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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 are rich in natural organic matter (NOM), originating from both natural processes and anthropogenic activities. Those materials can interact with chlorine, leading to the formation of disinfection by-products (DBPs) that pose public health risks and are environmentally unfriendly. This study examined the performance of synthetic and bio-based coagulants in removing natural organic matter (NOM) and associated turbidity from untreated water sources Water samples were obtained from the Legedadi Water Treatment Plant in April 2021, representing the dry season, and in July 2021, corresponding to the rainy season. 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/L for Aluminum sulfate, and 140 & 120 mg/L for MOS (Moringa Olifera Seed) for the dry and wet seasons, respectively. Enhanced coagulation experiments were conducted to assess the effectiveness of various coagulants in removing total organic carbon (TOC) and turbidity from raw water. The removal efficiency of TOC and UV_{524} followed the order: PACl > Aluminum Sulfate > Moringa Oleifera Seed (MOS) extract. Coagulant type, dosage, and solution pH were found to have a statistically significant effect ($p < 0.05$) on the removal of TOC and turbidity. The result obtained in this study indicated that bio-coagulants can be viable options for treatment of drinking water to remove NOM and minimize the formation of DBPs.

Keywords: *Bio-coagulant, NOM, Synthetic coagulant, TOC, Turbidity, Enhanced coagulation.*

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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, freshwater surface bodies serve as the principal source of potable water. These sources exhibit diverse physical, chemical, and biological properties that influence their suitability for drinking water supply[4, 5]. Water consumption is rapidly increasing globally in the past two centuries. However, water quality is progressively declining; even in regions with sufficient water availability, resources are increasingly contaminated due to both anthropogenic activities and natural processes [6, 7]. Conventional water treatment involves a series of unit operations, including screening and coagulation, flocculation, sedimentation, sand filtration, and disinfection, to meet national and international water quality standards [8]. Surface water sources are typically characterized by elevated levels 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*

2.1 Description of the study area

Figure 1 illustrates the location map of the Legedadi Water Treatment Plant, which the largest freshwater supply dam for Addis Ababa population, Ethiopia. It constitutes the primary and most extensive source of potable water for the city. The plant is geographically situated at approximately 9°20′N latitude and 38°45′E longitude, at an elevation of 2,450 meters above sea level. The treatment facility is constructed adjacent to the dam, with a maximum depth of 34 meters near the dam wall and a minimum depth of 4 meters along the periphery. The region experiences a mean annual maximum temperature of approximately 24 °C and a mean annual minimum temperature of about 12 °C. Rainfall is heaviest during the months of July and August, averaging around 260 mm per month, while the mean annual precipitation across the reservoir area is approximately 1,255 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.

