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ORIGINAL ARTICLE

Performance evaluation of Synthetic and Bio-organic coagulants for removal of Natural Organic Matter from Drinking Water

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ABSTRACT

Surface water sources contain a high amount of natural organic matter (NOM), which results from natural and anthropogenic activities. The NOM could react with chlorine to produce disinfection by-products (DBPs) that pose public health risks and are environmentally unfriendly. This study examined the effectiveness of synthetic and bio-coagulants for the removal of NOM and the associated turbidity from water. Water samples were collected from Legedadi water treatment plant during the months of April (dry season) and July (Wet seasons) 2021. Jar test was performed to test the coagulants' effectiveness for removing turbidity and NOM using synthetic and organic coagulants. The results revealed that the optimum coagulant doses were 70 & 30 mg/L for PACl (Poly Aluminum Chloride), 110 & 90 mg/Lfor Aluminum sulfate, and 140 & 120 mg/L for MOS (Moringa Olifera Seed) for the dry and wet seasons, respectively. Enhanced coagulation experiments were carried out to evaluate the efficiency of the coagulants in removing the TOC and turbidity. The enhanced coagulation removal of TOC and UV254 followed an order of PACl> Aluminum Sulfate > MOS. Coagulant dose, type and pH, have significant($p< 0.05$) effect on TOC and turbidity removal from the raw water. The result obtained in this study indicated that bio-organic coagulants can be viable options in thetreatment of water to remove NOM and reduce the formation of DBPs.

Keywords: *Enhanced coagulation, bio coagulant, NOM, Synthetic coagulant, TOC, Turbidity removal.*

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1. Introduction

Water is crucial for all forms of life. The increasing world population demands clean water for drinking, recreational, industrial, and agricultural activities [1]. water quality should be endlessly checked before being introduced into the supply system. Water used for potable purpose may come from various sources: groundwater, spring water; and water from rivers, streams, lakes, among others [2-4].

Globally the primary source of drinking water is fresh surface water. Surface water sources for potable uses are characterized by different physical, chemical, and biological characteristics [4, 5]. Water consumption is rapidly increasing globallyasobserved in the past two centuries. However, water quality continues to deteriorate ; even where there is enough water to meet current needs, water resources are increasingly becoming polluted due to anthropogenic and natural reasons [6, 7].

Conventional water treatment undertakes several processes, such as screening, coagulation, flocculation, sedimentation, sand filtration, and disinfection, to meet national and international water quality standards [8]. Surface water sources are known to contain a high amount of organic matter, which comes from natural sources such as soil and the decomposition of leaves, algae, and microorganisms, or anthropogenic sources such as organic alterations (compost or biosolids) or sanitary landfill spills [9, 10].

Together with anthropogenic compounds, natural organic matter (NOM) makes up a complex mix of organic compounds that are associated with chemical disinfectants, giving rise to several hundred distinct Disinfection byproduct (DBP) molecules [10, 11]. The NOM was reported to affect the drinking water quality and treatment processes by affecting the water quality in color, odor, and taste, increases the use of the amount of coagulants and disinfectants, increasing heavy metal adsorption and promoting microbial growth [12, 13].

The presence of NOM was reported in most freshwater resources like rivers and lakes all over the globe [10, 14]. It leads in the formation of defection by-products due to the humic and fluvic acids which are significant contributors to NOM in water and could react with chlorine and other disinfectants to produce DBPs [15]. NOM is not toxic by itself but it produces more than 600 reported DBPs which include aliphatic halogenated trihalomethanes (THMs), halo acetic acids (HAAs), haloacetonitriles (HANs), haloketones, and trichloronitromethane along with numerous aromatic halo-DBPs [16, 17]. An increase in NOM concentration was observed in fresh waters worldwide, which rationalizes the need for efficient and versatile water treatment processes to remove NOM [18, 19].The DPBs are reported to be carcinogenic, harmful, and are not eco-friendly [20]. The health consequences caused by DBP's include cancer kidney, bladeer, esophagus, lymph and other health issues such as birth loss weight [21]. The presence of DBs is becoming a growing concern in developing nations particularly where their lack of sophisticated treatment options are scarce[22, 23]. For instance, DBPs including Trichloromethane, Dibromochloromethane, Bromodichloromethane, Tribromomethane, 1,2-Dibromomethane and Dichlorobromomethane in potable water samples in Hossana town, Ethiopia [24]. Treatment techniques such as aeration or air stripping, oxidation, coagulation, enhanced coagulation, adsorption, biologically active carbon (BAC), ion exchange, and membrane filtration have been reported to be effective for the removal of NOM from freshwater sources[25, 26]. However, the search for alternative NOM removal processes in compliance with the influent and effluent water standard in water treatment plants is an going quest[27, 28]. Therefore, it is crucial assessing and incorporating an efficient method for elimination of NOM in water treatment where coagulation comes to in picture.

