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Research Article

Efficiency of *Moringa oleifera* seeds as a natural alternative to the chemical coagulants in the drinking water treatment process

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Abstract

Coagulants play an important role in natural water purification and sludge disposal. However, Coagulants are commonly used in traditional treatment processes as aluminium sulfate (Alum). There has been a lot of interest in creating and using plant-based natural coagulants such as *Moringa oleifera* (MO) because of their natural characteristics and the absence of metals in their structure. The main aim of the present study is to compare the efficiency of MO seeds as a natural coagulant and Alum (the traditional chemical coagulant) for decontamination of drinking water. Therefore, raw water samples were collected from Mahmoudia Canal (MC) intake during the course of the study, where quality parameters of raw water including temperature, pH, EC, DO, turbidity, TDS, BOD, COD, sulfates, aluminium, heterotrophic bacteria (HB), total coliform bacteria (TC) and total phytoplankton count were determined before and after the treatment process and also, the removal efficiencies were calculated. Treatment with MO seed powder didn't affect water temperature, Electrical conductivity slightly increased during the interaction of MO seeds with water but didn't affect water quality. Concerning turbidity, MO showed almost the same removal (83.6%) as alum (88.8%) with RC of 3.6 and 2.5 NTU, which is much lower than the MPLS. MO exhibited higher activity towards the removal of BOD (51.1%), COD (77.39%), sulfate (5.75%) and HB (90.0%) removal compared to 39.4, -4.36, 75.14 and 83.3% achieved by alum respectively. In addition, Moringa increased DO to (7.06 mg/l), TDS (2.9%) and aluminium (49.57%) in the water compared to 6.4 mg/l, 0.29% and 88.25% additions obtained by alum. This confirmed the positive role of MO in decreasing organisms that consume dissolved oxygen (DO),

breaking down complexes production of soluble salts (TDS) and reduction in aluminum levels. It is then concluded that using Moringa seed powder is more effective, economical and safe for removing turbidity and other contaminants from raw drinking water compared to alum.
Keywords: Alum, Coagulation, *Moringa oleifera*, Mahmoudia Canal, Turbidity

Introduction

Water is an essential resource for life, which covers 75% of the Earth in the form of oceans, rivers, and lakes, life on earth needs water (Oliveira et al., 2013). However, water becomes a problem if it isn't available under the right conditions. Because humans use water for a variety of purposes, the water cleanliness of water use is critical and is known to affect their health. Since many water sources are contaminated by waste from various human activities, good-quality water has become expensive because many water sources have been polluted by waste from various activities (Negm & Abu-hashim, 2019; Oliveira et al., 2013). This has reduced in the amount and quantity of water sources that cannot meet the growing demand. Clean drinking water has become scarce because of poor management of land use. Surface water is polluted in some ways, including sewage, industrial wastewater discharges, and land-clearing runoff, while groundwater is contaminated by saltwater intrusion and landfills. This contaminated water must be treated before it can be circulated to consumers for domestic use, including drinking water. The treatment of drinking water is usually based on coagulation, filtration, sedimentation and disinfection processes (Yuliastri et al., 2016).

Coagulants play an important role in water and wastewater treatment, removing toxic materials like arsenic, phosphorus, and fluoride. They include inorganic coagulants like aluminum sulfate and organic coagulants like polyelectrolytes. However, residues can pose health risks. Polyelectrolyte use in drinking water treatment is controversial due to manufacturing contaminants and health concerns. Therefore, research is underway to replace these organic and inorganic coagulants with alternative natural and safe coagulants (Miller et al., 2008; Rahmadyanti et al., 2020). Among plant materials, Moringa oleifera (MO) seeds are expected to be a major flocculant for pollutant removal. MO is the only tropical plant of the genus Moringa in the family Moringa ceae. It is a biodegradable, non-toxic and natural organic polymer that is used as aflocculant for water purification on a small scale in developing countries (Dandesa et al., 2023; Katayon et al., 2006). Natural coagulants (biopolymers) will be of great interest because they are natural, low-cost products, environmentally friendly and considered safe for human health. There is a lot of interest in the development, and use of the facility. Based on natural coagulants. There is a long history of using plant materials as water treatment agents, This suggests that using local MO seeds for drinking water treatment in developing countries for turbidity removal, Therefore, clarification using local MO seeds makes sense for drinking water treatment in developing countries where other chemicals used for water treatment are expensive (Bergamasco et al., 2012; Choudhary & Neogi, 2017; Koul et al., 2022; Sotheeswaran et al., 2011).

Removing colloidal and suspended particles in water is crucial for addressing turbidity issues studies have shown that MO seeds can effectively reduce turbidity and remove viruses, bacteria, and other pathogens from water., as contaminated water disrupts aquatic life and reduces reproductive capability. Traditional methods for water treatment, such as synthetic organic and inorganic substances, are expensive and not cost-effective due to their high dose requirements (Kinyua et al., 2016). MO seeds are cost-effective, biodegradable, and safe for human health. They reduce health threats such as Alzheimer's and neurodegenerative illnesses, reduce sludge production, and improve coagulation efficiency. These environmentally friendly natural coagulants offer an economical and efficient alternative for treating contaminated surface water at home (Jiang, 2015; Koul et al., 2022). MO seeds have been shown to be effective coagulants in removing suspended solids, COD, Turbidity, softening water and organic pollutants. The active coagulation component attaches to negatively charged particle surfaces through electrostatic interactions. Extracting active components with salt solutions improves coagulation efficiency of MO seeds (Sulaiman et al., 2017).

Additionally, Egypt is rich in biodiversity and the MO tree grows well. Therefore, it is not difficult to use MO seeds as natural coagulants or biocoagulants in water purification processes. Thus, the effectiveness of natural flocculants for water purification was tested during water and wastewater treatment (Negm & Abu-hashim, 2019; Yuliastri et al., 2016).