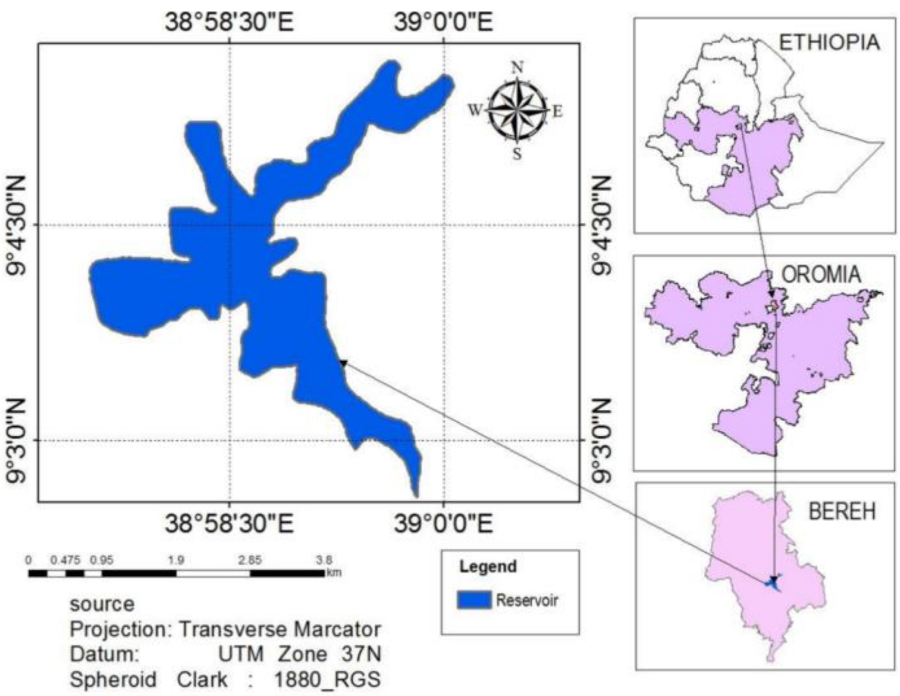


Fig. 1. Map of Legedadiwater treatment plant [40]

2.2 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.

2.3 Physicochemical parameters analysis of the raw water sample

The water samples were taken from Legedade WaterTreatment Plant once every season using representative sampling technique physicochemical parameters were analyzed following the standard procedures described in APHA (1998).

2.4 Preparation of *Moringa olifera* seed powder.

Moringa oleifera seeds (MOS) were collected and thoroughly washed with tap water, followed by rinsing with distilled water to eliminate surface impurities. The cleaned samples were then dried in an oven at 60 °C for 48 hours. 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.

2.5 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. Duplicate jar test experiments were conducted for each coagulant type and initial turbidity level to ensure statistical reliability of the results. In each set of tests, one of the six jars was left untreated and served as a control to assess the effectiveness of coagulation by comparing reductions in turbidity and TOC/UV254 absorbance. The percentage turbidity removal was calculated using the following equation:

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

Fig. 2. *Jar Test Experimental set up*

2.6 Determination of Total organic carbon

The Persulphate Oxidation Method (HACH 10129) was used for TOC analysis as described by [41]. A Shimadzu TOC-VCSH total organic carbon analyzer was employed to quantify organic carbon in both raw and treated water samples. Samples were initially heated at 103–105°C in an oven. Total organic carbon (TOC) determination involved sparging the sample under mildly acidic conditions to eliminate inorganic carbon. Subsequently, water samples in sealed vials were digested with persulfate under acidic conditions, converting organic carbon into carbon dioxide (CO_2). During digestion, the generated CO_2 diffuses into a pH-sensitive indicator reagent contained within an inner ampoule. The absorption of CO_2 forms carbonic acid, causing a pH shift that alters the color of the indicator solution. The extent of the color change, measured spectrophotometrically at wavelengths of 430 nm and 598 nm, is directly proportional to the original concentration of organic carbon in the sample.

The percentage removal of organic matter (% TOC reduction) was calculated using the following equation:

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

2.7 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 modified by adding a calculated volume of 0.1 M hydrochloric acid or 0.1 M sodium hydroxide prior to initiating the coagulation process. The raw water underwent rapid mixing at 120 rpm for 1 minute, followed by gentle stirring at 40 rpm for 19 minutes to promote floc formation. This was succeeded by a quiescent settling period of 10 to 20 minutes. Post-settling, a water sample was carefully collected from a depth of approximately 2 cm below the surface to avoid surface disturbances and floating particulates. The turbidity of the treated water 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.

2.8 Data evaluation and Analysis

The data was analyzed by SPSS statistical software version 26. Descriptive statistics such as mean, 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

3.1 Raw water characteristics

The physicochemical properties of raw water samples collected from the Legedadi Water Treatment Plant were analyzed in accordance with standard methods prescribed by the Association of Official Analytical Chemists (AOAC). The results are summarized in Table 1.

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

Table 1: Physicochemical properties of raw water sourced from the Legedadi Water Treatment Plant.

within the WHO permissible range for drinking water (6.5-8.5).The mean value of raw water

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

temperatures both in the dry seasons were found to be 20±0.1 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].