Coagulation is a conventional treatment process that neutralizes charges and forms a gelatinous mass to trap or bridge particles, thus forming a mass large enough to settle or be trapped in the filter. Coagulation is vital in purifying and enhancing water quality and rising adequate water volume [29].Coagulation is also reported to produce less DBP as compared to ozonation technique[30].It helped to prevent the formation of disinfection byproducts(DBPs)[31, 32]. Previous studies have reported coagulation processes was able to enhance the removal of DBP from water, which includes polymeric coagulants such as PACl, PFS, PASiC, PAF-SiC, PFSiS, and coagulation in combination with other treatment processes such as the magnetic ion exchange resin (MIEX), Peroxymonosulphate assisted Fe (III) coagulation, and chemical oxidation, [13, 30, 33, 34]. Recently, there has been a surge of interest in using bio-coagulants for various water treatment applications, such as chitosan, Moringa oleifera[35], Oak Leaves[36], Nano banana peel[37] and *Lepidium sativum* [38],which are produced from natural sources and offer significant advantages over conventional coagulants posing no harmful and hazardous chemicals release and cheaper. Hence, utilization of coagulants for NOM removal would be important and considered to alleviate the problem.

Despite the several efforts in removing NOM, there is a need for more reliable and yet cost-effective approaches for the removal of NOM due to water quality concerns and stringent requirements for drinking water supply. It has also been found essential to study the role of enhanced coagulation in reducing NOM to reduce DBPs during water treatment. Enhanced coagulation is a promising strategy which is based on increasing the amount of coagulant added or controlling the coagulation process by the reaction pH conditions. It is employed in order to maximize particulate matter, turbidity removal, TOC, DBP precursor removal, residual coagulant content reduction, sludge production reduction, and cost minimization (Cui, Huang et al. 2020). Reports on the role of enhanced coagulation by synthetic and organic coagulants are rare. Specially, study report on NOM removal using synthetic and bio-organic coagulants techniques in water treatment plants in developing countries such as Ethiopia, are scarce. Therefore, this study aims to utilize enhanced coagulation by synthetic and organic coagulants to reduce the DBPs precursors by removing the NOM from water supply reservoir of Legedadi, Addis Ababa.

2. *Methodology*

Description of the study area

The map of Legedadi water treatment plant is shown in Fig. 1, which is the largest freshwater water supply dam. It is the major and the largest drinking water source for Addis Ababa city, Ethiopia. The water treatment plant is located between 9º20'N and 38º45'E at an altitude of 2450 m. The water treatment plant is constructed with a maximum depth of 34m close to the dam and a minimum depth of 4m at the periphery. The dam's mean annual maximum temperature is about 24 °C, and the mean annual minimum temperature is about 12 °C. The mean monthly rainfall is high in July and August (about 260 mm). The mean annual rainfall in the dam is about 1255 mm [39]. The water samples for this study were collected from the Legedadi water treatment plant in April 2021 for the dry and July 2021 for the rainy season.

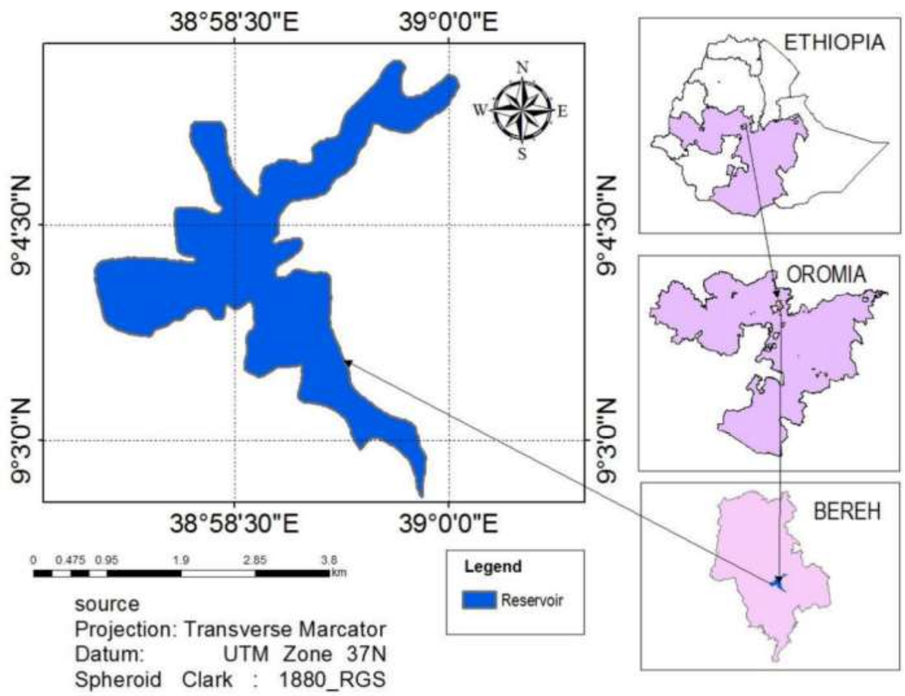


Fig. 1. Map of Legedadiwater treatment plant [40]

Materials and chemicals

2.2.1 Materials

The materials and apparatus that were used in this study include: multipurpose pH Meter (Hanna, model-HI 9023C) was used to measure the pH and temperature. The TDS and EC of the water samples were measured with (HACH, HQ30D) Portable Conductivity/TDS Meter. Turbidimeter (HACH,2100AN Laboratory Turbidimeter, EPA, 115 Vac) was used to measure the turbidity. UV/Visible spectrophotometer (HACH, DR 5000™) was used in the determination of UV254, NO_3-, NO_2^-, F-, Fe, Mn,SO_4^{2-}, TOC etc. Jar test Apparatus (PHIPPS AND BIRD MODEL NO 7790-9028) was used to undertake jar test experiments. Digital Titrator (WANT Balance Instrument Co., Ltd.) was used to undertake titrimetric determinations of COD, Total hardness and Total alkalinity.