Therefore, this study should be conducted to determine the effectiveness of MO seeds in improving water quality through use in the Mahmoudiya Canal (MC) an important water supply canal in Alexandria. Water quality parameters for performance include turbidity, conductivity, pH, temperature, metal absorption capacity and ability to reduce microbial levels.

Material and methods

Alexandria Water Sources

The Mahmoudiya Canal (MC) is located on the northern edge of the city of Behira. The MC is an important water supply canal in Alexandria governmental. The canal is 194,200 km above sea level on the Rosetta branch. The actual service area of the canal is 130,200 hectares. The total length of the canal is 77.170 km, and the Al-Khandaq East at the 13,200 km MC. The third water source is Zarkon sewage located 8,500 kilometers from the MC, which is discharged through the Edko Irrigation Pumping Station. The point source of pollution is the Edeko Drain in the Behira Region, which feeds the MC for irrigation needs along the canal and for the drinking water needs of the city of Alexandria. MC support fisheries, agriculture, industry, hydroelectric power, public water supply, and recreation (El-Gamal et al., 2009; Hamdard, 2010).

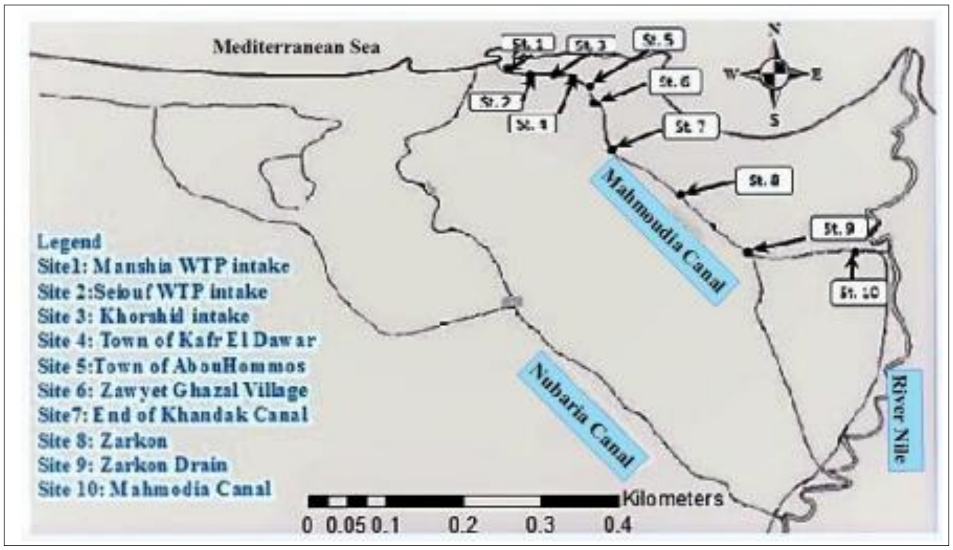

Figure 1. Location of MC, and sampling sites (Abdullah & Hussona, 2014).

Sampling

Sampling Procedure of Raw Water

During the duration of the study, samples of untreated water were collected from the intake of the Mahmoudia Canal (see Figure 1). Physical, chemical, and microbiological characteristics were measured and analyzed. Samples were collected from flowing water close to the source of the supply at approximately 30 cm under water surface. A large amount of untreated water (20-30 liters) was collected and used for the jar test. The collected water samples were stored refrigerated at 4^{o}C. The analysis of water is divided into two parts: where the first part was to be carried out immediately once it reaches the laboratory. Parameters were estimated at the spot immediately after the collection of the samples such as pH, EC, BOD, DO, and the second part was measured later as COD, Sulfate Aluminum, HB, TC and Phytoplankton. Samples for bacteriological analysis were collected in sterile glass bottles. Total coliforms (TC, CFU/100mL) and fecal coliforms (FC, CFU/100mL) were determined according to the standard method for water. Water samples were collected using flasks and phytoplankton stocks at harvest were estimated using the sedimentation method Analyses of water samples were performed using the American Public Health Association standard method (Association, 1926).

Working Site Description: Siouf Water Treatment Plant in Alexandria governmental)

(Siouf WTP) working site has the following characteristics:

- Siouf water treatment plant (Figure. 1) was established in 1934.
- It is the largest WTP of the Alexandria water company (AWCO) organization.
- MC is the main raw water supply for the plant
- Average (theoretical) plant design capacity estimated to be 980000 m^3/day. In practice the maximum capacity is approximately 780000 m^3/day and minimum capacity is approximately 500000 m^3/day (El-Gamal et al., 2009; Hamdard, 2010).

Raw Water Intake: Mahmoudia Canal

MC starts at ELatf and receives its water from the Rosetta Canal Branch by Elatf Pumping Station and additional water from Elkhanad Elsharkey originating from El Rayah Elbeheiri.

- Length: approximately 100 km.
- The total quantity of MC flow can be 9,000,000 m^3/day.
- Problems of intake include
    1. The quantity of raw water that results in a low level of the canal and the scouring of the bottom.
    2. The sedimentation is getting loose and the suspended solids (turbidity) increase in the raw water which directly increases the dose of the coagulation chemicals.
    3. In the summer season the low level of the El Mahmoudia Canal occure in July and August because at this time a lot of water is needed for the irrigation of rice and cotton which is approximately 80% of the total agriculture. After the intake and the screens of MC the water flows into the private canal, the function of the private canal is to let the raw water stay in the same composition for as long as possible so that the water quality can be stabilized.

Siouf Water Treatment Plant

Clarifiers and Sedimentation Process Siouf WTP has two types of clarifiers:

- Pulsator clarifiers: Contains 5 units of clarifiers.
- Italba clarifiers: Contains 3 units of clarifiers.

Description of Italba Clarifier

- Pumping house: to raise raw water.
- Chemical building preparation of the diluted coagulation solution and dosing them mechanically based on the Jar test experiment.
- Flash mixer part: The chemicals (coagulants) must be homogenously and uniformly dosed and distributed them in the water.
- Slow mixing part: where gentle movement of the motor using driven paddles at low speed.
- Sedimentation tank: composed of 4 partitions, each delivering 60,000 m^3/day and involves the removal of the suspended matter present in the water such as: sand, slurry, chemical precipitates, biological matter, contaminates and floccules. These solid matter are collected at the bottom of the clarifier by the effect of gravitational forces.

