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Research Article

Development, Characterisation, and Performance Evaluation of Some Indigenous Plants for Faecal Sludge Treatment in Ghana

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The search for alternative solutions for sustainable management of faecal sludge in the area of dewatering with biocoagulants/bioflocculants remains unfulfilled. Some available and accessible indigenous plants in the northern part of Ghana have been characterised and subsequently evaluated in their suitability for use as biocoagulant/bioflocculants. The Yila (Crossopteryx febrifuga) and the Voulo (*Grewia mollis*) plants were the indigenous plants used in this study. Three applications from the Yila wooden stem, the Yila bark, and the Voulo at different treatment concentrations with faecal sludge were monitored. The Yila wooden stem gave a potential of pollutant removal up to about 83.99%, 93.79%, and 91.54% for Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and turbidity, respectively. Application of the Yila bark gave a respective removal efficiency of up to about 77.39%, 82.02%, and 54.60% for COD, TSS, and turbidity. The efficiency of the Voulo plant obtained for COD, TSS, and turbidity was up to about 80.43%, 86.83%, and 72.55%, respectively. No cyanogenic or toxic compounds were identified in the characterised raw materials used for this study. The study has revealed the potential of producing biocoagulants that can perform as effectively as synthetic/chemical coagulants using locally natural raw materials but the use of it at large scale will only be applicable for batch or semi-batch systems. Some interesting constituents identified in the plants under consideration, such as trialkyl bismuthine and furan derivative, can open up opportunities to elucidate the potential applications of these identified plants in the areas of pharmaceuticals, cosmetics, glass and ceramics, rubber production, and other applicable medicinal advantageous areas.

1. Introduction

Most middle- to low-income countries are dominated by Onsite Sanitation Systems (OSSs) [1] because they serve as a more economically sustainable option than alternatives [2]. Effective management of sludge depends on the extent of solid separation from the liquid, and one of the major methods for separating sludge from the liquid is dewatering. Dewatering has been found to determine the moisture content of the sludge matrix [3, 4]. However, there are various pre-treatment methods to enhance dewatering output quality, of which coagulation/flocculation is the most widely used for wastewater treatment and management [5, 6]. Fresh water treatment has been mentioned to employ coagulation/flocculation in treatment operations to ensure water standard quality [7] and in other fields aside from water treatment industries, including paper production, oil extraction, and the mining industry [8, 9].

Coagulation/flocculation is the process, by which the suspended colloids in wastewater are destabilized and aggregated to form large flocs, by the addition of coagulants and flocculants, which can be removed by sedimentation. In most literature, the terms 'coagulation' and 'flocculation' are sometimes used interchangeably. Practically, the efficiency of flocculation is directly related to the type of flocculants used. Flocculants are categorized mainly into two types: inorganic coagulants, such as aluminium sulphate, polyaluminium chloride (PAC), and polymerized ferrous sulphate, and organic polymeric flocculants, which include synthetic and natural ones. However, the inorganic coagulant dominates organic ones in the market due to their availability.

The commercial coagulant for wastewater treatment, such as PAC, acrylamide (AC), polyacrylamide (PAM), methyl acrylate, and aluminium and ferric products, are expensive and are not readily available in developing countries making wastewater treatment difficult. Industries in the third world rely on importing some of these chemicals from the developed world making it expensive and time-consuming. Besides the economic challenges, researchers have reported other environmental issues associated with some of the coagulants/flocculants in the market. A suspected carcinogen and high neural toxicity have been identified with AC-based flocculants. As such concerns have been raised about the environmental and health risks to aquatics and humans through the utilization of PAM in water and wastewater treatment [10]. Other studies listed the following as drawbacks of inorganic coagulants: highly sensitive to pH, inefficient towards very fine particles, and applicable only to a few dispersed systems [11, 12]. According to Walton, an increase in metal concentration in treated water, resulting from inorganic coagulant, may have serious health concerns [13]. AC toxicity has been found in rats and water fleas to be 124 mg/kg and 160 mg/L, respectively, by researchers (Sigma–Aldrich; [14]).

Developing multifunctional and highly efficient processes and providing affordable/sustainable solutions to water/wastewater treatment, which do not rely on large infrastructures or centralized systems remains unfulfilled [15]. Therefore, the development of economical and stable materials and methods for the management of faecal sludge in the country remains wide for explorative research works.

According to research conducted by Awuah et al., faecal sludge treatment plants, when properly maintained and managed, can improve sanitation conditions and improve health outcomes in the serviced areas [16]. It is highly crucial and critical for the new emergence of the treatment plants being built in the country to be subjected to rigorous studies to evaluate their performance and provide continuous improvement alternatives for sustainability. One of the faecal sludge treatment plants in Ghana is the lavender hill faecal treatment plant [15–19].

The treatment plant under consideration is a two thousand cubic meters per day treatment plant (2,000 m^3/day) being expanded to about three thousand cubic meters per day capacity (3,000 m^3/day). The treatment has a reservoir where screened faecal sludge is stored. Dewatering of the raw faecal sludge is done with the use of a screw press. The dewatering of the sludge with a screw press is aided by a cationic polyelectrolyte (polymer). These polyelectrolytes are not locally produced in the country and have to be imported. Some of the challenges associated with this importation of chemicals include high costs of shipping and extended periods required for customs clearance [20]. A lot of this polyelectrolyte is consumed per day and the cost involved takes about 30–40% of the total treatment cost, as dewatering is the key stage where about 60–70% of treatment efficiency begins concerning the influent received.

Considering the high volumes of these flocculants being consumed per day, the associated cost involved, freight challenges as well as the rate at which newly built treatment plants in Ghana are emerging, it has become very necessary to step up the research into local polyelectrolyte (natural coagulants/flocculants) to support the value chain in the sustainability structure of faecal sludge management.

An organic natural resource, such as chitosan, cellulose, and starch has been reported to be an effective and reliable source of flocculants and they are available and affordable. There are several research papers on chitosan flocculants in the literature. Guibal et al. [21] presented the results obtained in their research, the effect of chitosan flocculants in the treatment of different types of wastewater. An overview of the coagulation/flocculation performance of chitosan was examined for various wastewater [22]. Roussy et al., utilized chitosan and tannin as coagulants and flocculants, respectively, to treat industrial effluent from soluble inks generated during packaging [9, 23]. Chitosan, despite its success also has several deficits that hinder its performance. Some of its deficits were reported to include inactive chemical properties and poor solubility in neutral or alkaline aqueous solutions in the literature [24–26]. Therefore, there will be the need to modify chitosan coagulant/flocculant with other materials to suit usage in the wastewater treatment industry and this will make it expensive and dependent on the availability of the required material.

