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Applying *Moringa oleifera* Extract in Water Treatment as a Natural Coagulant to Remove Turbidity and Algae

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ABSTRACT

The application of *Moringa oleifera* seeds (MOS) powder after extraction as a natural coagulant increases the removal effectiveness of all types of algae. Developing countries have recently given a lot of thought for adopting suitable, affordable technology for drinking purified water. The presence of several species of algae, particularly hazardous forms in the Nile River's waters has attested a review of conventional treatment methods. MOS was the most efficient coagulant, eliminating every algal group from untreated Nile water. The algal removal rate varied between 75% and 96% in the sedimentation basin and between 92% and 97% in the discharge water at doses between 1 and 10mg/l. The elimination percentage of turbidity was 81.43%, and the turbidity decreased from 8.24 to 1.53 (NTU). Comparative morphology of identifying keys has been used to classify and identify algae, and the Sedgwick-Rafter counting chamber has been used to measure algal abundance. The amount of algae that MOS successfully eliminated from untreated Nile waters and kept in top condition was considerable. In both small- and large-scale water treatment processes, MOS contains a coagulant protein that can take the place of common coagulants such as aluminum salts. By isolating active proteins as coagulants from MOS, it has been proposed to apply them in water treatment.

INTRODUCTION

Clean drinking water must be available to stop the spread of numerous water-transmissible diseases. They can create biological poisons, chemical odors and chemical tastes when exposed to certain environmental circumstances **(Abd El-Hady, 2014)**. In terms of water treatment authority, algae are crucial, particularly those from the cyanobacteria family **(Lei *et al.*, 2021)**. Additionally, they hinder several water treatment procedures, reducing the amount of potable water produced. Due to their silicon frustules, diatoms frequently block filters. **(Ahmed, 2016; Abouzied, 2021)**.

Algae have few inhabitants and are scattered throughout lakes and rivers, but when nutrients become more plentiful in surface waters, their population is vulnerable to fast growth **(Al-Jadabi *et al.*, 2023)**. This may cause the amount of oxygen in the atmosphere to decline and the turbidity of the water to increase, and the degradation of the aquatic environment, as demonstrated by **Shen *et al.* (2011)** and **Wang *et al.* (2013)**. Stressful environmental situations

can also lead to changes in taste, odor and toxic stimulus **(Heng *et al*., 2009; Nhantumbo *et al.*, 2023)**.

An established water purification facility's rapid sand filters and screens may get obstructed by unchecked algal blooms, which will hinder the system that delivers water for human use **(Xuan-Thanh *et al*., 2019)**. Algae may develop in water filtration systems and pass through filters while producing extracellular organic molecules because they are so microscopic. As a result, microbial regeneration in water distribution systems may be made possible by lowering the final water disinfection process **(Al-Jadabi *et al.*, 2023)**. It is advisable to eliminate surface water algae during the initial phases of treatment in order to keep enough water quantity and quality **(Henderson *et al.*, 2008; Babel & Takizawa, 2011)**. In the view of, the possibility that by separating algae cells as a suspended solid, the dissolved poisons that accompany them may be minimized, which may decrease the effectiveness of physical and chemical water treatment techniques.

Water treatment operations have previously described how to manage algae **(Devrimci *et al.*, 2012)**. The most popular technique for getting rid of algae is coagulation/flocculation since it can separate solids by stabilizing, flotation, and filtering them, while also getting rid of suspended solids by destabilizing particle structure **(Heng *et al.*, 2009; Shen *et al.*, 2011)**. Furthermore, algae cannot be successfully removed by applying chemical coagulation alone due to low specific gravity and their small size **(Zhao *et al*., 2021)**. Oxidizing chemicals like chlorine must be used to enhance coagulation for the reason that they may eradicate algal cells **(Gao *et al.*, 2010)**.

The typical steps of the drinking water treatment technique in Egypt are pre-chlorination, flocculation/coagulation, filtering and post-chlorination after the water settles into distribution tanks **(Mohamed *et al.*, 2020)**. According to **Badawy *et al.* (2012)** and **Nhantumbo *et al.* (2023)**, pre-chlorination is the most important procedure for inhibiting the growth of bacteria and algae in this environment. To determine the function that this stage plays in the development of secondary disinfection products in the final treated water and to provide recommendations for their use, several studies have been conducted in this area **(Badawy *et al*., 2012; Delelegn *et al.*, 2018; Deswal *et al.*, 2023)**. Nevertheless, a report by **Mohamed *et al*. (2020)** claimed that Egypt's current treatment technologies need to be updated to handle the recent increases in loads of chemical and biological pollutants transported via surface and water supplies.