3.2 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 shown in 3. The percentage of turbidity removal with different doses of Aluminum sulfate coagulant in the dry and wet seasons is shown on Fig 3. a and b, respectively. 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 is 110 mg/L with an average residual turbidity of 3.26 NTU. Likewise, the wet season result for aluminum sulfate was depicted 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/L with an average residual turbidity of 3.26 NTU According to Daryabeigi et al., increasing the dose of aluminum sulfate enhanced turbidity removal efficiency in synthetic water with an initial turbidity of 500 NTU [46].

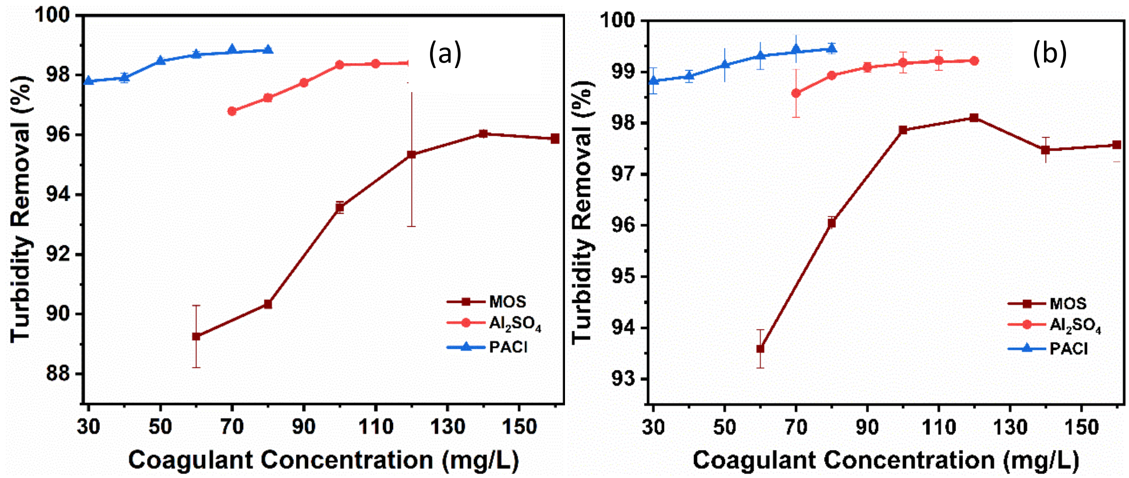


Fig.3. Turbidity removal as a function of coagulant dose: (a) Dry; (b) Wet Seasons: T = 25 ^{O}C; rpm =120 rpm mixing

The results of turbidity removal with different doses of PACl coagulant removal was in the range of 97.79 to 98.85% in the dry season (Fig. 3a). The optimal dose of PACl was determined to be 70 mg/L, resulting in average residual impurities 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]. Figure 3a and 3b illustrate the percentage of turbidity removal achieved using various doses of MOS coagulant for treating raw water from the Legedadi Water Treatment Plant during the dry and wet seasons, respectively. The study examined the MOS dosage ranges from 60 to 160 mg/l for the dry and wet seasons. The percent turbidity removal was seen to be between 89.41 and 96.04 % for the dry season. The optimum MOS dose for dry season was 140 mg/L with 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). The corresponding maximum turbidity removal for the wet season compared to conventional coagulation is 120 mg/L with an average residual turbidity of 4.92 NTU and the 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. The coagulation efficiency of Moringa oleifera increased with higher initial turbidity levels, likely due to the greater availability of particles for adsorption and enhanced particle aggregation [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.