Natural coagulants have been found to generate not only a much smaller sludge volume of up to five times lower [27] but also a higher nutritional sludge value. As such, sludge treatment and handling costs are lower making it a more sustainable option. The raw plant extracts are often available locally and hence, a low-cost alternative to chemical flocculants/coagulants. Since naturally occurring flocculants/coagulants do not consume alkalinity unlike certain other chemically existing polyelectrolytes, pH adjustments can be omitted and this provides extra cost savings. Natural coagulants are also noncorrosive [28], which eliminates the concerns of pipe erosions. Plant materials, such as flocculants/coagulants, offer several advantages over conventional coagulants. Its activity is maintained over a wide range of influent pH values—no pH correction is required. The natural alkalinity of the raw water or faecal sludge is unchanged following flocculation/coagulation—no addition of alkalinity required. The sludge production is greatly reduced and is essentially organic in nature with no chemical precipitates or residuals—sludge volumes are reduced by a factor of up to 5 [29]. It has the potential to yield minimal coagulant dosage requirements. On the other hand, if the raw materials needed for the production of bio-coagulants or bioflocculants are available locally and in abundance, this will be advantageous as it will give some respite in reducing the cost of the products and ensure the security of its supply.

Until recently, research on plant-based natural coagulants was mainly focused on some few most common natural coagulants, which included *Moringa oleifera* seeds, Nirmali seeds, tannin, and *Opuntia ficus-indica cactus* in water and wastewater treatments [30–33] as well as chitosan. In addition to the current database of studied natural coagulants, an extensive overview of the indigenous plants used by rural Africans in water purification has been provided [34]. Recently, an extensive review covering the studied vegetables and legumes has provided insight into the less commonly known water-clarifying agents [35].

Apart from the aforementioned plant-based coagulants, little is known about other plant categories with notable faecal sludge (FS) treatment properties. Hence, there is a need to account for such local materials that have the potential to act as naturally occurring bio-coagulants or bio-flocculants and to identify the key components of the plants that are making them act as the bio-coagulants or bio-flocculants.

Locally produced flocculants could provide a sustainable and affordable solution worldwide. Applications of flocculants from natural resources recorded a turbidity removal of 95% with *M. oleifera* seeds in industrial wastewater with *Jatroph curas* seed given 98% in synthetic wastewater [36, 37]. From the available literature, the use of natural coagulant/flocculant especially plant-based for sludge dewatering processes has not been fully documented. The objective of this study was to identify and use unreported plant-based flocculants in the treatment of wastewater/faecal sludge. Materials that are readily available in the community, and are affordable to access will be used in this study.

This research study can no doubt adds to the scientific body of knowledge of the already known plant-based flocculants/coagulants, whereas the ultimate beneficiary will be treatment plant managers who are supporting the attainment of sustainable development goals six by ensuring sustainable faecal sludge management. A newly identified indigenous plant based for flocculation and coagulation in wastewater and faecal sludge treatment is presented in this study.

2. Methodology

2.1. Sourcing of Raw Materials. The raw materials used for the preparation of bio-coagulants in this study were sourced from the Upper West Region of Ghana at different locations before being transported to the laboratory. The raw materials under consideration are local plants commonly found in the Northern part of Ghana. One of the plants locally called 'Voulo'/'Yolga' (*Grewia mollis*) was used in this study. This plant is locally used in Northern Ghana and other West African countries for brewing locally made beer 'pito' [38, 39]. Pito is a type of beer made from fermented millet or sorghum in northern Ghana, parts of Nigeria, and other parts of West Africa. This food drink is a traditional alcoholic beverage that is prepared from carbohydrate-rich cereal crops such as millet, guinea corn, or maize [40–45]. It is brewed in many different styles and different tastes. It has an alcohol percentage ranging from 2% to 3% [40]. The stem back of the plant is usually what is employed for the brewery fermentation and the same was considered in this work. The second plant is locally called 'Yila' or 'Yilapong' depending on the locality in the northern part of Ghana. The name of the indigenous plant varies across the regions from locality to locality. This plant 'Yila' according to the indigenes and a local herbalist in the locality of the upper west region is used in the treatment of hernia in men.

2.2. Preparation of the Plants

2.2.1. 'Voulo' (G. mollis). The stem back of a good quality, mature 'Voulo' plant was harvested and dried (Figure 1). The dried portion was ground into powder using an electric blender. The powder was then sieved with a mesh of 425 μm size to get fine powder to obtain an adequate surface area of the active ingredients in the plant for effective flocculation or coagulation actions (Figure 1). An appropriate mass of the powder was weighed and mixed with distilled water to produce 0.6, 5.0, and 10.0% w/v. This was done similarly as reported by Gold et al. [46].

2.2.2. 'Yila/Yilapong'. The stem of a good quality, mature 'Yila' plant was harvested (Figure 2) and divided into two portions. To one part of the stem is the 'stick' of the stem of the plant and the second part is the back of the stem. The two portions of the stem of the plant (stick and cover) were dried. The dried portion was ground into powder separately using an electric blender (Figure 2). The powder was then sieved with a mesh of 425 μm size to get fine powder to obtain an adequate surface area of the active ingredients in the plant for effective flocculation or coagulation actions. An appropriate mass of the powder was weighed and mixed with distilled water to produce 0.6, 5.0, and 10.0% w/v.

2.3. Characterisation of the Plants Constituents

2.3.1. Extraction Process. Five grams of each sample was weighed into a flat bottom flask. 100 mL of 70% ethanol was added to the sample in the flat bottom flask. The mixture was refluxed for 1 hour to extract the constituents. The flat bottom flask was then removed from the water bath after 1 hour and the solution was filtered. The filtrate was placed in a 1 L Eyela SB-1200 rotary evaporator to evaporate the ethanol. This procedure is adopted by Ciulei [47].