The use of a natural coagulant from MOS in place of conventional coagulants such as aluminum salts has been recognized as an effective and efficient technique to remove undesirable chemicals from contaminated water in both residential and industrial water treatment. The seeds of *Moringa oleifera* can be used to treat water because they contain coagulation-effective protein components **(Delelegn *et al.*, 2018; Zhao *et al.*, 2021; Koul *et al.*, 2022)**.

Regarding MOS powder, a pH of 7-9 is appropriate. The ideal adsorption equilibrium was also examined in the study, and it showed that 0.1g of MOS powder was sufficient to attain

it. According to all of the findings **(Desta and Bote, 2021; Kenea *et al*., 2023)**, *Moringa oleifera* seeds are particularly effective at removing pollutants.

Seeds taken from the *Moringa oleifera* plant are one of the recognized natural coagulants used for water treatment. The main goal of this study was to determine how well the ground-up seeds of the *Moringa oleifera* plant worked to get rid of algae and turbidity. In the act of, influencing elements on the amount eliminated percentages, the coagulant dosage and settling time were both taken into consideration.

MATERIALS AND METHODS

Sampling sites

For a year, monthly water samples have been taken. This occurred at the 120000m3/day Atfeeh water treatment plant's intake, which is around 70km south of the Giza governorate.

Physico-chemical characters and Biological Examinations. Tests were executed by Standard Methods **(APHA, 2023)**.

The "**Jar Test**" considered was used to measure coagulation and flocculation. It had been created by **Zeta-Meter (1993)**.

Jar Test is dependent on *Moringa Oleifera* seeds after extraction doses of coagulants and chlorine to reduce the amount of algae; the flash mixing was done at 60rpm for two minutes, the slow mixing was done at 40rpm for 15 minutes, and the settling period was one hour. The natural flocculants of *Moringa Oleifera* seeds were tested for coagulation efficiency against the Nile water algae.

Extraction technique for *Moringa Oleifera* seeds

The cutting fruits were cut into slices and left to air dry for three to seven days in order to harvest the seeds. The outer shells of the seed kernels were removed, and the kernels were ground into a powder in a lab mortar and pestle, which was then sieved through a sieve with holes size of $2.5mm^2$ to produce a powder. The powder was stored at room temperature and in a dark location in a sterile bottle to improve polarity. First, the powdered component was extracted simultaneously with methanol or ethanol, acetone and water. In this procedure, 250ml of acetone, methanol and water solvents were used in equal amounts to dissolve 50g of powdered MOS. Second, they were permitted to mix in a horizontal shaker for three hours. The oil was separated from the seed powder using three solvent separation cycles. Next, extraction with 1.0mol/l NaCl solution (50g of *M. oleifera* coagulant in 250ml of 1.0mol/l NaCl) increased the coagulation activity of *Moringa oleifera* seeds. Then, the turbidity levels of the coagulant extracted with a NaCl solution were seven times lower than those of typical MOC (*Moringa Oleifera* Coagulant) extracted with distilled water. Subsequently, each extract was run through a piece of Whatman No. 1 filter paper. Each extract supernatant was evaporated using a rotary evaporator (BUCHI Rotavapor R-100 Rotary) after centrifuging the filtrates at 5000rpm for 15 minutes. Finally, each collection was dried overnight in a furnace at 50°C, and MOS powder

extraction was used in Jar Test **(Delelegn *et al.*, 2018; Xuan-Thanh *et al.*, 2019; Abouzied, 2021)**.

Jar test relies on *Moringa Oleifera*

The *Moringa Oleifera* seeds after extraction were placed in each of the six beakers' 1000ml water sample. Weighing MOS powder and distilled water blank at weights of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0mg allowed us to generate six distinct stock solution concentrations for the given dose. To find a simple answer, the beakers were on the jar test device. As a control, 1000mL of distilled water was used but did not contain any MOS powder after extraction. Two milliliters of each of the prepared concentrations were added to a beaker that had 1000ml of the sample river water to provide control samples for all the administered dosages. On the jar test apparatus, the resulting liquids were quickly combined for 2 minutes, and then slowly mixed for 15 minutes to help produce a coagulant. Without interruption, the suspensions could be lifted for an hour. Since there is no standard method for conducting the jar test, this is alleged to be the better choice. Total organic carbon (TOC), Mn, Fe, chloride, turbidity, pH, alum, residual chlorine, sulfates, EC, TDS (total dissolved salts), and algal count were determined in the generated supernatants **(Abouzied, 2021)**.