2.2.2 Chemicals

Analytical grade chemicals and reagents were used for this study, including polyaluminum chloride, aluminum sulfate.Moringa seeds collected from Arba Minch City were used as bio-coagulant. Deionized water was used to prepare solutions. Organic free water was used in the determination of UV254. The pH 4 and 7 Buffers, hydrochloric acid (37%), and sodium hydroxide was used to adjust the pH of the water. Bromo cresol green indicator and potassium hydrogen phthalate (KHP) was used for the determination of total hardness and alkalinity.

Physicochemical parameters analysis of the raw water sample

The raw water samples were taken from LegedadeWaterTreatment Plant once every season using representative sampling technique physicochemical parameters were analyzed following thestandard procedures described in APHA (1998).

Preparation of *Moringa olifera*seedpowder.

The Moringa Olifera Seed (MOS) was collected and washed thoroughly with tap water andrinsed with distilled water to remove dirt particles. All samples were dried at 60°C for 48 h. The dry MOS samples were crushed into fine particles using a laboratory scale grinder (Jinesh War enterprise, product code JE00000017). The ground MOS was later sieved with a mesh size of 315 μm. The MOS powder was stored in vials. The prepared MOS wassubsequently added to water samples during the coagulation experiments without any pretreatment.

Jar test experiments to evaluate performance of coagulant on turbidity removal.

Jartest was performed for rapid mixing, slow mixing, and sedimentation to evaluate and optimize the coagulation process. The Phipps & Bird jar test apparatus with six beakers (1L) was used in all the coagulation experiments. The jar test apparatus used enables six beakers to be agitated at a time, with different stirringspeeds(rpm).A given amount of coagulant solution carefully pipetted into 50 mL beakers with different doses (mg/L) of each coagulant has been added into each beaker and rapidly stirred at 120 rpm for 1 min. The stirring speed was then lowered to 40 rpm (slow stirring speed) for 19 minutes. Afterwards, beakers were left to settle for twenty minutes (20 min). The jar tests were performed at room temperature and following the design of Legedadi water treatment plant. Using a standard pipette, samples for turbidity measurement and TOC/UV254 analysis were collected from the supernatant. Turbidity measurement and TOC/UV254 analysis were carried out using a turbidity meter and Dr5000spectrometer, respectively. For each coagulant and turbidity level, duplicate jar tests were carried out to obtain statistically reliable results. In the jar test experiments, one of the six jars received no treatment, serving as a control for comparing the TOC/UV254 and turbidity reduction for all other jars. The Percentage removals of the Turbidity (% Turbidity Removal) was calculated based on the following formula:

$$\%\ \text{Turbidity Removal} = \frac{(\text{Raw Water Turbidity} - \text{Treated Water Turbidity})}{\text{Raw Water Turbidity}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Fig. 2. *Jar Test Experimental set up*

Determination of Total organic carbon

The Persulphate Oxidation Method (HACH 10129) was used for TOC analysis as described by [41]. A total carbon analyzer Shimadzu TOC-VCSH was used to analyze organic carbon in raw and treated water by heating at103-105°C in an oven. The total organic carbon (TOC) is determined by first sparging the sample under slightly acidic conditions to remove inorganic carbon. the water samples in a vial were digested by persulfate and acidic form carbon dioxide. The carbon dioxide diffuses into a pH indicator reagent in the inner ampoules during digestion. The adsorption of carbon dioxide into the indicator forms carbonic acid. Carbonic acid changes the pH of the indicator solution, which, in turn, changes the color. The amount of color changes is related to the original amount of carbon present in the sample. The test result is measured at 598 and 430nm.

The Percent removal of the organic matter load (% TOC Reduction) was calculated based on the following formula:

$$\%\ \text{TOC Removal} = \frac{(\text{Raw Water TOC (mg/l)}) - (\text{Treated Water TOC (mg/l)})}{\text{Raw Water TOC mg/l}} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

Enhanced coagulation experiments

The Coagulation experiments of 1 L raw water were performed at room temperature, in a wide range of pH, coagulant doses (mg/L) and coagulant type (Aluminium Sulphate, PACl, and MOS powder). The pH of the test solution was adjusted by adding a pre-determined amount of 0.1 M hydrochloric acid or 0.1M sodium hydroxide solution prior to the coagulation. The raw water was mixed at the agitation speed of 120 rpm for 1 min, followed by a low mix of 40 rpm for 19 min, and finally a 10-20 min settling. The sample was taken from 2 cm below the water. The turbidity of the supernatant was measured by using a turbidimeter. The TOC and/ UV254 absorbance were measured after filtering the supernatant through a 0.45μm membrane filter. The effects of synthetic and bio-organic coagulants dose, and types of coagulants on coagulation performance experiments were conducted similarly for dry and season samples without any futher treatment in duplicate and reported with average values computed.

Data Analysis

The data was analyzed by SPSS statistical software version 26. Descriptive statistics such asmean, frequency, percent, and range were calculated and other results were then reported as mean plus standard deviation in tables and diagrams.

3. Results and discussions

Raw water characteristics

The Physico-chemical characteristics of raw water collected from Legedadi Water Treatment Plant were analyzed as per Association of Official Analytical Chemists (AOAC) standard methods as show below in Table 1.