2.4. Gas Chromatography-Mass Spectrometry Analysis of the Plants. Gas Chromatography-Mass Spectrometry (GC-MS) analysis of the samples was performed using a PerkinElmer GC Clarus 580 Gas Chromatograph interfaced to a Mass Spectrometer PerkinElmer (Clarus SQ 8S) equipped with ZB-5HTMS (5% diphenyl/95% dimethyl polysiloxane) fused a capillary column ($30\,\mu\text{m} \times 0.25\,\mu\text{m ID} \times 0.25\,\mu m$ DF). The oven temperature was programmed from 100°C (isothermal for 2 minutes), with an increase of 10°C/minute to 200°C, then 5°C/minute to 280°C, and held for 22 minutes at 280°C.

For GC-MS detection, an electron ionization system was operated in electron impact mode with an ionization energy of 70 eV. Helium gas (99.9999%) was used as a carrier gas at a constant flow rate of 1 mL/minute, and an injection volume of 1 μL was employed. The injector temperature was maintained at 250°C, the ion-source temperature was 220°C. Mass spectra were taken at 70 eV; a scanning interval of 1 second and fragments from 50 to 500 Da. The solvent delay was 0–3 minutes, and the total GC/MS running time was 50 minutes. The mass-detector used in this analysis

Figure 1: Matured, dried raw, and powdered ‘Voulo’.

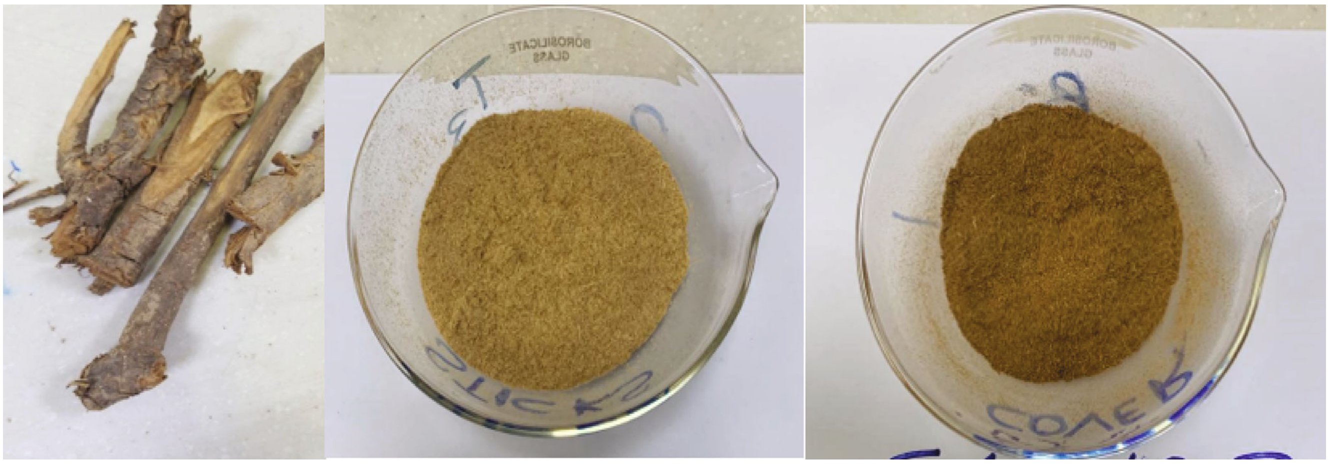

Figure 2: Matured, dried, and powdered (wooden stem and bark) ‘Yila’.

was Turbo-Mass, and the software adopted to handle mass spectra and chromatograms was Turbo-Mass ver-6.1.0. Interpretation of mass spectrum GC-MS was conducted using the database of the National Institute of Standard and Technology, which has more than 62,000 patterns [48].

2.5. Coagulation and Flocculation Experiments (Jar Test). The two (2) indigenous plants were subjected to jar tests to determine the performance of those locally identified bio-coagulants/flocculants. A Stuart SW6 Flocculator was used for the jar test experiments. The set-up comprised six (6) 1,000 mL beakers coupled with mechanical stirrers. Five (5) dosages (0.6–5% w/v) of coagulants were added to 600 mL of FS and compared with parallel to one (1) blank being the control. 150 rotations per minute (rpm) for 3 minutes was selected as stirring speed and time, respectively, based on literature review and trial experiments with variable stirring speeds and times. A settling time of 60 minutes was also selected based on literature review [46, 49] as well as trial experiments carried out in the laboratory.

Some selected physico-chemical parameters of the raw FS samples were measured before the jar test experiment, whereas those of the treated FS samples (effluent) were measured after the jar test experiments. Measurement of the physico-chemical parameters was done according to the Standard Methods for Water and Wastewater [50]. Treated FS samples (effluent from the experiment) were collected from 1 cm below the supernatant using a pipette.