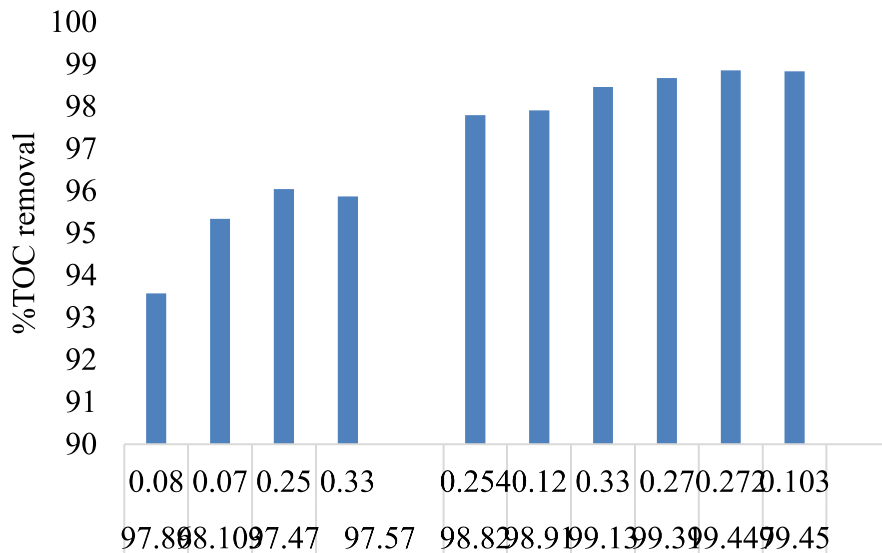
Generally, the obtained results showed an increase in coagulants dose of the aluminum sulfate, PACl, and MOS coagulants resulted in a significant turbidity decrease of the raw water resulting within the WHO permissible limit for the wet and dry seasons. In comparison to PACl and Aluminum sulfate, a larger dose of MOS was required for raw water coagulation treatment in both seasons. 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, a high color-to-turbidity ratio is favorable for the coagulation process, as demonstrated by the use of aluminum sulfate, which achieved a removal efficiency of 61%[50, 51].

These findings are consistent with previous studies conducted by various researchers using different natural coagulants such as 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.

3.3 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]. Enhanced coagulation experiments were conducted by increasing the doses of the three coagulants using common multipliers of 1, 1.25, 1.5, and 1.75 times the optimal dose (O.D). The removal efficiencies of TOC and UV_{524} from raw water were then evaluated.

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 to 1.5*O.D of the initial dose, while no further increase in TOC removal was found with an increase of coagulant dose to 1.75 O.D. The highest removal efficiency of aluminum sulfate was observed at 1.5 times the optimal dose (O.D.) during the enhanced coagulation experiments, effectively reducing the TOC concentration to below 2 mg/L, with a residual TOC of 1.96 mg/L. 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 to 1.5*O.D time the initial 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 .