Data statistical analysis

The statistical software Statgraphics (Statistical Graphics Corporation, Princeton, USA) was used to assess the significance of differences between means using the t-test and ANOVA procedures.

RESULTS

Quality of water changes

The physicochemical characteristics of theNile water are described in Table (1). The results showed that turbidity in the Nile water was between 5.4 and 12.8 NTU, nitrogen and phosphate levels in phytoplankton were constantly low, never exceeding 0.38mg/l of nitrogen and 0.130mg/l of phosphorus. However, there is a questionable connection between phosphate or nitrate and algal biomass. Between 0.6 and 4.8mg/l of silica were present in the sample. Low silica levels were associated with high diatom populations in the untreated water. High algal biomass also affected the water's dissolved oxygen content, with 98.1% oxygen saturation being noted as algal biomass increased. Other measurements, including pH, dissolved solids, total alkalinity, total hardness, and chloride content did not change noticeably over the course of the study's several months. As a result, the assessment of water quality may have relied on this information since biological analysis is an crucial part of microbiological investigations. These results support the observations of **Ahmed (2016)** stating that algae biomass and phosphorus or nitrate concentrations in the River Nile water have a negative connection.

Table 1. Physicochemical parameters of samples of Nile water

Parameter	Unit	Minimum	Maximum
PH	--	7.9±0.2	8.4±0.3
Turbidity	NTU	5.4±0.4	12.8±0.6
Electric conductivity	µmohs/Cm	320±7	450±10
Total dissolved solids	mg/l	175±2	245±5
Total residue at 105^0C	mg/l	193±4	356±7
Total residue at 550^0C	mg/l	115±3	194±5
Dissolved oxygen	mg/l	6.5±0.2	10±0.5
Total alkalinity (as CaCO)	mg/l	108±2	154±4
Total hardness	mg/l	116±4	150±6
Calcium hardness	mg/l	68±2	88±3
Magnesium hardness	mg/l	46±1	54±2
Chlorides	mg/l	16±0.5	32±1
Sulphate	mg/l	10.6±0.4	24±1
Dissolved silica	mg/l	0.6±0.02	4.8±0.3
Nitrite	mg/l	0.0± 0.0	0.02±0.001
Nitrate	mg/l	0.04±0.002	0.18±0.004
Ortho-phosphorus	mg/l	0.002±0.0001	0.125±0.0005
Dissolved phosphorus	mg/l	0.022±0.002	0.130±0.004
Total phosphorus	mg/l	0.06±0.001	0.16±0.003
Iron	mg/l	0.06±0.002	0.57±0.005
Manganese	mg/l	0.02±0.001	0.21±0.004
Nitrogen	mg/l	0.15±0.005	0.38±0.008

The average of three replicates for all data ± standard deviation

The jar test was carried out; the Nile River exhibited an algal count of 6250 Organism/ ml, a turbidity of 8.24 NTU and pH value of 8.1. *Moringa Oleifera* seeds powder dosages (mg/l) were employed as a natural coagulant combined with a chlorine dose (4.0mg/l) to decrease the algal count and turbidity.

The highest algal count (280 Organism/ml) was found at 0.5mg/ l, and the lowest algal count (180 Organism/ml) was found at 2.5mg/ l. The ideal dose of *Moringa oleifera* was determined to be 2.5mg/ l. The amount of algal removal was 97.12% at this dosage, drinking water requirements for residual chlorine were satisfied, and TOC increased as a result of an excess of *M. oleifera* extract. The pH values as a chemical agent ranged from 7.75 to 7.65. Turbidity dropped from 8.24 NTU to 1.53 NTU, and the removal percentage of turbidity was (81.43%). The water from the Nile had 0.06mg/l of alum. Between 2.0 and 2.1mg/l of residual chlorine was detected, as shown in Table (2).