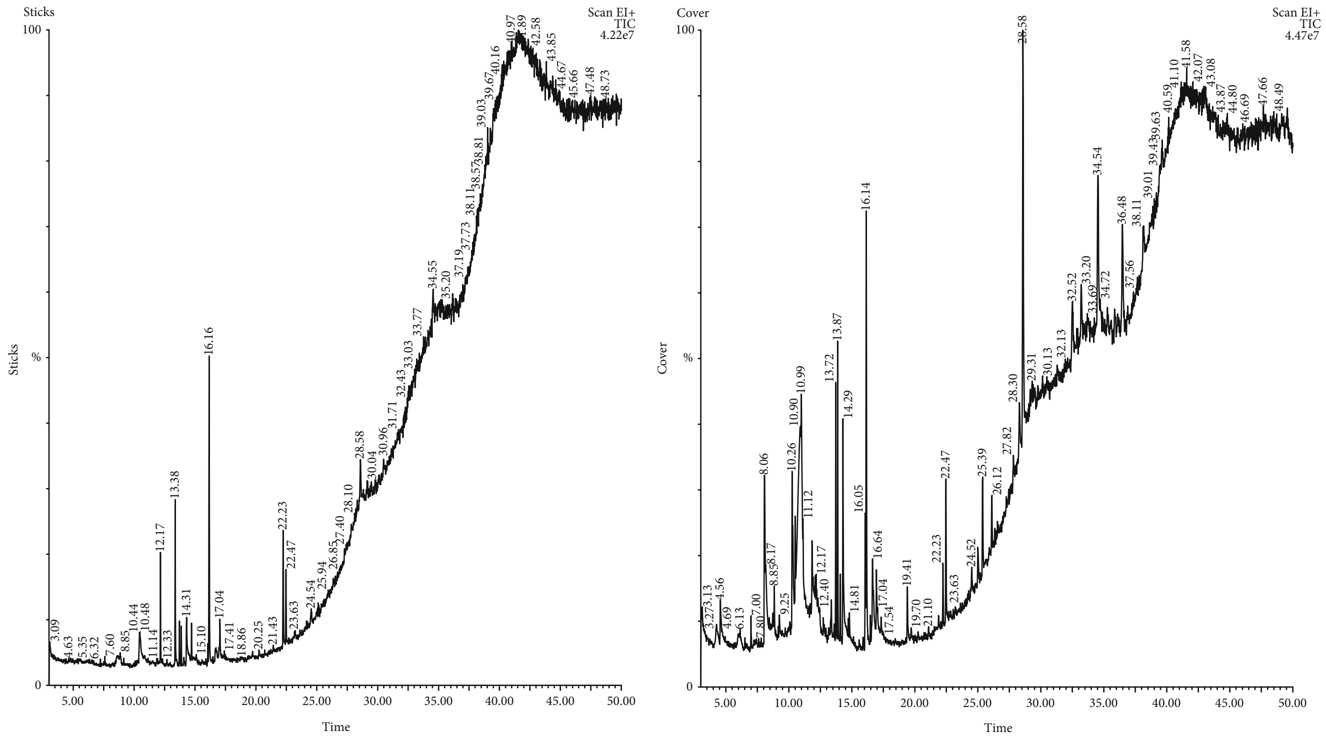

Figure 3: A chromatogram plot of ethanolic 'Yila' wooden stem and bark extracts showing peaks of identified constituents.

3. Results and Discussion

3.1. Characterisation of the Source Materials. In the quest to determine the constituents present in the source materials, the obtained powdered samples of the natural bio-coagulants were subjected to GC-MS analysis to determine the constituents that are present in them. The active compounds present in these local source materials will provide a general guide on the potential of the material to exhibit coagulation/flocculation characteristics.

3.1.1. Characteristics of the 'Yila' Wooden Stem and Cover. The chromatogram obtained for both the stick (Figure 3) and cover (Figure 3) of the 'Yila' plant did not show any variation in terms of constituents' presence. The graphs from Figure 3 depict a similar trend and the percentage compositions of the active constituents are shown in Table 1. From Table 1, the GC-MS analysis conducted on the ethanolic extract of the plant showed the presence of numerous chemical compounds. The list of chemical components found in the plant is over twenty (20) different constituents. These compounds are noted to be sugars (sucrose and glucose), carboxylic acids, esters, ketones, phenols, and alcohols. Out of these chemical compounds identified, sucrose (45.5%), 4(1*E*)-3-hydroxy-1-propenyl)-2-methoxyphenol (73.5%), hexadecanoic acid, methyl ester (65.0%), *n*-hexadecanoic acid (76.6%), octadecanoic acid (38.9%), and 2,4(I*H*)-cyclo-3,4-secoakuammilanium,3,17-dihydroxyl-16(methoxycarbonyl)-4methyl-, (3*á*,16*R*)- (28.6%). Others also include cis-vaccenoic acid (12.5%), 6-hydroxy-9-oxa-bicyclo [1, 3] nonan-3-one (16.0%), myo-inositol, 2-*C*-methyl (18.4%), myo-inositol, 4-*C*-methyl (15.6%). Some of the compounds found in this plant (Yila) in both the cover and the stick of the stem plant have also been identified in earlier works on *M. oleifera* by refs. [51–53] where the *M. oleifera* seed and press cake were used as bio-coagulant to treat wastewater on the laboratory scale. The chemical compounds identified in this work for the 'Yila' plant as highlighted in Table 1 are in most cases higher than those identified in earlier works using the *M. oleifera* [52, 53]. This is a potential confirmation of the high possibility of the 'Yila' plant being used as an effective bio-flocculant or bio-coagulant. As reported by many other studies, the presence of these chemical compounds in a natural plant, which is acting as a bio-coagulant or bio-flocculant confers a positive overall net charge and thus gives it the ability to attract suspended and dissolved particles that are usually negatively charged in wastewater and FS. Ionic distributions in faecal sludge, which affects its electrical conductivity and its net surface charge ionicity have been reported by Ahmed et al. [18]. The 'Yila', therefore, has a high potential to coagulate or flocculate the faecal sludge.

Other chemical compounds were identified such as 2-propenoic acid, 3-phenyl-, phenylmethyl ester (10.4%), which was also reported in earlier works by Oshiobugie et al. [48] using neem leaves. Again, the percentage compositions identified is higher than that obtained in the works of Oshiobugie et al. [48].

Some of the constituents of the 'Yila' plant also have the potential to act as antibacterial apart from the potential to be a bio-coagulant. In this study, from Table 1, hexadecanoic acid (76.6%) and hexadecanoic acid, ester (65%) were identified as part of the constituents of the 'Yila' plant. Research works by Hema et al. and Akpuaka et al. [54, 55] showed that, hexadecanoic acid has been used as an antioxidant, anti-inflammatory hypolipidemic, and antimicrobial agent.

Table 1: List of chemical constituents identified in the 'Yila' plant using GC-MS analysis.

S/No.	Retention time	Probable compounds	Percentage probability
1.	8.059	Sucrose	45.5
2.	10.259	1. 6-Hydroxy-9-oxa-bicyclo [3,3,1] nonan-3-one	16.0
		2. Dodecanoic acid	8.74
		3. Hexanoic acid, 2-ethylhexyl ester	8.4
3.	10.993	1. Myo-inositol,2-C-methyl	18.4
		2. Myo-inositol, 4-C-methyl	15.6
		3. 3-*O*-methyl-d-glucose	11.3
4.	11.836	1. 4(1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol	73.5
5.	13.871	1. Hexadecanoic acid, methyl ester	65
6.	14.293	1. *n*-Hexadecanoic acid	76.6
7	16.145	1. Benzylcinnamate	11.7
		2. 2-propenoicacid, 3-phenyl,phenylmethyl ester(E)	10.4
8.	16.64	1. Cis-vaccenoic acid	12.5
		2. Cis-13-octadecanoic acid	9.35
		3. Trans-13-octadecanoic acid	8.98
9.	16.92	Octadecanoic acid	38.9
10.	25.386	1. 17.Alfa.21á-28,30-Bisno-hypane	11.2
		2. 4-(3,3-Dimethyl-but-1-ynyl)-4-hydroxy-2,6,6 Trimethylcyclohex-2-enone	7.69
11.	28.576	1. 2,4(IH)-Cyclo-3,4-secoakuammilanium, 3,17-dihydroxyl-16(methoxycarbonyl)-4methyl-, (3á,16R)-2. 1-cyclopropyl-6,7,8-trifluoro-4-oxo-dyhydroquinoline-3-	28.6
		Carboxylic acid	6.41
		3. 2-Methoxy-4-methyl-10H-acridin-9-one	4.4

This will also imply that, when the 'Yila' plant is used as a bio-coagulant in treating faecal sludge or wastewater, it has the potential to also decrease the microbial loadings in the influent being treated at the right dose.