Table 1: Physico-chemical characteristics of the raw water collected from the Legedadi Water Treatment Plant

NB:

ND= Not Detected, TH = Total Hardness, EC = Electrical Conductivity, TDS = Total Dissolved Solid, TOC = Total Organic Carbon.

As depicted in Table 1, the raw water characteristics of the Legedadi treatment plant has a pH of 7.97 ±0.014and 7.86 ±0.022 for dry and wet seasons, respectively; which is slightly alkaline ,but within the WHO permissible range for drinking water (6.5-8.5).The mean value of raw water temperatures both in the dry seasons were found to be 20±0.1

Parameters	Dry season (mean with STD)	Wet season (mean with STD)	WHO Standard(Reference)
pH	7.97±0.014	7.86±0.022	6.5-8.5
Temperature (ºC)	20±0.1	18.9±0.1	25
Turbidity (NTU)	201±0.05	394±0.05	< 5
EC (μS/cm)	140.65±0.33	132.6±0.32	<400
TDS (mg/L)	66±0.83	68±0.78	<500
Alkalinity (mg/L as $CaCO_3$)	212.95±0.21	74.4±0.22	200
TOC (mg/L)	28±0.05	41±0.12	-
UV_{254} (1/cm)	0.32±0.08	0.4±0.1	-
NO_3^- (mg/L)	7.32±0.11	8.6±0.14	11
NO_2^- (mg/L)	0.0080±0.05	0.194±0.03	1
Fe (mg/L)	2.84±0.007	3.8±0.004	0.3
Mn (mg/L)	0.43±0.001	0.8±0.001	0.1
F- (mg/L)	ND	ND	1.5
SO_4^{2-} (mg/L)	2.5±0.7	2.1±0.45	250
TH (mg/L as $CaCO_3$)	134.6±0.26	251.56±0.13	300
COD	17±0.3	28±0.23	10

and wet 18.9±0.1 for dry and wet seasons, respectively. within the The turbidity, in the wet season (394±0.05) wasmuch higher than the dry season (201±0.05 NTU). This is because high sediment is charged into the water system during the wet season from the catchment. In both seasons,theturbidity of the raw water was found beyond the permissible limits set by WHO.The alkalinity of the raw water in the wet season was high compared to the dry season, this might be due to dilution with the rain waterin the wet season.The total dissolved solids and electrical conductivity of the water samples were in the normal interval for raw water for both dry and wet seasons respectively.
The mean concentrations of the major anions studied for the raw water NO_3^-, NO_2^- and SO_4^{2-}were found to obey the permissible limits of WHO in both seasons. F^- was not detected in Legedadi water treatment plant raw water for wet and dry seasons. The concentration of Fe and Mn are an important indicator for water quality. The meanconcentrations of Fe and Mn in both seasons were found beyond WHO allowed limits in drinking water.

The higher total organic carbon and UV_{254} results of the raw water samples for both seasons showed the existence of significant portion of natural organic matter in raw water. The quantities obtained were within similar range of fresh water resources [42]. On the other hand, these results revealed that there exists a significant portion of natural organic matter in raw water. Moreover, the highest turbidity, alkalinity, and total organic carbon values in dry and wet seasons indicated that the treatment plant reservoir tributaries were exposed to large organic loads, sediment, and pollutants. These may arise from poor watershed management, lack of knowledge of surrounding society, and other associated factors. Álvarez et al. similarly, water treatment plant reservoirs were affected by poor watershed management, lack of knowledge, and practice associated factors regarding watershed management[43].

Performance of coagulant on turbidity removal

Coagulant dosage is critical in influencing coagulation efficiency in the coagulation-flocculation process [44]. This study examined different synthetic and bio- coagulants doses to obtain the optimum doses required for conventional coagulation with three coagulants: Aluminum sulfate, PACl, and MOS. The efficiency of the coagulants in the extent of percent removal of turbidity was studied based on their ability to remove the turbidity in raw water and obtain treated water having turbidity in range within WHO permissible limit (i.e. 5 NTU) [45]. The results obtained for the three coagulants to obtain the optimum dose (O.D) and associated turbidity removal are shownin 3.

The percentage of turbidity removal with different doses of Aluminum sulfate coagulant inthe dry and wet seasons shown on Fig 3. a and b, repectively. The degree of turbidity removal by aluminum sulfate coagulant was found between 96.79 and 98.4 percent for the range of coagulant dosage studied for the dry season. The best dose of aluminum sulfate for conventional coagulation was found to be 110 mg/Lwith average residual turbidity of 3.26 NTU. Likewise, the wet season degree of turbidity removal with aluminum sulfate was depicted similarly in Fig. 3a. The degree of turbidity removal by aluminum sulfate coagulant was found between 98.58 and 99.24 percent. The optimum aluminum sulfate dose for conventional coagulation was found to be 90 mg/Lwith an average residual turbidity of 3.26 NTU. According to Daryabeigi et al. an increase in Aluminum Sulphate dose resulted in an increase in the percent of turbidity removal for synthetic water with a turbidity of 500 NTU[46],.