Preparation of *Moringa oleifera*

The *Moringa oleifera (MO)* seeds were harvested when they were fully mature from the tree of the best and matured quality, seeds with a brown color are exclusively utilized because of their heightened coagulation activity. Thus, the seeds were air-dried at 40°C for two days. Remove the shell around the seeds with a knife, grind the seeds to a powder with a laboratory mortar and pestle, and sieve through a 2.5 mm aperture sieve to obtain a fine powder (Arnoldsson et al., 2008; Sarpong & Richardson, 2010; Tunggolou & Payus, 2017).

Treatment bioassay of drinking water using Moringa oleifera

MO efficiency was examined in the present study as a natural non- traditional substance to replace the commonly used chemical coagulant for the treatment of drinking water not only for removing suspended solids but also other pollutants either -physical, chemical or biological. For comparison with the traditional treatment of drinking water, alum (Aluminum Sulphate) was tested as an example of a chemical coagulants under the same conditions as MO.

Determination of the Moringa and Alum Doses

The alum (Aluminum Sulphate) optimum fixed dose was estimated (0.04 g/l) using a B-900 PHIPPS&BIRD jar tester which simulated the field case on bench scale and samples tested using HACH Turbidmeter Different doses (from 0.1 to 1.0 g/l) of MO were selected based on literature cited and experimentation.

Figure 2. The Jar Test Procedure

Procedure

The jar test procedure is summarized in (Table 1 and Figure 2) Coagulants (alum and MO) were added to individually to jars under rapid mixing at the start of the experiment. The applied dosages varied according to the experiments. Samples that were pre-chlorinated immediately prior to coagulant and adsorbent injection and before the start of rapid mixing.

Table 1. Jar Test Protocol

Process Step	Mixing Speed (rpm)	Duration (min)
Rapid Mix	100	1
Flocculation (Slow mix)	40	20
Sedimentation	none	60

Results and discussion

This study was performed to investigate the efficiency of MO seed powder as a natural coagulant to replace traditional chemical coagulants such as Al- Sulfate (Alum) or ferric chloride. The study was carried out in one of the drinking water treatment plants (Siouf Plant) that belong to Alexandria

Drinking Water Company. Analysis was performed over six months (from Jun 2022 to December 2022) where samples were collected on different temporal schemes to cover seasonal oscillations in the quality of the raw water. The following represents study was treatment of the raw water with the proposed doses of MO seeds during the summer and autumn seasons with the subsequent changes in the treated water quality. During present study, samples were collected during representing totally different climatic and environmental conditions. Therefore, the samples showed differences in their physical, chemical and biological contents. Tables 2, 3 and 4 represents levels of the different pollutants in raw and treated drinking water samples collected during this study.

Physical Water Quality Parameters

Temperature

Table 2 represent the variation in temperature of the raw and treated drinking water after using MO seed powder and alum. It is known that the higher the temperature faster the reaction and the results clearly show that the interaction of MO seed powder and alum with water does not affect the temperature. Treatment with MO seed powder did not affect the water temperature.

pH

Table 2 show the variation in the pH values of the raw and treated drinking water after using MO seed powder and alum. MO seeds powder does not need specific acidity to interact with water and perform coagulation which is a characteristic feature of MO a seeds powder. On the other hand, alum requires an alkaline medium to interact with the impurities in water during the coagulation process. The degree of turbidity and pH increased with increasing doses of MO seed powder, which was essentially a protein polyelectrolyte (Sánchez-Martín et al., 2012).

Electrical Conductivity (EC)

Table 2 represent the variation in the electrical conductivity (EC) of the raw and treated drinking water after using MO seed powder and alum. Electrical conductivity slightly increased during the interaction of MO seeds with water but did not affect water quality (conductivity varies rang 588 and 578 µS/cm) with use MO.

Total Dissolved Solids (TDS)

Table 2 represents the residual concentration (mg/l ,RC) and removal efficiency (RE%) of total dissolved solids (TDS) in raw and treated drinking water using MO seed powder and alum. Raw drinking water recorded 343 mg/l of TDS which is slightly and insignificantly increased due to the interaction of MO seeds and Alum to record the highest residuals of 344 mg/l with alum and 353 mg/l with 0.2 g/l MO powder representing 0.29 and 2.9% salts addition respectively. All of the samples were below the MPL of TDS (1000 mg/l). The little drop in Moringa activity during autumn compared to alum may be attributed to a decrease in temperature.

Conclusion for physical properties that this is mainly attributed to the irrigation scheme which controls the feeding of different canals such as Mahmoudia with water from the Nile River and consequently controls the concentration or dilution of the included contaminants. It could also be attributed to the temperature increase in summer which decreases the dissolution of oxygen in water, increases the metabolic activity of the included microorganisms with the subsequent biodegradable organic matter and decreases SO2 levels. Moreover, ultraviolet rays during the summer season are known to have detrimental effects on bacteria and phytoplankton decreasing their counts, especially near the water surface. High water evaporation rates during summer concentrate pollutants as shown by Al level which is nearly 2 fold that recorded in autumn, turbidity due to excessive growth and death of microorganisms as well as COD due to accumulation of non-biodegradable organic matter.

Turbidity (NTU)

(Tables 2 and 5) and (Figures 3 and 6), represent the removal efficiency (RE) and residual concentration (RC) of turbidity in raw drinking water recorded 22.3 NTU and treated drinking water using MO seed powder and alum. Alum produced the highest RE (88.8%) at the tested dose. On the other hand, MO seeds at 0.4 g/l achieved the best reduction of turbidity (83.6%) which is nearly similar to that achieved by alum. The RE% of turbidity decreased with increasing the dose of MO seeds powder reaching the lowest reduction (53%) at 1 g/l. Thus, RCs of turbidity in the water treated with Alum and MO seeds powder during the whole study were below the WHO (5 NTU), where higher removal efficiencies (RE%) of turbidity were recorded 55%, 58%, 52% and 62%, turbidity removals achieved during the present study are supported by those obtained by (Ramesh et al., 2016).