3.1.2. *Characteristics of the 'Voulo' Plant.*

Figure 4 shows the chromatogram obtained for the 'Voulo' plant and the percentage compositions of the active constituents are shown in Table 2.

From Table 2, various chemical compounds from the GC-MS analysis conducted on the ethanolic extract of the plant are summarised. Over fifteen (15) different constituents were found in the Voulo plant, among which includes carboxylic acids, esters, ketones, heterocyclic aromatic compounds, alkanoids, dienes, alkanes, amides, and interestingly organometallic compound.

From the identified constituents in the Voulo plant extract, bismuthine, tripropyl (72.6%), 5,7,7-Trimethyl-4,5,7,8-tetrahydroazuleno[4,5-*c*]furan (81.0%), pyrazole-3-carboxylic acid, 4-iodo-1-methyl (83.3%), 1,5-undecadiene, 6,7,8,8,9,9,10,10,11,11,11-dodecafluoro-3-methyl (48%), *N*-(7,7-dimethyl-4-oxo-5,6,7,8-tetrahydro-4*H*-thiazolo[5,4-*c*]azepin-2-yl]-*N*-methyl-acetamide (29.9%), hexanoic acid (16.6%), 2,4(1*H*,3*H*)-pyrimidin edione, 6-iodo-5-methyl (21.0%), 2-propenoic acid, 2-propenyl ester (13.6%), and *n*-decanoic acid (10.7%).

Sucrose (45.5%), 4(1*E*)-3-hydroxy-1-propenyl)-2-methoxyphenol (73.5%), hexadecanoic acid, methyl ester (65.0%), *n*-hexadecanoic acid (76.6%), octadecanoic acid (38.9%), and 2,4-(I*H*)-cyclo-3,4-secoakuammilanium,3,17-dihydroxyl-16(methoxycarbonyl)-4methyl-, (3*á*,16*R*)- (28.6%). Others also include cis-vaccenoic acid (12.5%), 6-hydroxy-9-oxa-bicyclo [3,3,1]nonan-3-one (16.0%), myo-inositol,2-*C*-methyl (18.4%), and myo-inositol, 4-*C*-methyl (15.6%).

Unlike the Yila plant constituents for both the stem and cover, which has some of the compounds found in it being earlier reported by earlier works on *M. oleifera* [51–53], the Voulo plant constituents did not follow such a trend except for *n*-decanoic acid. However, 2-propenoic acid, ester had been reported regarding earlier works of Oshiobugie et al. using neem leaves as bio-floculant [48]. The percentage of compositions identified in this work is higher than that obtained in the works of Oshiobugie et al. [48] use neem trees.

Most of the identified constituents in this plant have not been reported in bio-coagulant research works. These constituents have very interesting characteristics, which need to be highlighted. One of the most abundant constituents identified is tripropyl bismuthine, it is an organometallic