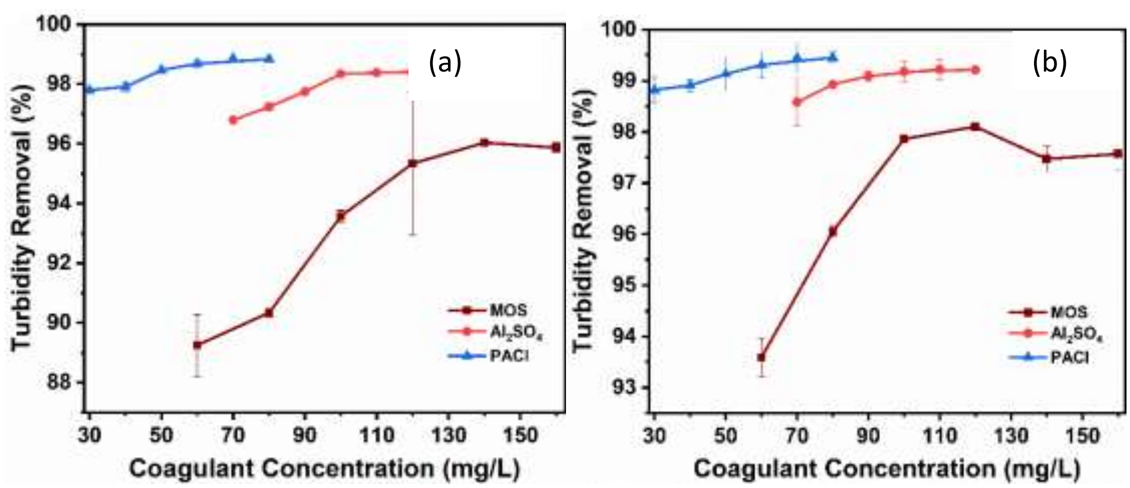


Fig.3. Turbidity removal as a function of Coagulant dose for (a) Dry and (b) Wet Seasons: T = 25 ^{O}C; rpm =120 rpm mixing

The results of turbidity removal with different doses of PACl coagulant removal was in the rangeof 97.79 to 98.85% in the dry season (Fig. 3a). The optimum PACl dose was found to be 70 mg/Lwith average residual turbidity of 2.3 NTU. The wet season percent turbidity removal was found to be between 98.82 and 99.45%. The optimum PACl dose for conventional coagulation was found to be 70 mg/Lwith average residual turbidity of 4.61 NTU. According to Saxena et al. similar fashion to this study, an increase in PACl dose resulted in an increase in percent turbidity removal[47].

The results of percent turbidity removal of treating raw water from Legedadi water treatment plant with different doses of MOS coagulant in the dry and wet seasons (Fig. 3 a & b) are depicted in. The study examined the MOS dosage ranges from 60 to 160 mg/l for the dry and wet seasons. The percent turbidity removal was found to be between 89.41 and 96.04 % for the dry season. The optimum MOS dose for dry season was 140 mg/Lwith average residual turbidity of 4.95 NTU, but sedimentation time was longer (> 35 minutes). Varkey et al. reported similar findings that optimum dose with turbidity level of 3-5 NTU by MOS needs large sedimentation time[48].
For the wet season, using MOS turbidity removal ranged from 93.58 to 98.1% (Fig 3b). The MOS dose, corresponding to maximum turbidity removal for the wet season was 120 mg/L. The average residual turbidity was 4.92 NTU, and sedimentation time was found to be longer (> 30 minutes). corresponding to maximum turbidity removal for the wet season compared to conventional coagulation was found to be 120 mg/Lwith average residual turbidity of 4.92 NTU andThe efficiency of bio-coagulant (MOS) greatly increased in the wet season than in the dry season, because the mechanism for MOS is via adsorption and neutralization. Moreover, the residual turbidity obtained was within the permissible limit set by WHO (<5 NTU). The dose of MOS required was reported to depend on the water samples' turbidity. Using Moringa oleifera as coagulant The efficiency of Moringa oleifera coagulant increased with increasing initial turbidity due to greater chance of particles being adsorbed and higher coagulation [49]. It is noteworthy to mention that with the use of MOS (bio-based coagulant) comparable economical turbidity removal was achieved to fulfill the water quality standards.

Generally, the obtained results showed an increase in coagulants dose of the aluminum sulfate, PACl, and MOS coagulants resulted in a significant turbidity decrease of the raw water resulting within the WHO permissible limit for the wet and dry seasons. In comparison to PACl (70 & 30 mg/L) and Aluminum sulfate (110 & 90 mg/L), a larger dose of MOS (140 and 120 mg/L) was required for raw water coagulation treatment in the dry and wet seasons, respectively. The percentage removal of turbidity was directly proportional to the dose and type of coagulant up to a point where the charge of suspended particles is balanced. But, beyond this point, the percentage turbidity removal either becomes constant or decreases due to charge imbalance. Hence, the removal efficiency of the three coagulants increased with turbidity during the dry season. Similarly, With the high color turbidity ratio, we will be favourable for coagulation process. where Aluminum Sulfate used as a coagulant with removal rates of 61 %[50, 51];.
These findings are in agreement with studies carried out by several scholars with different coagulants *Moringa oleifera*, *Cicer arietinum* and *Dolichos lablab* [52], *Dicerocaryumeriocarpum (DE)* [53], PACl, Ferric chloride and Aluminum sulfate which similarly reported higher turbidity resulted better coagulant efficiency which usually associated with wet season[54]. The coagulants used in our study showed better efficiency in the wet season than in the dry season. The efficiency of the coagulants based on residual turbidity (percent turbidity removal) in our study follows PACl >Aluminum sulfate > MOS.