In another study, MO seed was examined as a natural coagulant to replace synthetic coagulant in water treatment where it could reduce 98.6% RE of turbidity. Reached residual turbidity levels of 15 NTU from 100 NTU at the optimum coagulant dosage (combination of 30 mg/l alum + 40 mg/1 MO). Compared with the present results MO powder (0.4 g/l) only recorded a higher removal efficiency (83.6%) from raw drinking water with 22.3 NTU (Yuliastri et al., 2016).

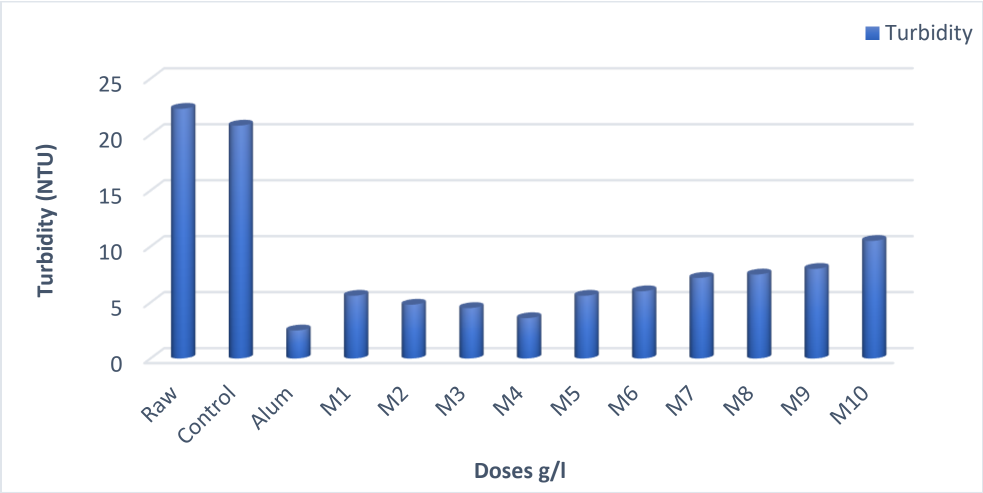

Figure 3. Variation in turbidity of raw and treated drinking water after using MO seed powder and alum

Table 2. Physical Characteristics for Temperature, PH, EC, TDS and Turbidity of The Raw and Treated Drinking Water After Using Moringa Speed Powder and Alum

MPL			6.5-8.5		1000	5
Sample Type	Dose (g/l)	Temperature (0C)	PH	EC µs/cm	TDS (mg/l)	Turbidity (NTU)
Raw	0.0	28.8	7.81	571	343	22.3
Control	0.0	28.5	7.8	570	343	20.8
Alum	0.04	28.7	7.55	574	344	2.5
M1	0.1	28.6	7.77	578	347	5.6
M2	0.2	28.6	7.75	588	353	4.8
M3	0.3	28.5	7.73	587	352	4.5
M4	0.4	28.6	7.72	586	351	3.6
M5	0.5	28.6	7.71	580	348	5.6
M6	0.6	28.7	7.75	581	349	6.0
M7	0.7	28.8	7.74	584	350	7.2
M8	0.8	28.7	7.79	586	351	7.5
M9	0.9	28.7	7.78	587	352	8.0
M10	1.0	28.8	7.75	584	350	10.5

M: Treated with Moringa Powder

MPL: Maximum permissible limits

Chemical Quality Parameters

Dissolved Oxygen (DO)

Table 3 represents the average of the dissolved oxygen (DO) content of the raw and treated drinking water after using MO seed powder and alum. The raw water sample recorded 5.03 mg/l. DO levels increased from 5.03 to 6.4 mg/l upon treatment with 0.04 g/l alum. Treatment with MO seed powder showed higher increases in the DO levels compared to alum, which increased regularly with increasing MO dose reaching the highest DO level (7.02 mg/l) at 1.0 g/l MO powder. MO seeds powder had positive effects on DO compared with alum. Increasing DO levels may be attributed to the elimination of aerobic organisms that consume DO from the turbid water was better with MO than with alum. This may be attributed to its anti-bacterial effects on the HB included in the raw water, leading to reduced DO consumption by such organisms and consequent replacement of DO from the atmosphere (Ogunshina et al., 2023). The DO value improved to 4.34 mg/l after treatment. Therefore, it is strongly suggested that MO seed is used to improve DO values (Shan et al., 2017).

Biochemical Oxygen Demand (BOD_5)

Table 3 & (Figures 4 and 6), illustrate that the BOD_5 in raw and treated water were highly decreases during the treatment trial in the laboratory (chemically). The results revealed that the BOD_5 of influent drinking water was very low (6.65 mg/l). While, the BOD_5 of treated water reduced after treatment using alum at 0.04 g/l recorded 4.03 mg/l. The highest removal efficiency with alum (39.4%) at 0.04 g/l, while the highest RE of BOD_5 was 51.1 % with MO seeds power at 0.1 g/l and the lowest RE was 32.3% at 0.9 g/l, BOD_5 of water increased with increased doses of MO seed powder as shown in Table 5. The results revealed higher positive effects of MO seeds powder on water quality compared to alum.

Chemical Oxygen Demand (COD)

Tables 3 & (Figure 4 and 6), represent residual concentration (mg/l, RC) and removal efficiency (RE) of COD in the raw and treated drinking water using MO seed powder and alum. The raw drinking water recorded a very low BOD (27.64 mg/l). This value was significantly reduced after treatment to record the highest RE with alum (75.14%) at 0.04 g/l that was increased with MO seeds powder recording a maximum of 77.39% at 0.7 g/l, which is also, recorded a minimum of 67.15% at 0.1 g/l as shown COD of water decreased with increased doses of MO seed powder as

Table 5. Again, results revealed higher positive effects of MO seeds powder on the water quality compared to alum.