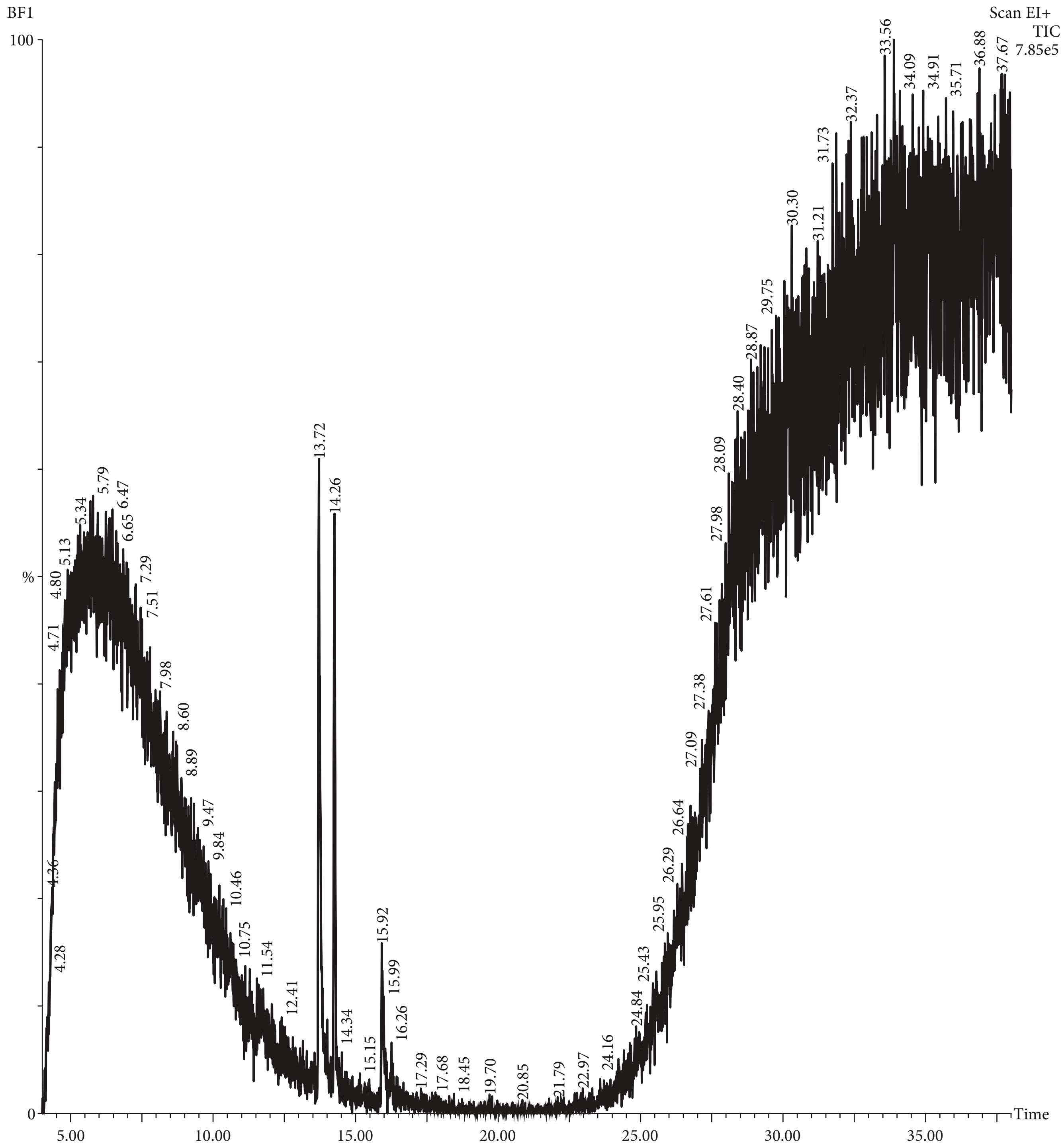

Figure 4: A chromatogram plot of ethanolic 'Voulo' stem extracts showing peaks of identified constituents.

compound (trialkyl bismuth) containing carbon to bismuth chemical bonds, which generally have few applications [56, 57]. Knowledge about alkylated species of bismuth in environmental and biological media is limited [58]. Even though few or limited applications had been identified for trialkyl bismuthine, the central metal atom making up the organometallic compound, bismuth has found several applicable areas. Some of these areas of applications include pharmaceuticals, atomic fire alarms, sprinkler systems, solders and other alloys, and pigments for cosmetics, glass, and ceramics. It is also used as a catalyst in rubber production [59]. The tripropyl bismuth identified in the Voulo plant with these characteristics, can be said to have a very high potential in support of the plant acting as a bio-flocculant and it is not surprising it has been used in the northern part of Ghana and other west African countries for the brewing of pito [38].

Another abundant constituent of the plant identified is 5,7,7-trimethyl-4,5,7,8-tetrahydroazuleno[4,5-*c*] furan. It is

Table 2: List of chemical constituents identified in the 'Voulo' plant using GC-MS analysis.

S/No.	Retention time	Probable compounds	Percentage probability
1	13.720	Hexanoic acid	16.6
		n-Decanoic acid	10.7
		Undecanoic acid	9.18
2.	13.910	Bismuthine, tripropyl-	72.6
		2,4(1*H*,3*H*)-pyrimidin edione, 6-iodo-5-methyl	21.0
		Thiophen-2-methylamine, *N*,*N*-dionyl-	1.61
3	14.260	5,7,7-Trimethyl-4,5,7,8-tetrahydroazuleno[4,5-*c*]furan	81.0
		2,2,4-Trimethyl-1,2,3,4-tetrahydro-*c*-carboline	17.1
		2-Methyl-7-methylthio-1,3,4-thiaadiazolo(3,2-*a*)(1,3,5)triazine-5-one	1.38
4	15.840	Pyrazole-3-carboxylic acid, 4-iodo-1-methyl-	83.3
5	15.921	1,5-Undecadiene, 6,7,8,8,9,9,10,10,11,11,11-dodecafluoro-3-methyl-	48
		2-Propenoic acid, 2-propenyl ester	13.6
		Butane, 1,2:3,4-diepoxy-, (ñ)-	6.61
6	15.991	*N*-(7,7-Dimethyl-4-oxo-5,6,7,8-tetrahydro-4*H*-thiazolo[5,4-*c*]azepin-2-yl]-*N*-methyl-acetamide	29.9
		3,6-Di(4-morphlinyl)-1,2,4,5-tetrazine	8.13
		Benzothiophene-3-carboxamide, 4,5,6,7-tetrahydro-5-tertbutyl-2-cyclohexanolamino-	7.82

a compound of a furan derivative. Not much had been reported on such a compound but much work had been done on furan and other derivatives. The basic skeleton of numerous compounds possessing cardiovascular activities has been reported to be furans [60]. These have been reported to be compounds that are widely engaged as anti-bacterial, antiviral, anti-inflammatory, anti-fungal, anti-tumor, antihyperglycemic, analgesic, anti-convulsant, and other medicinal properties [61–64]. Some of the recent works reported on furans indicated that they have the potential to possess some immune-regulatory effects and several of these furans natural derivatives have been introduced with favourable biological functions, which also include antioxidant activity, anti-proliferative, and antiviral activity as well [65–67]. By this, it is in no doubt that, the Voulo plant has the potential to also act as any of the aforementioned characteristics. The use of Voulo in making pito in the Northern part of Ghana yielded beverages with no microbial loadings [40]. There were other available compounds with diene and amide bases, which also have the potential to contribute in several unknown beneficial ways by using the plant. One of the most potent commercially available flocculants is PAM, which has an amide base.

The characteristics potential of the Voulo plant will imply that, when it is used as a bio-coagulant in treating faecal sludge or wastewater, the potential to also decrease the microbial loadings in the influent being treated at the right dose is very high.

3.2. Coagulation/Flocculation Potential of the 'Yila' Wooden Stem.

Various faecal sludges ranging from low strength to high strength were all used in this study. The characteristics of the faecal sludge used in this study are not different from the characteristics of faecal sludge reported by earlier researchers [18, 68–72]. Key experimental parameters of the FS sample including pH (7.368), turbidity (10,380 NTU), oxidation–reduction potential (ORP; −268.810 mV), TSS (15,122 mg/L), Dissolved Oxygen (DO) (0.0 mg/L), temp (27.247°C), and COD (13,639 mg/L) were observed after the jar test experiment to determine the treatment performance of the natural bio-coagulants (Yila wooden stem, Yila bark, and Voulo) via coagulation/flocculation. These experimental parameters were observed because of the potential influence they have on the coagulation/flocculation process and baseline parameters to determine separation potential of any coagulant or flocculants. Other factors, such as settling time [51], stirring speed [73, 74], and temperature [75, 76], equally affect the coagulation/flocculation performance. The dependent variable, which is the dosage of the bio-coagulant was constant for all the bio-coagulants and its effect on other parameters was observed. From Table 3, the effect of the bio-coagulant dosages on selected experimental parameters for the three different indigenous plants can be seen. When the Yila plant stick was used at 0.6% concentration, the efficiency obtained on average was 76.83%, 86.18%, and 91.54% for COD, TSS, and turbidity, respectively. The removal efficiency was significant for these three parameters. No significant variations were observed for pH and temperature upon treatment of the bio-coagulant at this dosage. This is in agreement with Choy et al., Imam, and Teixeira and Camacho [35, 77, 78], that most natural, plant-based bio-coagulants do not require pH adjustment since they do not consume alkalinity. The ORP became more positive by about 27.951 and there were some DO values recorded. ORP is considered to be a more accurate measure of the disinfection rate as it indicates how sanitized

Table 3: Efficiencies of the indigenous plants on some key parameters at various concentrations.