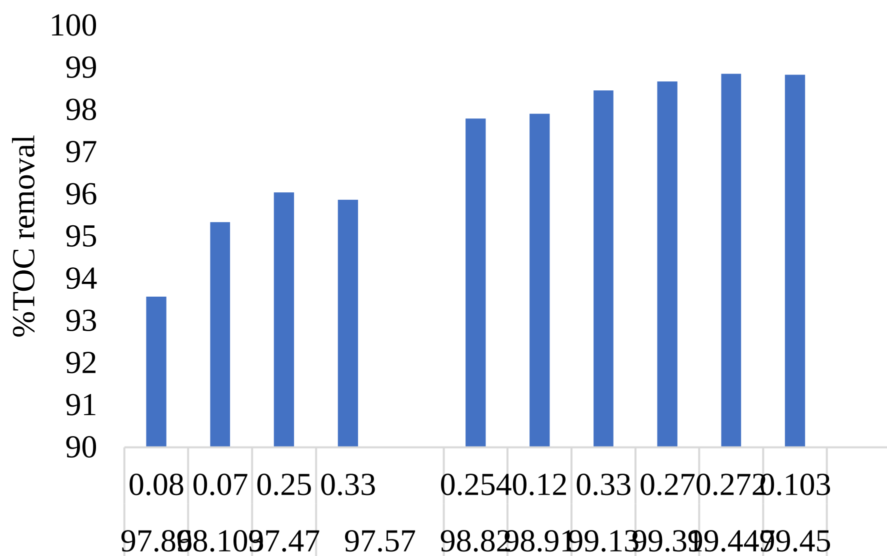
TOC, and UV254, Removal by Enhanced Coagulation

The enhanced coagulation study was carried out as per USEPA guideline recommendations while maintaining the water turbidity and pH as recommended by WHO. USEPA, 1999 states that raw water samples with TOC > 2mg/l required enhanced coagulation to reduce the DBPs formation[55].

The enhanced coagulation experiments were carried out by increasing the doses of the three types of coagulants with common multipliers 1, 1.25, 1.5. and 1.75 times O.D. The percentage of TOC and UV254 removal from raw water were measured.

Dry season: Percent of TOC removal of raw water from Legedadi water treatment using Aluminum sulfate ranged from 69.39 to 93.25% (Fig. 4). There was an increase in the percentage removal of TOC as the dose of the Aluminum sulfate coagulant increased from the initial dose to the 1.5*O.D. dose, while no further increase in TOC removal was found with an increase of coagulant dose to 1.75 O.D. The maximum removal efficiency of Aluminum sulfate was pronounced at the dose of 1.5*O.D. in enhanced coagulation experiments to lower the TOC level to less than 2mg/l (1.96 mg/L of residual TOC).

Given, the TOC removal using PACl ranged from 79.09 to 95.23% (Fig. 4). There was an increase in the percentage of TOC removed as the dose of the PACl coagulant increased from the initial dose to the 1.5*O.D. dose but the increment becomes marginal when the does increase to 1.75 O.D. The best results in terms of efficiency of PACl was pronounced at the dose of 1.5*O.D. in enhanced coagulations experiments to lower the TOC level to less than 2mg/L(1.4 mg/L of residual TOC) as shown in Fig. 6 .



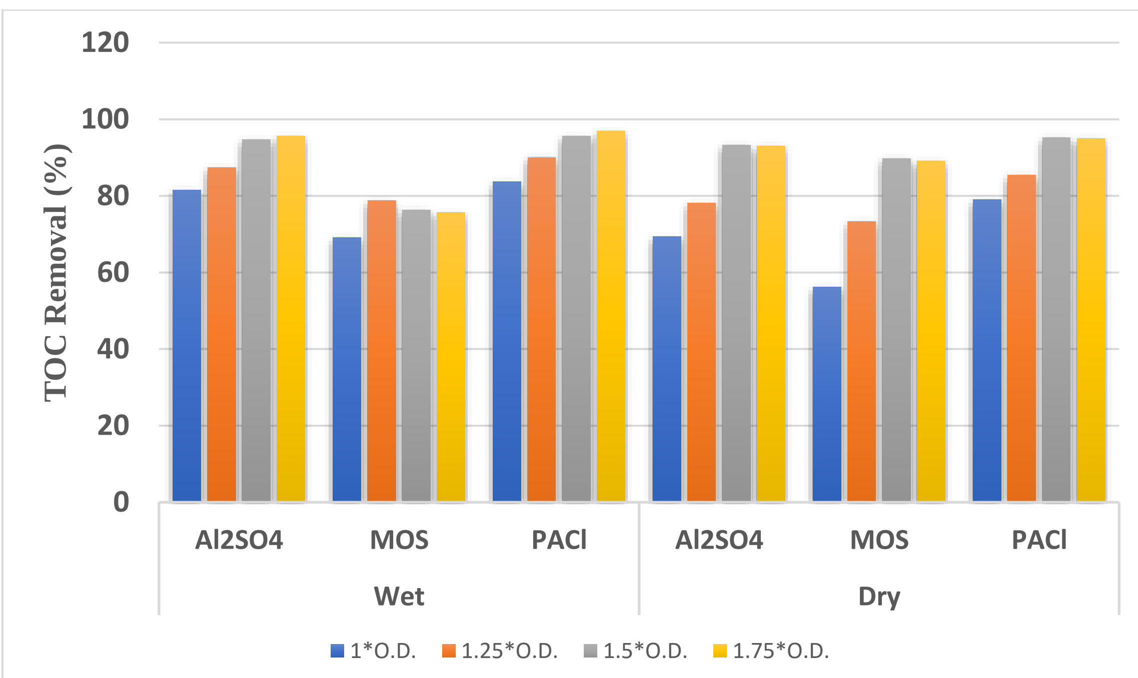


Fig. 64. Effect of enhanced coagulation in percent removal of TOC from raw water for Wet and Dry Seasons