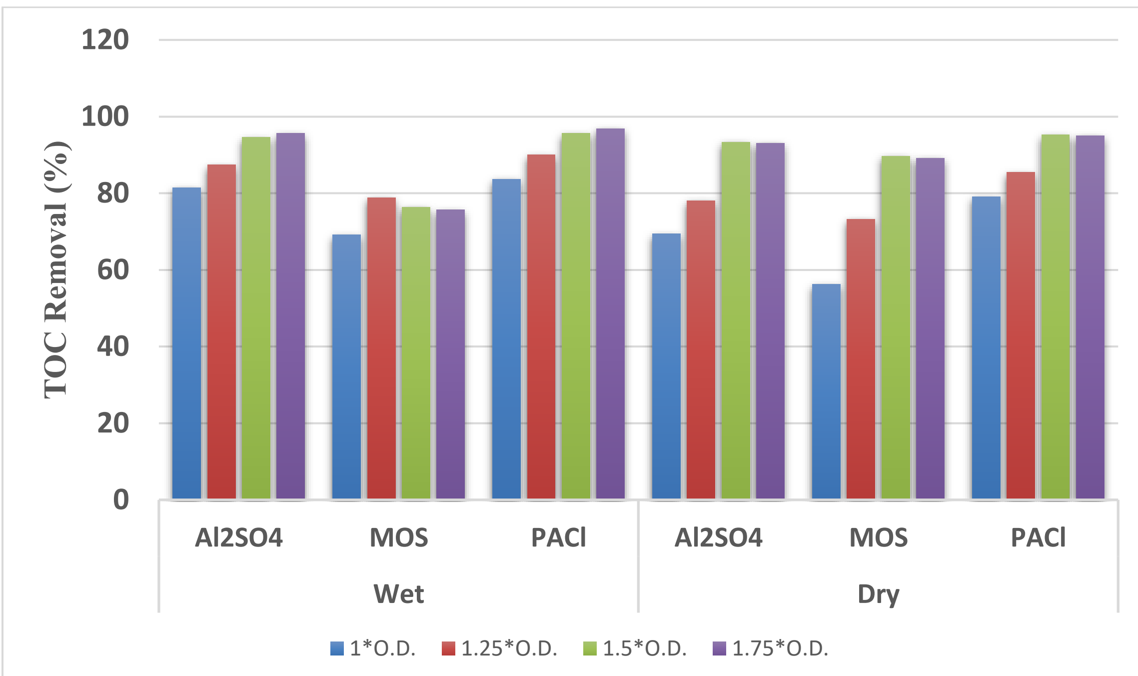


Fig. 64. Effect of enhanced coagulation in percent removal of TOC from raw water for Wet and Dry Seasons

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 increased to 1.5*O.D. of the initial 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 efficiency. 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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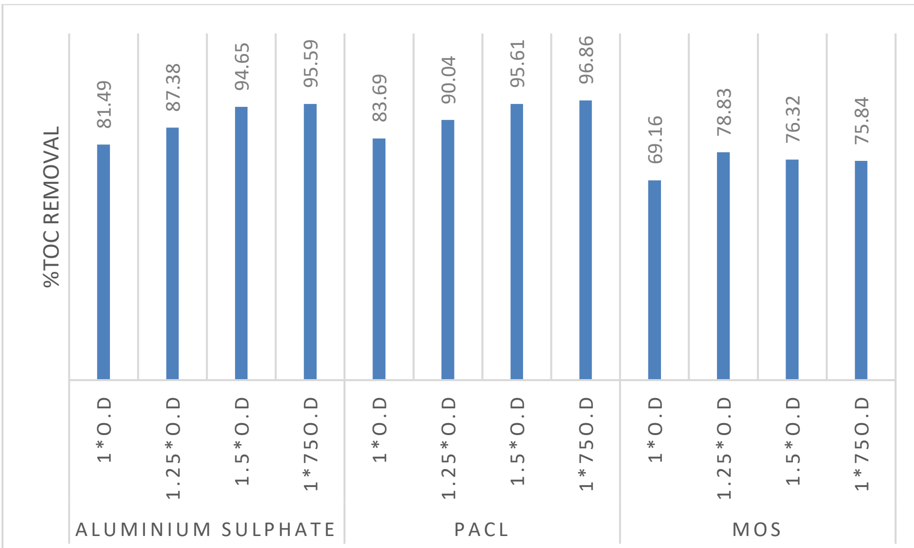
Wet season: Aluminum sulfate TOC removal efficiency in the wet season ranged from 81.49 to 95.59% (Fig. 4). When compared with the O.D. There was an increase in the percentage of TOC removed as the dose of the Aluminum sulfate increased to the 1.75*O. D dose unlike the dry season. The optimum removal 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)..