Parameter	COD (mg O_2/L)	TSS (mg/L)	TUR (NTU)	pH	ORP (mV)	DO (mg/L)	Temp. (°C)
Sample (S)	13,639	15,122	10,380	7.368	−268.810	0	27.247
Commercial polymer (cationic PAM)							
Concentration	0.1% (40 mL)						
S + PAM	1,937	906	414	7.53	−169.7	0	26.984
Biocoagulant/bioflocculant							
Concentration	0.6%						
S + Yila stick	3,160	2,090	877	7.175	−193.675	0.015	27.010
S + Yila cover	4,604	4,265	4,712	7.165	−178.482	0.051	26.862
S + Voulo	3,916	3,697	3,034	7.213	−247.760	0	27.247
Concentration	1.0%						
S + Yila stick	2,183	938	6,642	7.441	−56.715	0	27.081
S + Yila cover	3,083	2,719	8,729	7.335	−190.319	0.01	26.716
S + Voulo	2,668	1,991	9,482	7.580	−208.573	0	27.055
Concentration	5%						
S + Yila stick	2,840	1,568	1,236	7.436	−186.12	0	26.955
S + Yila cover	4,244	3,905	5,481	7.334	−200.225	0	27.123
S + Voulo	2,949	2,354	5,176	7.560	−213.003	0	27.227

or contaminated water is based on its oxidation and reduction properties. Oxidising trace elements, such as oxygen and chlorine, contribute heavily to a higher ORP level in the water and the increased breakdown of unwanted contaminants, therefore, higher ORP levels can be correlated with higher levels of water sanitation. This implies that, when OR *P* values become more positive regarding wastewater and or faecal sludge treatment, it is a clear primary indication of pollutant decontamination taking place whether physically, chemically, or biologically. When the dose of the Yila wooden stem was increased to 1%, the COD and TSS efficiency increased, respectively, to 83.99% and 93.79% but turbidity declined to 36.0%. The decline in the turbidity of the treated sample can be attributed to the higher dosage of the bio-coagulant as the Yila wooden stem was a raw crude wooden stem used and contains a lot of organics and in solution releases its natural colour to the solution and potentially affected the clarity of the final treatment. The trend in the increase of the turbidity values resulting in the decline of the percentage removal efficiency of the treatment has also been reported in other works [52, 79, 80]. No significant change in terms of temperature and pH was observed, however, there was a slight increase in pH from the initial 0.6% dose treatment to the 1% dose treatment. Again, the ORP recorded became more positive with a percentage positivity increase of 74.39%. When the treatment dosage was increased from 0.6% to 1% for the Yila wooden stem, the coagulation potential also increased. At 5% dose treatment, concerning the control sample, removal efficiency of 79.17%, 89.63%, and 88.09%, respectively, for COD, TSS, and turbidity was observed. No significant variation was observed in the pH and temperature. Just as in the case of the 0.6% and 1% treatments, the ORP observed for the 5% treatment was also more positive. However, there was a decline in efficiency in the treatment of the raw sample moving from 1% dose treatment to 5% treatment. The slight decline in the performance observed in this case can be attributed to the excess dose. In the coagulation and flocculation process there is an optimum dose concentration for every potentially active chemical with such characteristics, above such optimum dose point, the end treatment effluent gets disturbed and parameters such as COD, TSS, and turbidity are affected. The potential of the re-stabilisation effect resulting from saturation of polymer bridge sites in bio-coagulants is great in the coagulation or flocculation process. Any time such a process takes place it causes the already destabilised particles (as a result of coagulation) to be re-stabilised due to the insufficient number of particles available in the suspension to form more inter-particle bridges of flocs or agglomerates [11]. pH is an important factor concerning its effect on the surface properties of the bio-coagulants, it also affects the stabilisation of the suspension [75, 76]. Even though no significant change was observed in pH, however, there was a slight increase from the initial sample. The motivation to use this plant to monitor its performance in terms of faecal sludge treatment had come from the claim of one herbalist in the Upper West Region of Ghana. According to the claim, he used such a plant in the treatment of hernia in men. The principle of the treatment according to the herbalist is that, at the initial dose rate, the fluid in the scrotum begins to coagulate and at an increased dose rate as the days of treatment go by, then the coagulated fluids begin to disperse until it is completely dissolved. The perceived patient is then deemed healed at that point of dispersion and dissolution. The observed experimental behavior of this Yila wooden stem for the treatment of the faecal sludge in this work is confirming the characteristics claim behaviour of the indigenous plant in the treatment of the hernia as claimed by the herbalist in the upper west part of Ghana. For all the experimental treatments, the observed final solution after each treatment gave less flocs, but more of a well-coagulated solid that subsequently gave sediment due to the gain in solid weight. By these characteristics, it can be inferred that the Yila wooden stem acted more like a coagulant than a flocculant. By these characteristics, the Yila wooden stem can be said to have a bio-coagulative characteristics and hence a bio-coagulant.

3.3. Coagulation/Flocculation Potential of the 'Yila' Bark. Even though the constituents found in the Yila bark and the Yila wooden stem were the same (Figure 3), separate experimental treatments were done at the laboratory at the same constant dosage.

After the 0.6% treatment of the sample with the Yila plant cover, the treatment efficiency for COD, TSS, and turbidity were, respectively, 66.24%, 71.79%, and 54.60%. The removal efficiencies were significant for the three parameters. Just as in the case of the stick treatments, no significant variations were observed for pH and temperature values. After the application of the 0.6% treatment, the ORP also was noted to be more positive as was seen in the case of the stick experiment and the percentage of positivity change was about 33.60% concerning the initial faecal sludge sample. Even though the treatment efficiency recorded was significant concerning the initial sample used, the percentage efficiencies for the 0.6% cover were less than that observed for the stick treatment.

