 0.01$^d$ | 0.113 ± 0.001$^d$ | 6.9 ± 0.1$^d$ | 2.75 ± 0.01$^d$ | 6.65 ± 0.02$^d$ | 11 ± 0$^d$ |
| L5        | 51.2 ± 0.1$^e$ | 6.9 ± 1.088E-15$^d$ | 2.5 ± 0.01$^e$ | 0.105 ± 0$^e$ | 7.2 ± 0.1$^e$ | 4.7 ± 0$^e$ | 11.75 ± 0.01$^e$ | 11 ± 0$^e$ |
| L6        | 55.5 ± 0.1$^f$ | 6.9 ± 1.088E-15$^d$ | 3.3 ± 0.1$^f$ | 0.054 ± 0.001$^f$ | 8.1 ± 0.1$^f$ | 0.76 ± 0.1$^f$ | 1.90 ± 0.05$^f$ | 18 ± 0$^f$ |
| L7        | 57 ± 0.1$^g$   | 6.8 ± 0$^d$ | 3.5 ± 0.05$^g$ | 0.054 ± 0.001$^g$ | 5.59 ± 0.01$^g$ | 1.25 ± 0.01$^g$ | 3.13 ± 0.02$^g$ | 15 ± 0$^g$ |
| L8        | 22.6 ± 0.1$^h$ | 7.3 ± 0$^h$ | 3.8 ± 0.01$^h$ | 0.044 ± 0.001$^h$ | 5.6 ± 1.088E-15$^h$ | 1.06 ± 0.01$^h$ | 2.65 ± 0.01$^h$ | 17 ± 0$^h$ |
| L9        | 19 ± 0.173$^i$ | 6.7 ± 0$^h$ | 2.2 ± 0.1$^i$ | 0.062 ± 0$^i$ | 6 ± 0$^i$ | 2.63 ± 0$^i$ | 6.58 ± 1.088E-15$^i$ | 10 ± 0$^i$ |
| L10       | 4.2 ± 0.2$^j$  | 6.2 ± 0$^h$ | 2 ± 0.1$^j$ | 0.092 ± 0.001$^j$ | 4.1 ± 0.1$^j$ | 2.75 ± 0.01$^j$ | 6.85 ± 0.0173$^j$ | 3 ± 1$^j$ |
| L11       | 9.2 ± 0$^k$    | 6.5 ± 0$^h$ | 2.3 ± 0.1$^k$ | 0.076 ± 0.001$^k$ | 8.6 ± 0.173$^k$ | 3.62 ± 0.01$^k$ | 9.05 ± 0.05$^k$ | 12 ± 0$^k$ |
| L12       | 14.8 ± 0.23$^l$ | 6.6 ± 1.088E-15$^h$ | 0.90 ± 0.1$^l$ | 0.069 ± 0$^l$ | 8.1 ± 0$^l$ | 4.16 ± 0$^l$ | 10.40 ± 0$^l$ | 12 ± 0$^l$ |
| L13       | 5 ± 0.1$^m$    | 7.2 ± 0$^h$ | 3.8 ± 0.1$^m$ | 0.099 ± 1.67E-17$^m$ | 8.3 ± 0.173$^m$ | 2.9 ± 0.1$^m$ | 8.25 ± 0$^m$ | 5 ± 0$^m$ |

Note: Mean values followed by the same letters (superscript) in the same column are statistically the same at $p < 0.05$ levels.
micro-organisms in the sample for the stabilization of the organic matter therein (Penn, Pauer, & Mihelcic, 2009). In accordance with previous works, 50% of BOD could be reduced by treating with moringa seed cake (Folkard & Sutherland, 2001). This shows that seed cake of moringa has noticeable effect on BOD. Unlike Sajidu, Henry, Kwamdera, and Mataka (2005) who reported no alternation on BOD value after the treatment, BOD value was reduced from 5.2 to 2.3 mg/L. This was consistent with results obtained in Shan, Mater, Makky, and Ali (2016) and the conclusions of Folkard and Sutherland (2001). High BOD noticed in various combinations of cassava and moringa may be because cassava and moringa are organic compounds, with tendencies of increasing the organic content of the wastewater hence causing BOD to rise (Adamu et al., 2014). All the results after treatment were within the World Health Organization (2017) standards for drinking water. The highest reduction was recorded in A70C30, while A50M50 and C70A50 showed the lowest reduction value.