Similar removals of BOD (50.6%), COD (74.8%) were achieved by MO . Low dosages (40-80 mg/l) of MO and Strychnos potatorum showed more efficiency compared with chemical coagulants. MO achieved 94, 60 and 81% removal of turbidity, COD and phosphorus respectively while Strychnos potatorum achieved 97, 54 and 82% removal of turbidity, COD and phosphorus respectively (Mohamed et al., 2014). Not only raw freshwater used for drinking but MO exhibited excellent efficiency in treating industrial wastewater. MO and tamarind seeds were used as natural coagulants for treating industrial wastewater containing very high organic matter. Industrial wastewater contains (510 and 800 mg/1) BOD and COD respectively. MO could reduce the BOD content to 76 mg/l and COD content to 96 mg/l which is considered an excellent achievement (Shan et al., 2017). (Rahmadyanti et al., 2020) Obtained the high removal efficiency of COD, BOD and TP in the study recorded 98.06, 97.67 and 11.47 % respectively.

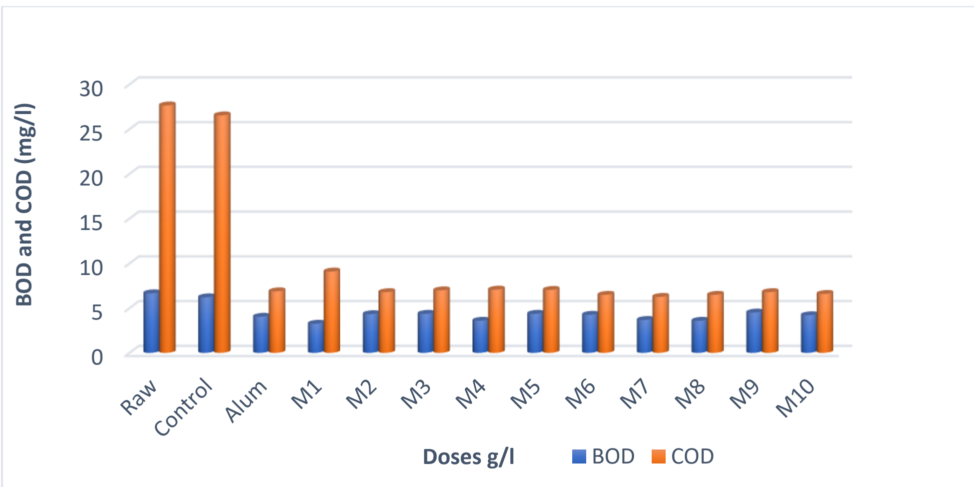

Figure 4. Variation in biological oxygen demand (BOD) and chemical oxygen demand (COD) of raw and treated drinking water after using MO seed powder and alum

Sulfates and Aluminum

Table 3 represent residual concentration (RC) and removal efficiency (RE) of sulfates in the raw and treated drinking water using MO seed powder and alum. The raw drinking water contained 50.003 mg/l of sulfate. Alum treatment increased sulfate concentration (4.36%) since contains sulphate salts. Oppositely, MO seeds powder reduced sulfate to a certain extent recording a highest

RE (5.75%) at 0.4 g/l and a minimum of 1.4% at 0.1 g/l as shown in table 5. Results confirmed the beneficial characteristics of MO seeds powder to water quality compared to alum. The study reveals that raw drinking water contains 0.0468 mg/l of aluminum, with alum treatment increasing it to 88.25%. MO seed, also increases aluminum concentration, with MO seeds recorded a maximum of 49.57% at 0.5 g/l and a minimum of 25.43% at 0.1 g/l as shown in Table 4.

Where, aluminum is hazardous to human health and increasing aluminum in water causes a human disease most commonly known as Alzheimer's. Therefore, coagulants such as alum must be restricted since it releases significant amounts of Al into drinking water and must be replaced by natural non-hazardous coagulants such as MO seeds powder to protect water quality.

Table 3. Physical characteristics for do, bod, cod, sulfate and aluminum of the raw and treated drinking water after using moringa speed powder and alum.

MPL			10	6	250	0.2
Sample Type	Doses (g/l)	DO (mg/l)	BOB (mg/l)	COD (mg/l)	Sulfate (mg/l)	Aluminum (mg/l)
Raw	0.0	5.03	6.65	27.64	50.003	0.0468
Control	0.0	5.20	6.2	26.53	50.000	0.0466
Alum	0.04	6.40	4.03	6.87	52.18	0.0881
M1	0.1	5.66	3.25	9.08	49.281	0.0587
M2	0.2	6.75	4.32	6.78	48.069	0.0678
M3	0.3	6.70	4.36	6.98	47.921	0.0676
M4	0.4	6.82	3.58	7.06	47.128	0.0689
M5	0.5	6.80	4.36	7.03	47.369	0.0700
M6	0.6	6.70	4.25	6.48	47.365	0.0680
M7	0.7	6.80	3.67	6.25	48.024	0.0683
M8	0.8	7.06	3.58	6.48	49.528	0.0699
M9	0.9	7.05	4.5	6.78	47.225	0.0679
M10	1.0	7.02	4.2	6.58	48.921	0.0667

M: Treated with Moringa Powder

MPL: Maximum permissible limits

Biological Quality Parameters

Total Coliform Bacteria (TC) and Heterotrophic Bacteria (HB)

(Figures 5 and 7) & table 4, represent density (CFU/ml), RE % of heterotrophic bacteria (HB) and Total Coliform Bacteria (TC) in raw and treated drinking water using MO seed powder and alum. HB and TC recorded 120 and 900 CFU/ml, respectively water. Alum treatment could remove (via adsorption) 83.3% and 97.8% of that amount at the tested dose (0.04 g/l alum). While MO seed powder could eliminate as high as 90.0% of such bacteria leaving only 12 CFU/ml at 0.4 g/l of the HB and 97.8% of the TC as shown in Table 5. Alum and MO powder exhibited similar removal efficiency. Moreover, the lowest achieved RE% was recorded 75.0% and 96.7% at 0.1 g/l, respectively indicating a strong effect of MO seed powder on drinking water- associated bacteria. Results indicated the excellent characteristics of MO seed powder in the removal of all the tested parameters compared to alum making it one of the highly efficient natural agents for purification of raw drinking water. It is also safe and more economic for removing turbidity and other contaminants from raw drinking water than Alum and brought contaminant levels below the environmental regulations (MPLS).