When 1% of the cover treatment was applied, COD and TSS efficiency increased, respectively, to 77.39% and 82.02% but again, the turbidity declined to 15.91% just as was noted in the treatment applications of the stick component. No significant change in terms of temperature and pH was also observed, however, there was a slight increase in pH compared to the 0.6% dose treatment. Observed ORP followed other treatment dosage trends for the Yila plant by becoming more positive with a percentage positivity increase of 74.39%. The relatively higher removal efficiency was seen for the 1% treatment compared to the same treatment application at 0.6% dose and the same trend was observed for the treatments of the stick.

When the dosage of treatment was increased to 5%, concerning the control sample, removal efficiency for COD, TSS, and turbidity were, respectively, 68.88%, 74.17%, and 47.19%. The observations for the percentage removal of the COD, TSS, and turbidity were all significant regarding the base sample (control). No significant variation was observed in the pH and temperature as observed for the 0.6% and 1% treatments. The ORP observed for the 5% treatment was also more positive. However, there was a decline in efficiency in the treatment of the raw sample moving from 1% dose treatment to 5% treatment. The slight decline in the performance observed in this case can be attributed to the excess dose as above the optimum dose, the leachate at the end of every coagulation process being disturbed, and the characteristics of the leachate being affected. The observed trends were also the same for the treatments realised using the Yila wooden stem and it is not surprising they both have the same constituents as mentioned in the characteristics discussion of the plant.

Again, as observed in the case of the wooden stem, the bark treatments also yielded more of a well-coagulated solid that subsequently gave sediment and it can be inferred that the Yila bark behaved like a coagulant than flocculants. By these characteristics, the Yila bark can be said to have a bio-coagulative characteristics and hence a bio-coagulant.

3.4. Coagulation/Flocculation Potential of the 'Voulo' Plant. As shown in Table 3, when the 'Voulo' plant was dosed at 0.6% concentration, the efficiency obtained on average was 71.28, 75.55%, and 70.77% for COD, TSS, and turbidity, respectively, and percentage removal for these parameters was significant at 95% confidence interval (CI). No significant variations were observed for pH and temperature upon treatment of the Voulo plant at this dosage. As well, this observation is the same as the one noted for the Yila plant and is consistent with earlier research works reported [35, 77, 78]. The ORP at the end of the treatment was more positive by about 7.83%. At the increase of dose rate to 1%, percentage removal for COD, TSS, and turbidity increased, respectively, to 80.43%, 86.83%, and 72.55%. Temperature and pH did not give any significant change, however, there was a slight increase in pH by increasing the dosage from 0.6% to 1%. Again, the ORP recorded became more positive with a percentage positivity gain of 22.41%. As well, at the increase of the treatment dosage to 1% the yielded percentage removal was higher than that seen for the 0.6% dose treatment. When the application of the 5% dose treatment was effected for the Voulo plant, removal efficiency of 78.37%, 84.43%, and 50.14%, respectively, for COD, TSS, and turbidity was realised. As noted in the lower dose rate and also in the treatment applications of the Yila plant, pH and temperature did not give any significant variations. In addition, as in the case of the 0.6% and 1% dose rates, the ORP observed for the 5% treatment was also more positive. However, there was a decline in efficiency in the treatment of the raw sample at this 5% dose rate treatment. Even though, no significant change was observed in pH, however, a slight increase from the initial noted at the end of the experiment concerning the initial sample. The observed experimental behaviour of this Voulo plant for the treatment of the faecal sludge for all the experimental treatments gave a better floc formation compared to the Yila plant. This can be attributed to other available compounds that were identified in the voulo and not in the Yila plant, for example, the presence of the trialkyl bismuth and furan derivative compound. The Voulo plant unlike the Yila plant, behaved characteristically more as flocculants than a coagulant.

4. Conclusion

The rising need for High performing biocoagulant/bioflocculant in the area of wastewater and faecal sludge treatment is of great interest due to its ease of acceptance for use and environmental friendliness. Several chemical compounds were identified as active constituents of the raw materials used to produce the bio-coagulants, of which some confirmed results reported in other works, whereas others are newly identified compounds in a plant-based bioflocculant.

The performance of the selected locally available materials in the treatment of the raw faecal sludge was evaluated. The Yila wooden stem gave a potential of pollutant removal up to about 83.99%, 93.79%, and 91.54% for COD, TSS, and turbidity, respectively, at appropriate dose rates. Application of the Yila bark gave a respective removal efficiency of up to about 77.39%, 82.02%, and 54.60% for COD, TSS, and turbidity at the appropriate dose rate. The efficiency of the Voulo plant obtained for COD, TSS, and turbidity was up to about 80.43%, 86.83%, and 72.55%, respectively. For all the locally based materials used, no significant variations were observed for pH and temperature upon application of their treatment in this study irrespective of the dose rate or concentration applied. Where there were reductions in pollutants, the removal efficiency was significant at a 95% CI for all cases, and in all the cases, the ORP became more positive after each dose treatment. No cyanogenic or toxic compounds were identified in the characterised raw materials used for this study.

The utilisation of bio-coagulants/bio-flocculants in the treatment of faecal sludge in Ghana looks viably as an option due to the observed efficiencies obtained from the applications used in this study. This study has revealed the potential of producing coagulants that can perform as effectively as synthetic/chemical coagulants using locally natural raw materials but the use of it at a large scale will only be applicable for batch or semi-batch systems. Newly identified indigenous plant-based flocculants/coagulants that are unknown but locally available and accessible in Ghana have been identified and the viability of its being used as bio-coagulant or bio-flocculant in the treatment of wastewater/faecal sludge is great.

The development of these biocoagulants/bioflocculants for faecal sludge and wastewater treatment has good prospects as a green technology for treating effluent and yielding value-added products, such as fertilizers/soil conditioners, in the future. As well, the characteristic constituents of the identified compounds will give the locally identified plants in this study a new challenge for future research. The presence of some interesting constituents identified in the plants under consideration especially those in the Voulo plant, can open up opportunities to elucidate the potential applications of these identified plants in the areas of pharmaceuticals, cosmetics, glass and ceramics, rubber production, and other applicable medicinal advantageous areas.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request. The corresponding author is responsible for data distribution and can be reached via the email eagleskertoozer@yahoo.co.uk. However, substantial data information on the research is provided in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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