3.4. Nutrient analysis

Phosphorus and nitrogen are nutrients needed for plant growth. Where the levels of these elements are much in the treated water, there will be a tendency for algae growth during storage, making the water aesthetically displeasing. It is obvious that nitrates must be limited in drinking water to avoid the risk of methaemoglobinemia in infants (United States Environmental Protection Agency, 2012). Table 3 gives the values of the nutrient (P and N) content of the treated water samples. The control (no coagulant) recorded the highest values of N and P at 15.4 and 1.56 mg/l respectively. This can be traced to the food items found in the waste as it was gotten from a domestic source (kitchen). The levels of the nutrients dropped for all treated samples and are all within the World Health Organization (2017) allowable limit for drinking water, unlike what Ndabigengesere and Narasiah (1998a) reported that nutrient was not successfully removed by Moringa extracts. In the phosphorus result obtained, M70C30 and M50C50 were statistically the same at 0.105 mg/l, C100 and C70M30 with the value of
0.054 ± 0.001 mg/l which has no significant difference at \( p < 0.05 \) levels. The nitrogen composition in Table 3 shows that M100 and M70A30; M70C30, C100, C70A30 and A70C30; C70M30 and A70M30; C50A50, A70C30 and A50M50 are statistically the same respectively. It was noticed that the mixtures containing Moringa gave higher values than others. This can be attributed to the fact that Moringa seeds contain proteins with Nitrogen and Phosphorus as its major constituents (Michael, 2014). The nutrient content of the treated water when reused should be taken into consideration to avoid the effect of algae boom which may occur if the values of N and P are high (United States Environmental Protection Agency, 2012).

### 3.5. Hardness analysis

Calcium levels in drinking water have no fixed value according to Nigerian Industrial Standard (2007) standards. In the US and Canada, the values ranged from 1 to 135 mg/l with an average of 21.8 mg/l, and inadequate intake of this element has been implicated for osteoporosis and bone deficiency (Simon, Esteban, Basil, & Joseph, 2006). The other aspect of calcium importance is in the hardness of water, which is the level of CaCO\(_3\) in the water. To obtain the level of CaCO\(_3\), the value of Ca is divided by 0.4 (Simon et al., 2006), which is the mass ratio of Ca alone in the compound. Table 3 gives the level of Ca and CaCO\(_3\) in the water samples analyzed. For Ca, M70A30 and A100 are statistically the same, but all other results of Ca and CaCO\(_3\) are significantly different at \( p < 0.05 \) probability level.

---

**Table 4. Analysis of variance for Turbidity, pH, BOD, Ca, Hardness, N, P and Coliform**

| Source of variation                        | df | SS            | MS            | VR  | \( F \) pr. <0.05 |
|--------------------------------------------|----|---------------|---------------|-----|------------------|
| 1 %_mixtures_of_optimum_dosage of BOD mg/l | 12 | 48.447692     | 4.037308      | 831.77 | <0.001*       |
| Residual                                   | 26 | 0.126200      | 0.0004854     |     |                 |
| Total                                      | 38 | 48.573892     |               |     |                 |
| 2 %_mixtures_of_optimum_dosage of CaCO\(_3\) mg/l | 12 | 879.36711     | 73.28059      | 58,444.64 | <0.001*     |
| Residual                                   | 26 | 0.032600      | 0.001254      |     |                 |
| Total                                      | 38 | 879.39971     |               |     |                 |
| 3 %_mixtures_of_optimum_dosage of Ca mg/l   | 12 | 1.405E+02     | 1.17E+01      | 13,966.62 | <0.001*     |
| Residual                                   | 26 | 2.180E-02     | 8.39E-04      |     |                 |
| Total                                      | 38 | 1.405E+02     |               |     |                 |
| 4 %_mixtures_of_optimum_dosage of Coliform count cfu/100 ml | 12 | 96,926.7692   | 8,077.231     | 26,251.00 | <0.001*     |
| Residual                                   | 26 | 8.0000        | 0.3077        |     |                 |
| Total                                      | 38 | 96,934.7692   |               |     |                 |
| 5 %_mixtures_of_optimum_dosage of N mg/l    | 12 | 256.020000    | 21.33500      | 2,510.00 | <0.001*     |
| Residual                                   | 26 | 0.221000      | 0.000850      |     |                 |
| Total                                      | 38 | 256.241000    |               |     |                 |
| 6 %_mixtures_of_optimum_dosage P mg/l       | 12 | 6.049E+00     | 5.04E-01      | 61,248.75 | <0.001*     |
| Residual                                   | 26 | 2.140E-04     | 8.23E-06      |     |                 |
| Total                                      | 38 | 6.050E+00     |               |     |                 |
| 7 %_mixtures_of_optimum_dosage Turbidity af- ter_treatment_NTU | 12 | 2.769E+04     | 2.31E+03      | 1.4E+05 | <0.001*     |
| Residual                                   | 26 | 4.267E-01     | 1.64E-02      |     |                 |
| Total                                      | 38 | 2.769E+04     |               |     |                 |
| 8 %_mixtures_of_optimum_dosage pH after_ treatment | 12 | 3.0876923 | 0.257308 | 334.50 | <0.001* |
| Residual                                   | 26 | 0.020000      | 0.00077       |     |                 |
| Total                                      | 38 | 3.1076923     |               |     |                 |