Total Phytoplankton

(Figures 5 and 7) and tables 4, represent density (cell/ml) and RE % of total phytoplankton in the raw and treated drinking water using MO seed powder and alum. Total phytoplankton count recorded 620 cells/ml in the raw drinking water. Alum and MO seed powder could eliminate 62.9 and 61.7% of the phytoplankton cells respectively with doses of 0.04 and 0.4 g/l respectively. The lowest recorded RE of phytoplankton using MO seed powder (51.6%) was achieved at 0.1 g/l as shown as Table 5.

The turbidity level in raw water controls the removal efficiency of other parameters during treatment with MO seeds. For the bacteriological quality of the treated water, it was found that at 15 NTU, the count recorded >100 cell/100 ml for all three different bacteria types whereas recorded < 1 cell/100 ml at 50 NTU turbidity level. The number of fecal streptococci was reduced to 3 after treatment at 15 NTU turbidity level while fecal coliforms were increased to 7 after treatment at 50 NTU turbidity level. It was also found that at 15 NTU, COD increased from 2 to 2.4 mg O_2/l after the sedimentation stage at the optimum dosage of M. oleifera, whereas at 50 NTU COD decreased from 40 to 7 mg/l. Other studies also revealed that the use of M. oleifera generally leads to an increase in COD levels in the treated water (Matsinhe, 2008). While, the bacterial count was reduced with an increased dose of MO. In addition, earlier studies, reported MO as an effective natural coagulant in reducing the microbial count as well as values of physicochemical parameters in the water purification process, where dosage used was 0.4 g/500 ml of MO recorded removal efficiency of COD and turbidity were 65.8 and 99.5 %, respectively (Desta & Bote, 2021).

In a recent investigation, it was shown that MO exhibited higher activity toward the removal of BOD (51.1%), COD (77.39%) and sulfate (5.75%). This study HB (90.0%) removal was achieved compared with 83.3% achieved by alum. Concerning sulfate RCs (47.128, 52.181 mg/l) and HB density (12, 20 CFU/ml) were achieved after treatment with M.O and alum respectively.

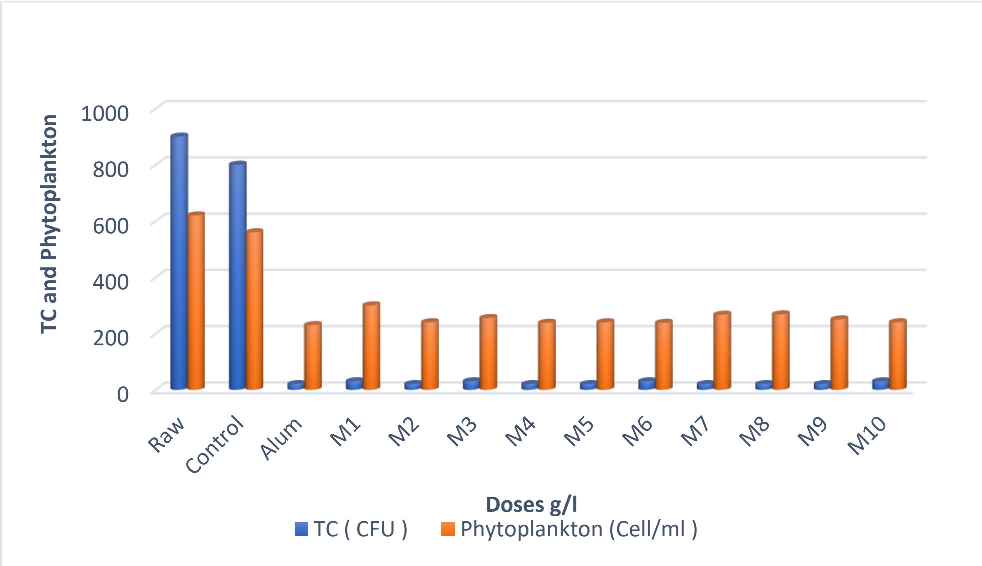

Figure 5. Variation in the total coliform bacteria (TC) and total phytoplankton of the raw and treated drinking water after using MO seed powder and alum

Table 4. Physical characteristics for temperature, HB, TC and phytoplankton of the raw and treated drinking water after using moringa seed powder and alum

Sample Type	Dose (g/l)	HB (CFU/ml)	TC (CFU/ ml)	Phytoplankton (cell/ml)
Raw	0.0	120	900	620
Control	0.0	116	800	560
Alum	0.04	20	20	230
M1	0.1	29	30	300
M2	0.2	16	20	240
M3	0.3	18	30	255
M4	0.4	12	20	238
M5	0.5	15	20	240
M6	0.6	19	30	238
M7	0.7	30	20	267
M8	0.8	22	20	268
M9	0.9	25	20	250
M10	1.0	24	30	240

M: Treated with *Moringa* Powder; MPL: Maximum permissible limits

Table 5. Removal Efficiency (RE%) of TDS, BOD, COD, Sulfate and Aluminum, HB, TC and Phytoplankton in the Raw and Treated Drinking Water Using Morinaga Seed Powder and Alum