The treatment with MOS ranged from 56.23 to 89.69% TOC removal (Fig. 4). There was an increase in the percentage of TOC removed as the dose of the MOS improved from the initial dose to the 1.5*O.D. dose, while no further increase in TOC removal was pronounced with an increase of coagulant dose. The treatment with dose of 1.5*O.D of MOS was pronounced higher efficency. But the residual TOC is still a bit higher than 2 mg/L at this optimal dose which was found to be 3.08 mg/L.

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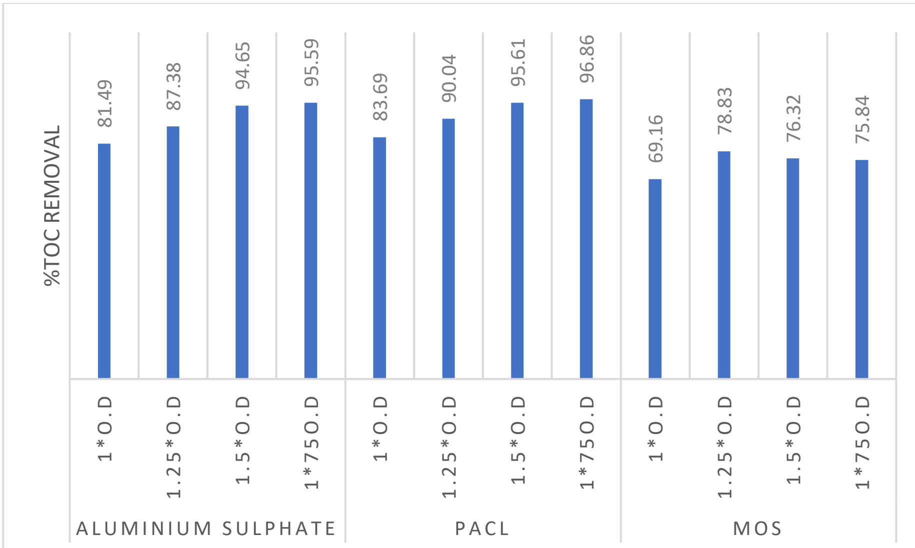
Wet season: Aluminum sulfate TOC removal efficiency in the wet season ranged from 81.49 to 95.59% (Fig. 4). When compared with the O.D. There was an increase in the percentage of TOC removed as the dose of the Aluminum sulfate increased to the 1.75*O. D dose unlike the dry season. The maximum removal efficiency of Aluminum sulfate was obtained at the dose of 1.75*O.D. in enhanced coagulation experiments to lower the TOC level to less than 2mg/l (1.8 mg/L of residual TOC)..



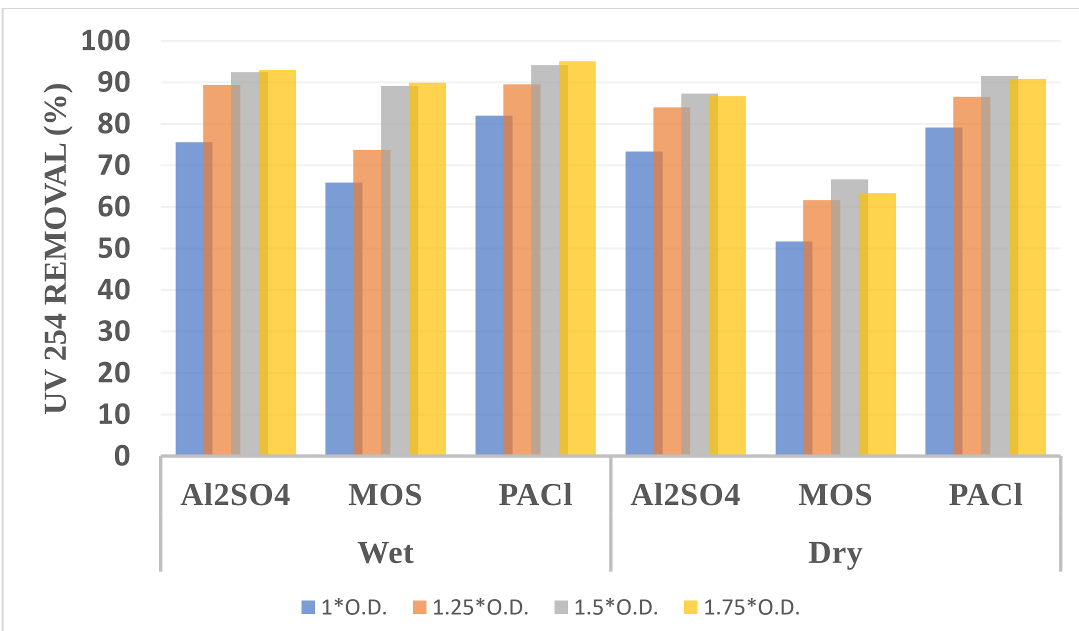


Fig. 5. Effect of enhanced coagulation in UV_{254} Removal from raw water for wet and Dry Seasons