Notes: * = Significant (5% level); df = degree of freedom, SS = sum of squares, MS = mean square, VR = variates, \( F \) pr. = \( F \)-value.
From Figure 4, apart from the control, mixtures containing Moringa gave relatively higher values of calcium, though the levels in all the treated water were within the standard classified as soft water (World Health Organization, 2017), while that of the untreated fell into the range of slightly hard (Sharon & Bruce, 2009). Sample C100 showed lowest value for both Ca and CaCO₃. This result was in agreement with the report of Muyibi and Evison (1995a) and Adamu et al. (2014) that M. oleifera and cassava extracts are capable of softening hard water, but at variance with the result obtained by Ndabigengesere and Narasiah (1998b) which reported increase in hardness. The implication of this is that they would not consume much soap before lather formation if used for washing or cleaning purposes, unlike when the untreated is used.

3.6. Microbial analysis
Aside the removal of turbidity, Moringa and Cassava extracts also possesses antimicrobial properties. As shown in Figure 4, all ratios gave very good reduction in the level of Coliform to between 90 and 98.5%. M100, A100 and A50M50, reducing the coliform count from 200 cfu/100 ml by 97.5, 98.5 and 97.5% respectively. These results gave acceptable range of 0–5 cfu/100 ml which agreed with World Health Organization (2017) standards. All Moringa combinations achieved over 90% reduction. This outperformed the result of Pritchard, Craven, Mkandawire, Edmondson, and O’Neill (2010) which showed that for a dose of 125 mg/l M. oleifera, 84% was obtained. Osei (2009) obtained 97.88–99.96% reduction of faecal coliform within one hour. In Boateng (2001), Moringa olifera seed also achieved 90–99% reduction of faecal coliform in drinking water. Ghebremichael, Gunaratna, Henriksson, Brumer, and Dalhammar (2005) reported reductions of several microorganisms including E. coli. Table 3 shows results of a comparative performance of all samples under the same condition which achieved 91.5–98.5% coliform reduction. It was observed that A70C30 and A70M30; M100 and A50M50 are statistically the same at \( p \leq 0.05 \) confidence level. In all, Alum (singularly or in combination) performed better than other coagulants considered. This however beckons for further disinfection with higher concentrations of Moringa extract as recommended in Yousif, Elamin, Ali, and Sulieman (2013) to achieve enhancement as well as avoid recontamination of treated water where applicable.

4. Conclusion
Coagulants from M. oleifera and M. palmate (cassava) were successfully extracted and tested at different ratios and doses in comparison with the alum solution singularly or in combination with each other. All coagulants tested reduced all the tested parameters considerably. Although the results of combining Cassava and Moringa at varying ratios did not meet most of the WHO standards, they all showed high potentials.

Alum alone (A100) achieved reduction of the other parameters, but increased acidity of the treated water and sludge. In the case of Moringa seed extract alone (M100), all other parameters were brought within WHO tolerable level with less sludge except turbidity. Combining the advantages of both Moringa and Alum (A50M50) yielded overall best results with all parameters within WHO drinking water standards and ultimately enabling reusability of sullage. This combination minimizes negative impacts of alum on the environment with respect to the production of non-biodegradable sludge after treatment and its residual effect on treated water.

It is further recommended that increased doses of cassava, Moringa and other natural coagulants as well as varying ratios be studied with a view to isolating the bioactive ingredients from these natural coagulants at much cheaper cost than what is obtainable presently to attract usage at a larger scale water and water treatment.

Funding
The authors received no direct funding for this research.