Sample Type	TDS	Turb	BOD	COD	Sulfate	AL	HB	TC	Phyto
Raw	0.0	0.0	0.0	0.0	0	0.0	0..5	0.0	0.0
Control	0.0	6.73	6.8	4.02	0	0.0	3.3	11.0	9.7
Alum	0.29	88.8**	39.4	75.14	-4.36	-88.2	83.3	97.8	62.9
M1	1.2	74.9	51.1**	67.15	1.4	-25.4	75.0	96.7	51.6
M2	2.9**	78.5	35.0	75.47	3.87	44.8	86.0	97.8	61.3
M3	2.6	70.8	34.4	74.75	4.16	44.4	85.0	96.7	58.9
M4	2.3	83.6	46.2	74.46	5.75**	47.2	90.0**	97.8**	61.7**
M5	1.4	74.9	34.4	74.57	5.27	-49.5**	87.5	97.8	61.3
M6	1.7	73.1	36.0	76.56	5.28	45.3	84.2	96.7	61.6
M7	2.0	67.7	44.8	77.39**	3.96	45.9	75.0	97.8	56.9
M8	2.3	66.6	46.2	76.56	0.95	49.3	81.7	97.8	56.7
M9	2.6	64.1	32.3	75.47	5.56	45.0	79.2	97.8	59.6
M10	2.0	52.9	36.8	76.19	2.16	42.5	80.0	96.7	61.3

** Highest RE%; M: Treated with MO powder

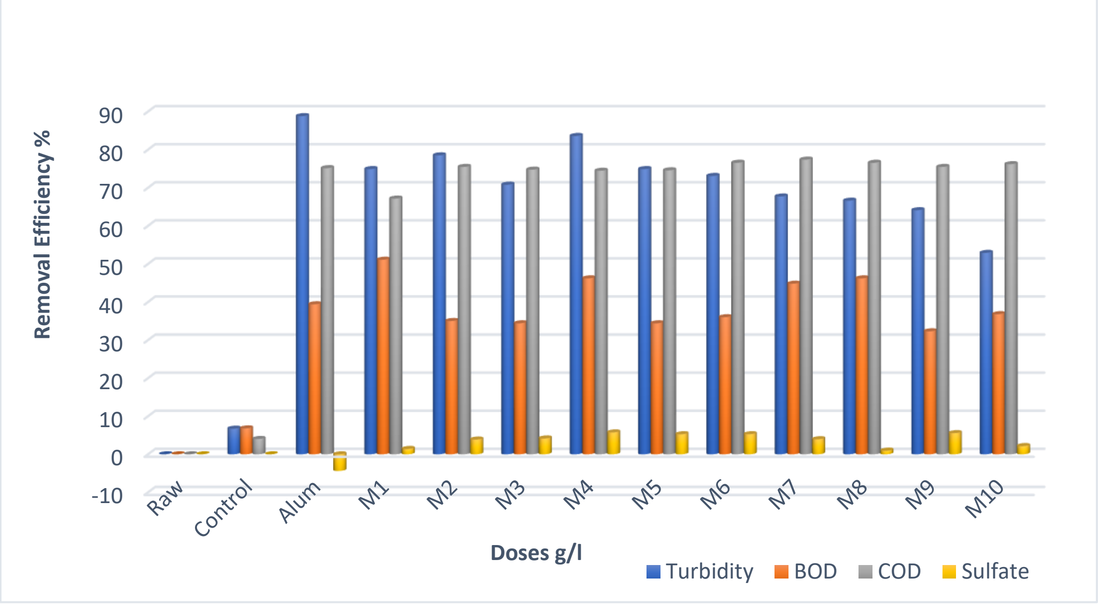

Figure 6. Removal Efficiency (RE%) of Turbidity, BOD5, COD, and sulfate in the raw and treated drinking water using MO seed powder and alum

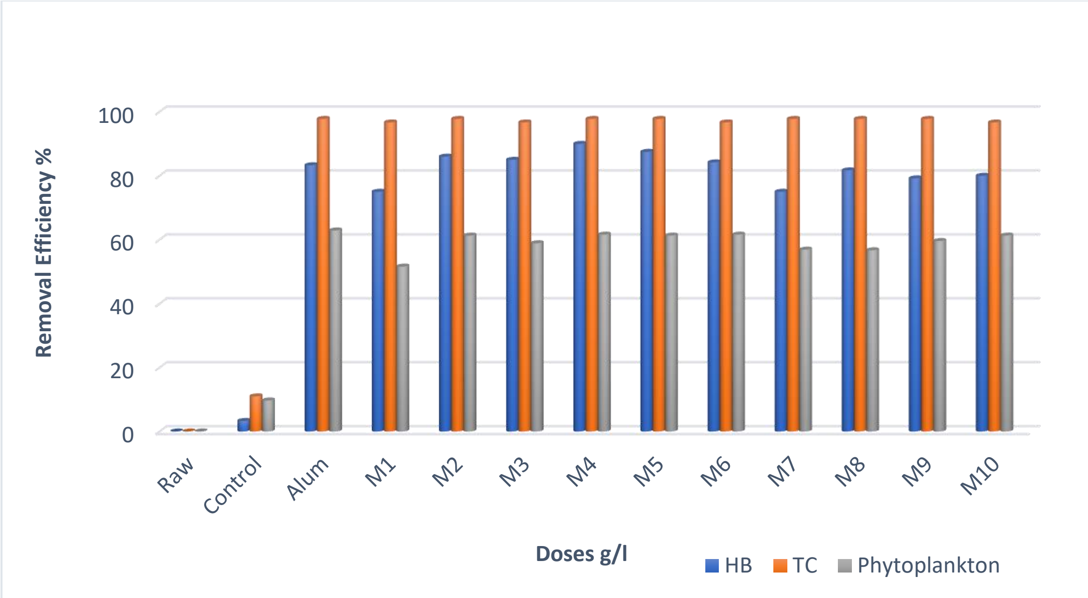

Figure 7. Removal Efficiency (RE%) of HB, TC and Phytoplankton in the raw and treated drinking water using MO seed powder and alum

Comparison of Alum and Moringa seed powder for the treatment of raw drinking water

Table 6 shows dissolved oxygen (DO) recorded at 5.03 mg/l in the raw drinking water, where DO levels increased to 6.04 and 7.06 mg/l by alum and MO seeds powder respectively. MO seeds powder had positive effects on DO levels compared to alum during the period study. This may be attributed to its anti-bacterial effects on the HB included in the raw water which leads to reduced DO consumption by such organisms and consequently replacement of DO from the atmosphere. Turbidity recorded 22.3 NTU in the raw drinking water. MO showed almost the same removal (83.6%) with MO powder (0.4 g/l) only as alum (88.8%) as shown in Table (5). While TDS recorded 343 mg/l in the raw drinking water. During the study, MO and Alum showed higher removal efficiency recording 2.9 and 0.29% salts addition respectively.