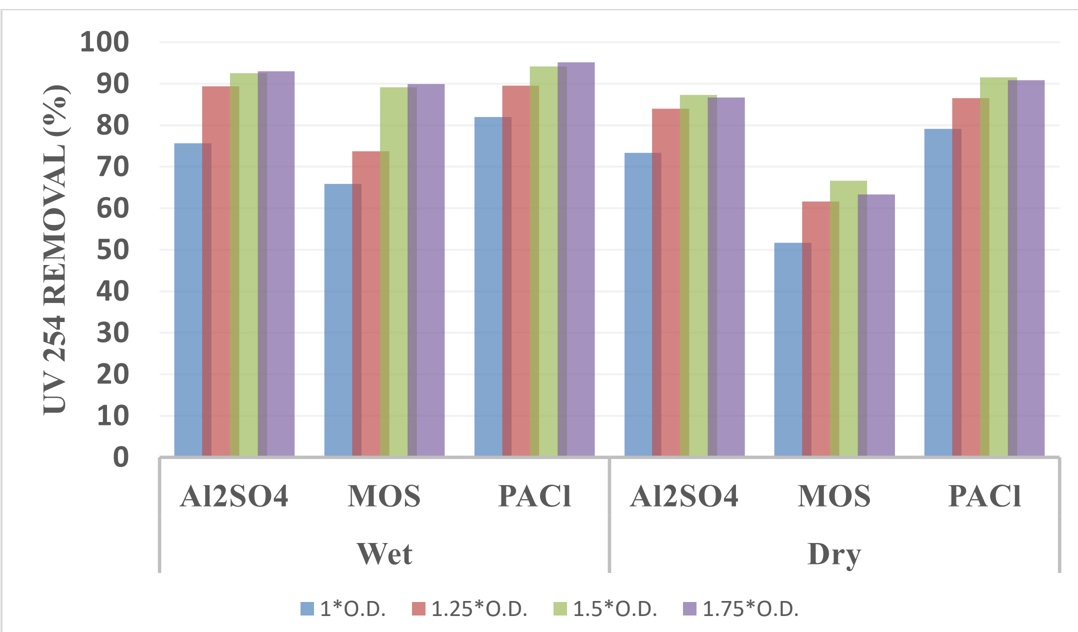


Fig. 5. Effect of enhanced coagulation in UV_{254} Removal from raw water for wet and Dry Seasons

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) was also achieved with PACl. On the other hand, the percent TOC removal of raw water using MOS ranged from 69.16 to 75.84% (Fig. 4). The optimal removal efficiency of MOS was achieved at 1.75 times the optimal dose (O.D.) during enhanced coagulation experiments, resulting in a residual TOC concentration of 9.9 mg/L. Generally, 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. Consistent with the findings of this study, Tanwi et al. reported that natural coagulants exhibit improved performance in waters containing high concentrations of humic substances, hydrophobic organic matter, and high molecular weight compounds[65]. PACl was found to be effective in removing UV_{254}-absorbing compounds from raw water, accompanied by significant TOC reduction. The UV_{254} removal efficiency was notably higher during the wet season compared to the dry season. Those results are 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 both seasons. These findings highlight the potential of bio-based coagulants as viable and sustainable alternatives for NOM removal in water treatment processes.

4 Conclusions

This study evaluated the effectiveness of both synthetic (PACl and aluminum sulfate) and bio-organic (Moringa oleifera seed, MOS) coagulants in removing natural organic matter (NOM) from raw water sourced from the Legedadi Water Treatment Plant across dry and wet seasons. The findings clearly demonstrated that all three coagulants significantly improved water quality by reducing turbidity, total organic carbon (TOC), and UV254 absorbance to levels compliant with WHO guidelines. Among the coagulants tested, PACl consistently outperformed aluminum sulfate and MOS, achieving the highest removal efficiencies of TOC and UV254 in both seasons. Enhanced coagulation with PACl effectively reduced TOC to below 2 mg/L, indicating its superior potential to minimize disinfection by-product (DBP) precursors. Aluminum sulfate also showed commendable performance, particularly during the wet season. MOS, while requiring higher doses and longer settling times, showed promising potential as a sustainable, low-cost, and biodegradable alternative for conventional coagulants, especially in resource-constrained settings.

The seasonal variation in removal efficiency, with generally better performance in the wet season, underscores the influence of raw water characteristics, especially turbidity and NOM concentration on coagulation outcomes. The observed correlation between increased coagulant dosage and improved NOM removal confirms the effectiveness of enhanced coagulation strategies in addressing water quality challenges, particularly in systems with high organic loads.

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