Author details
S.N. Ugwu1,2 E-mail: sammaemeka.ugwu@unn.edu.ng
ORCID ID: http://orcid.org/0000-0003-0809-6740
A.F. Umuokoro2 E-mail: umuokoro@yahoo.com
E.A. Echiegu2 E-mail: emmanuel.echiegu@unn.edu.ng
B.O. Ugwuishiwu2 E-mail: boniface.ugwuishiwu@unn.edu.ng
References

Adamu, A., Adie, B. D., & Alka, U. A. (2014). A comparative study of the use of cassava species and alum in waste water treatment. Nigerian Journal of Technology, 33, 170-175. https://doi.org/10.4314/njte.v33i2.5

Ali, E. N., Muyibi, S. A., Salleh, H. M., Salleh, M. R. M., & Alam, M. (2009). Moringa oleifera seeds as natural coagulant for water treatment. In Thirteenth International Water Technology Conference, IWTC 13 2009, Hurghada, Egypt.

APHA and AWWA. (2012). Standard methods for the examination of water and wastewater. Washington, DC: Author.

Boateng, P. D. (2001). Comparative studies of the use of Alum and Moringa oleifera in surface water treatment (Unpublished Msc Thesis). Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi.

CDC. (2015). A guide to water treatment technologies for household use. Retrieved from www.cdc.gov/healthywater/drinking/home

CLIMATE-DATA. (2017). Retrieved from https://en.climate-data.org/location/404904/

Folkard, G., & Sutherland, T. (2001). The use of Moringa oleifera seed as a natural coagulant for water and wastewater treatment. Leicester: Department of engineering, University of Leicester.

Ganjidoust, H., Tatsumi, K., Yamagishi, T., & Gholian, R. N. (1997). Effect of synthetic and natural coagulant on lignin removal from pulp and paper wastewater. Water Science Technology, 35, 291–286.

Ghebremichael, K. A., Gunaratna, K. R., Henriksson, H., Brumer, H., & Dalhammar, G. (2005). A simple purification and activity assay of the coagulant protein from Moringa oleifera seed. Water Research, 39, 2338–2344. https://doi.org/10.1016/j.watres.2005.04.012

Himesh, S., Rao, C. V. C., & Mahajan, A. U. (2000). Application of steady state stream water quality model. Journal of Indian Association for Environmental Management, 27, 33–37.

Jodi, M. L., Birnin-Yauri, U. A., Yahaya, Y., & Sokoto, M. A. (2012). The use of some plants in water purification. Global Advanced Research Journal of Chemistry and Material Science, 1, 71–75.

Kawamura, S. (1991). Effectiveness of natural polyelectrolytes in water treatment. Journal American Water Works Association, 83, 88–91.

Kumar, K. V., Rubha, M. N., Manivasagam, M., Bobu, N. G., & Balaji, P. (2012). Moringa oleifera—The nature’s gift. Universal Journal of Environmental Research and Technology, 2, 203–209.

Lee, S. H., Lee, S. O., Jang, K. L., & Lee, T. H. (1995). Microbial flocculant from Aracaudendron sp. TS-49. Biotechnology Letters, 17, 95–100. https://doi.org/10.1007/BF00134203

Marty, C. N., Barker, D. J. P., Osmund, C., Harris, E. C., Edwardsion, J. A., & Lacey, R. F. (1989). Geographical relation between Alzheimer’s disease and aluminium in drinking water. Lancet, 333, 59–62.

McConnachie, G. L., Folkard, G. K., Mtwalli, M. A., & Sutherland, J. P. (1999). Field trials of appropriate hydraulic flocculation processes1Neither DFID nor the authors accept any responsibility for any deficiencies resulting from the findings described in this paper.1 Water Research, 33, 1425–1434. https://doi.org/10.1016/S0043-1354(98)00339-X

Michael, L. (2014). BIoremidiation of turbid surface water using seed extract from the Moringa oleifera Lam. Hoboken, NJ: Wiley.

Muyibi, S. A. (2005). Quenching the thirst of millions in the world-application of processed Moringa seeds in drinking water treatment. Bioenvironmental Engineering Research Unit, Islamic University of Malaysia.

Muyibi, S. A., & Elison, L. M. (1995). Moringa oleifera seeds for softening hardwater. Water Research, 29, 1099–1104. https://doi.org/10.1016/0043-1354(94)00250-B

Muyibi, S. A., Noor, M. M. M., Ong, D. T., & Kai, K. W. (2001). Moringa oleifera seeds as a flocculant in waste sludge treatment. International Journal of Environmental Studies, 58, 185–195. https://doi.org/10.1080/00207230108711326

Ndabiengesere, A., & Narasiah, K. S. (1998a). Use of Moringa oleifera seeds as a primary coagulant in wastewater treatment. Environmental Technology, 19, 789–800. https://doi.org/10.1080/00431354.1998.96806635

Ndabiengesere, A., & Narasiah, K. S. (1998b). Quality of water treated by coagulation using Moringa oleifera seeds. Water Research, 32, 781–791. https://doi.org/10.1016/S0043-1354(97)00295-9

Ndabiengesere, A., Narasiah, K. S., & Tobalt, B. G. (1995). Active agents and mechanism of coagulation of turbid waters using Moringa oleifera. Water Research, 29, 703–710. https://doi.org/10.1016/0043-1354(94)00161-Y

Nigerian Industrial Standard. (2007). Nigerian standard for drinking water.