Biochemical Oxygen Demand (BOD_5) recorded 6.65 mg/l in the raw drinking water. MO exhibited higher activity towards the removal of BOD_5 (51.1%) compared to alum with 0.04 g/l recorded (39.4%). Chemical Oxygen Demand (COD) was recorded 27.64 mg/l in the raw drinking water, while MO exhibited slightly higher activity towards the removal of COD (77.39%) compared to alum 75.14% as shown in Table 5. However, sulfates (SO) recorded 50.003 mg/l in the raw drinking water. MO exhibited higher activity towards the removal of SO, (5.75%) compared to alum which increased SO, by 4.36%. Alum treatment increased SO_2 levels due to its chemical structure as sulfate salt. Similarly the present study, Al contents (0.0468 and 0.0288 mg/l) in the raw drinking water during summer and autumn respectively. Al levels increased (49.57 and 88.25%) by MO and alum respectively.

Effect of *Moringa Oleifera* on biological characteristics of drinking raw water

Table (5) shows total heterotrophic bacteria recorded 120 CFU/ml in the raw drinking water. MO efficiently removed HB count (90.0%) in the treated water during summer compared to 83.3% achieved by Alum. Total coliform (TC) was recorded at 900 cells/ml in the raw drinking water. Alum and MO powder exhibited similar removal efficiency (97.8 %). While Total phytoplankton recorded 620 cells/ml in the raw drinking. Again, Alum and MO powder exhibited very close phytoplankton removals where they achieved 62.9 and 61.6% RE during the study respectively.

Results indicated the excellent characteristics of MO seed powder in the removal of all the tested parameters compared to alum making it one of the highly efficient natural agents for purification of raw drinking water. It is also safe and more economical for removing turbidity and other contaminants from raw drinking water than Alum and brought contaminant levels below the environmental regulations (MPLS).

Table 6. Comparison between Alum and Moringa seed powder for the treatment of Raw drinking water

Parameter RE%	Raw water (RC, mg/l)	RE%		Doses g/l
		Treatment with Alum (0.04 g/l)	MO %	
DO	5.03	6.40	7.06	0.8
Turbidity	22.3 NTU	88.8	83.6	0.4
TDS	343	0.29	2.9	0.2
BOD	6.65	39.4	51.1	0.1
COD	27.64	75.14	77.39	0.7
Sulfate	50.003	-4.36	5.75	0.4
Al	0.0468	88.25	49.57	0.5
HB	120 CFU/ml	83.3	90.0	0.4
TC	900 CFU/ml	97.8	97.8	0.2
Phytoplankton	620 cell/ml	62.9	61.6	0.4

Conclusions

Coagulants play an important role in natural water purification and sludge disposal. There has been a lot of interest in creating and using plant-based natural coagulants such as Moringa oleifera (MO) due to their natural characteristics. Furthermore, they are low-cost agents with environmentally good behavior that is thought to be safe for human health. Results revealed the following which are correlated with standard criteria or the maximum permissible limits (MPL) for drinking water quality set by the Ministry of Health and Population

- Raw water samples contained (mg/l) 5.03, 22.3, 343, 6.65, 27.64, 50,003, and 0.0468 for DO, turbidity, TDS, BOD, COD, sulfate, and Al respectively. Samples also contained a total count of 120, 900, and 620 cells/ml of HB, TC, and phytoplankton respectively. Treatment with MO seed powder did not affect water temperature.
- Moringa does not need a specific acidity to interact with water and perform the coagulation which is a characteristic and advantageous feature of MO seeds powder treatment.
- Electrical conductivity slightly increased during the interaction of MO seeds with water but did not affect water quality. Concerning turbidity, MO showed almost the same removal (83.6%) as alum (88.8%) with RC of 3.6 and 2.5 NTU which is much lower than the MPLS.
- Concerning turbidity, MO showed higher removal efficiency at 0.4 g/l (83.6%) as alum (88.8%) with RC of 3.6 and 2.5 mg/l which is much lower than the MPLS.
- Moringa exhibited higher activity towards the removal of BOD (51.1%), COD (77.39%), sulfate (5.75%), and HB (90.0%) removal compared to 39.4, -4.36, 75.14, and 83.3% achieved by alum respectively. Concerning sulfate RCs (47.128, 52.181 mg/l) and HB density (12, 20 CFU/ml) after treatment with MO and Alum respectively, they exhibit excellent levels that are compiled with the regulations (MPLS).
- Also, MO increased DO (7.06 mg/l), TDS (2.9%), and Al (49.57%) in the water compared to 6.4 mg/l, 0.29%, and 88.25% additions obtained by Alum. This confirmed the positive role of MO in decreasing aerobic organisms that consume dissolved oxygen (DO↑), breaking down complexes and production of soluble salts (TDS↑), and increasing Al levels (Al↑). These are advantageous features of MO over alum. RCS of TDS recorded 344 &

353 mg/l while Al recorded0.0881 and 0.0700 mg/l after treatment with Alum and MO respectively which are also highly compile with the regulations (MPLS).

- Moreover, MO achieved the same RE% of TC as alum (97.8%) and almost the same RE of phytoplankton as alum.
- It is then concluded that using MO seed powder is more effective, economic an safe for removing turbidity and other contaminants from raw drinking water, the excellent characteristics of MO seed powder in the removal of all the tested parameters compared to alum making it one of the highly efficient natural agents for purification of raw drinking water.

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