Similarly, TOC removal using PACl increases when the dose increases. The removal rates ranged from 83.69 to 96.86% when the dose increases from O.D to 1.75 *O.D which is a bit high compared to Aluminum sulfate coagulant. TOC level to less than 2mg/L(1.28 mg/L of residual TOC) waa also achived with PACl. On the other hand, the percent TOC removal of raw water using MOS ranged from 69.16 to 75.84% as shown in Fig. 4. The maximum removal

efficiency of MOS was pronounced at a dose of 1.75*O.D. in enhanced coagulation experiments (9.9 mg/L of residual TOC).
Genrally, the enhanced coagulation of dry and wet seasons resulted in a substantial decrease in the TOC from the raw water for all types of coagulants used in this study. These findings are in line with the research carried out by different scholars [56, 57]. The authors reported increase in percentage removal of TOC with an increase in coagulant dose occurred due to an increase in the concentration of positively charged particles in solution from the coagulants. These ions stabilize most of the suspended and NOM in the raw water irrespective of the type of coagulant used. Thus, the coagulants significantly reduced the percentage of TOC from raw water. The percentage of TOC removal had been reported to be higher than 60% for enhanced coagulation and larger than 13% for conventional coagulation using [58]. The enhanced coagulation experiments using the three coagulants increased the amount of TOC removed greatly as compared to TOC removal by conventional coagulation. A comparable result reported by Parastoo et al. obtained turbidity removals of 95% and 50% and 75%, respectively using Ultrasonic/O_3 with coagulation using Aluminum sulfate, ferric chloride, and PACl coagulants. In this regards the enhanced coagulation revealed that coagulants resulted in the TOC removal efficiency required by USEPA D/DBP rules (15-30%) as mentioned elsewhere [59].
Again, PACl was the most effective coagulant for removing TOC from raw water followed by Aluminum sulfate and MOS in the wet and dry seasons. The higher TOC removal efficiency in enhanced coagulation experiments can show that less potential for the formation of DBPs in the chlorination step. Similar finding was reported by [60] and [59], the inorganic coagulants (PACl, $FeCl_3$ and Aluminum sulfate) resulted in higher removal of TOC to different extents to fulfill USEPA D/DBPs requirement. The findings of these study confirm the tested coagulant's TOC removal efficiency was higher than to the earlier studies reported[59, 61]. Therefore, the results suggest that water treatment plants need to consider the target TOC removal rates for selecting the type of coagulants to be used. Hence, from environmental and health perspective we recommend that enhanced coagulation can be used to impacts of potential DBP associated issues in comparison to conventional techniques.

UV254 is a good approach to measuring the NOM content of freshwater resources [62]. The present study explored UV254 alongside TOC to better estimate the amount of NOM removed from the raw water for the dry and wet seasons from Legedadi WWTP. The percent decrease of UV254 with enhanced coagulation ranged from 73.33 to 87% for Aluminum sulfate, 79.16 to 91.5% for PACl and 51.66 to 66.66%, for MOS coagulants for dry season (Fig. 5). For all coagulants the maximum UV254 removal was recorded at an enhanced dose of 1.5*O.D.

In the wet season the percentage decrease of UV254 with enhanced coagulation ranged from 75.62 to 93% for Aluminum sulfate, 82 to 95.12% for PACl and from 65.87 to 89.87% for MOS (Fig. 5). While the maximum UV254 removal was recorded at an enhanced dose of 1.75*O. D for all the three coagulants. UV 254 (NOM) removal by using multiwall carbon nanotubes and conventional coagulants together have been similarly reported elsewhere [63] and [64], respectively. In line to this study, Tanwi et al. natural coagulants work better in water with large concentrations of humic, hydrophobic, and high molecular weight compounds[65]. It is found that PACl was effective in removing UV254 from raw water with high TOC reduction. The removal of UV 254 from raw water was more pronounced during the wet season than dry season. This results was consistent with other literature reports[66] and [67]. Enhanced coagulation with PACl, Aluminum sulfate, and MOS showed a significant decrease of UV254 which indicates the removal of NOM from the raw water in the dry and wet seasons from the raw water. Such a finding pinpoints the importance of use of bio-based coagulants as potential coagulants for removal of NOM.

Conclusions

In this study, the performance of *Moringa Olifera seed* bio-coagulant and two conventional/synthetic coagulants were evaluated for the effective removal of natural organic matter from Legendaria drinking water supply system. It was found that all the coagulants significantly reduced the turbidity of the raw water to the extent of attaining the WHO's requirement limits for potability during both the dry and wet seasons at optimal conditions. The enhanced coagulation study with synthetic and bio-organic coagulants for dry and wet seasons resulted in increased removal of turbidity, TOC and UV254 from the raw water. The type of coagulants the percent turbidity removal from the raw water where PACl was found to be the most effective coagulant. It was also observed that higher turbidity removal was attained during the wet season than the dry season. The bio-coagulant tested in this study is promising and can be scaled up as an alternative treatment of NOM, which are the main contributor for formation of harmful DBPs.

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