Nilanjana, R. (2005). Use of plant material as natural coagulants for treatment of wastewater. VisionNIous, 1, 2–5.

Osei, B. K. (2009). The effects of the seed powder of Moringa oleifera LAM on the quality of water for vegetable farming in the Kumasi metropolis (Thesis) Department of Chemistry, College of Science, Kwame Nkrumah University of Science and Technology, pp. 95–96.

Penn, M. R., Pauer, J. J., & Mihelcic, J. R. (2009). Biochemical oxygen demand. In A. Sabljic (Ed.), Environmental and ecological chemistry (Vol. 2, p. 278). Isle of Man: UNESCOOELSS.

Prasad, S. M., & Rao, B. S. (2013). Environmental sciences a low cost water treatment by using a natural coagulant. Intl. Islamic Journal of Malaysia. International Journal of Research in Engineering and Technology, 2, 2319–1163.

Pritchard, M., Craven, T., Mkandawire, T., Edmondson, A. S., & Edwardson, J. A., & Lacey, R. F. (1989). Geographical relation between Alzheimer’s disease and aluminium in drinking water. Lancet, 333, 59–62.

Renuka, M. S., Binayke, A., & Jadav, M. V. (2013). Application of natural coagulants in water purification. International Journal of Advanced Technology in Civil Engineering, 2, 118–123.
Rodríguez-Núñez, J. R., Sánchez-Machado, D. I., López-Cervantes, J., Núñez-Gastélum, J. A., SánchezDuarte, R. G., & Correa-Murrieta, M. A. (2012). *Moringa oleifera* seed extract in the clarification of surface waters. *International Journal of Environmental Protection*, 2, 17–17.

Sajidu, S. M., Henry, E. M. T., Kwamdera, G., & Mataka, L. (2005). Removal of lead, iron and cadmium ions by means of polyelectrolytes of the *Moringa oleifera* whole seed kernel. *WIT Trans Ecol Environ*, 80, 1–8.

Shan, T. C., Mater, M. A., Makky, E. A., & Ali, E. N. (2016). The use of *Moringa oleifera* seed as a natural coagulant for wastewater treatment and heavy metals removal. *Applied Water Science*, 7, 1369–1376. doi:10.1007/s13201-016-0499-8

Sharon, S., & Bruce, D. (2009). *Drinking water: Hard water (calcium and magnesium)*. Neb Guide, University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources.

Simon, M., Esteban, C., Basil, A., & Joseph, M. (2006). How much calcium is in your drinking water? *HSS Journal*, 2, 130–135.

Tropilab. (2014). Retrieved January, 2015, from www.tropilab.com/manihot-esc.html

UN Report. (2013). Retrieved October 8, 2014, from www.un.org

United States Environmental Protection Agency. (2012). *Water: Monitoring and assessment*. Retrieved from https://archive.epa.gov/water/archive/web/html/index-19.html

Victoria, B. (2010). Coagulation and flocculation in water and waste water treatment. Retrieved from www.waterwiki.org

Vogel, A. I. (2000). *Vogel’s textbook of quantitative chemical analysis* (6th ed., p. 806). Revised by J. Mendham, R. C. Denney, J. B. Barnes, M. Thomas. Harlow, England; New York, NY: Prentice Hall.

Wikipedia. (2014). *Alum*. Retrieved from http://en.wikipedia.org/wiki

World Health Organization. (2007). Combating waterborne disease at the household level (Vol. 1, 2nd ed.). Geneva: Author.

World Health Organization. (2017). *Guidelines for drinking-water quality: Fourth edition incorporating the first addendum* (p. 631). Retrieved from https://apps.who.int/iris/bitstream/10665/2546371/1/9789241549950-eng.pdf?ua=1

Yousif, N. N., Elamin, H. B., Ali, H. A., & Sulieman, A. M. E. (2013). Utilization of *Moringa oleifera* seeds in purification of tap water in Khartoum state, Sudan. *Journal of Microbiology Research*, 3, 171–175. doi:10.5923/j.microbiology.20130305.02