Table 2. Jar test relying on *M. Oleifera* doses (mg/l) and chlorine dose (4.0 mg/l) in the water samples

***M. Oleifera* (mg/l)** parameter	**0.5 (mg/l)**	**1.0 (mg/l)**	**1.5 (mg/l)**	**2.0 (mg/l)**	**2.5 (mg/l)**	**3.0 (mg/l)**
Algal count (Org. /l)	280±10	270±8	250±7	230±6	180±5	180±5
Removal rate %	95.52	95.68	96.00	96.32	97.12	97.12
pH	7.70±0.04	7.70±0.04	7.70±0.03	7.65±0.03	7.65±0.02	7.55±0.02
Turbidity (NTU)	1.92±0.09	1.84±0.08	1.70±0.06	1.61±0.05	1.53±0.06	1.51±0.04
Alum (mg/l)	0.06±0.002	0.06±0.002	0.06±0.002	0.06±0.002	0.06±0.002	0.06±0.002
Residual Cl^- (mg/l)	2.0±0.08	2.0±0.08	2.0±0.06	2.0±0.06	2.1±0.05	2.1±0.09

The average of three replicates for all data ± standard deviation

Algal count (180 Organism/ml) was measured during studies to determine the influence of *Moringa oleifera* seed (2.5mg/l) as a natural coagulant upon the algal removal in water pretreated with a dose of chlorine (4.0mg/l), while Algal count was 6250 org./ml in the Nile water. At this dose, the percentage of algal removal was 97.12%. An objective physical parameter was turbidity (1.53 NTU) in treated water, whereas turbidity was 8.24 NTU in the Nile water. The pH value 7.6 was in treated water, and the pH value (8.1) was recorded in the Nile water, using pH values as a chemical agent. Alum was detected at 0.06mg/ l (the normal range should not exceed 0.2mg/l). 2.0mg/ l of residual chlorine was determined; this level is suitable for drinking water. EC 334 (µs/Cm) and TDS 220.4mg/l were detected in treated water by MOS, while EC 328.7 (µs/Cm) and TDS 216.9mg/l were detected in the Nile water. The data of Mn, Fe, chloride, sulfate and TOC were obtained and explained in Table (3). The results of this study support those of **Ibrahim *et al.* (2015)** and **Abouzied (2021)**. A dose of 2 to 8mg/ l of *Moringa Oleifera* was successful in decreasing the turbidity of the water from 8.24 NTU to 1.53 NTU (81.43%). This proved that adding *M. Oleifera* between 1 and 10mg/ l to the pre-chlorinated waters resulted in a primary algal elimination effectiveness of 97% for the amount of algae. The results presented here support the findings of **Ashenafi, *et al.* (2018)** and **Desta and Bote (2021)** who reported that *M. Oleifera* reduced water turbidity to approximately 86.98%.

By applying *Moringa oleifera* seeds (2.5mg/l), diatoms, green algae, and blue-green algae were observed throughout the entire examination time in the sedimentation basin, Synedra, Asterionella, Melosira, Fragilaria, Navicula, and Cyclotella (Diatoms) were removed with (85-96), (87-98), (90-97), (88-100), (94-100), and (90-97) percent, respectively. Chlorella, Scenedesmus, Pediastrum, Oocystis, Actinastrum, and Spirogyra (Green algae) were removed with (80-96), (75-97), (87-95), (80-92), (85-95), and (90-99) percent, respectively. Oscillatoria, Anabaena, Microcystis, Anacystis, Coelosphaerium, and Chroococcus (Blue-green algae) were removed with (97-100), (99-100), (99-100), (98-100), (96-100), and (95-100) percent, respectively, as shown in Table (4). The

current study on *Moringa Oleifera* was successful in the removal rate of algae from 75% to 100% of the total algal count during the water treatment in the sedimentation basin that depends on the algal type and the detention time of the clarifiers. These findings correspond with those of **Ahmed (2016)** and **Abouzied (2021)** who stated that the numbers of diatoms, blue-green algae, and green algae fluctuated.

Table 3. The impact of chlorine and *M. Oleifera* as coagulants on the properties of water

Parameter	Unit	Nile water sample	*M. oleifera* (2.5 mg/l) and chlorine dose (4.0 mg/l)
Algal count	Org./ml	6250	180 ± 5
Algal removal	%	-	97.12 %
Turbidity	NTU	8.24	1.53 ± 0.06
pH	-	8.1	7.6 ± 0.03
Alum	mg/l	0.06	0.06 ± 0.002
Residual chlorine	mg/l	-	2.0 ± 0.08
EC	µs/Cm	328.7	334 ± 16
TDS	mg/l	216.9	220.4 ± 8.8
Residual Mn	mg/l	ND	ND
Residual Fe	mg/l	0.19	0.08 ± 0.001
Chloride	mg/l	23	28 ± 1.26
Sulfates	mg/l	21.8	22.0 ± 0.99
TOC	mg/l	4.32	5.19 ± 0.18

The average of three replicates for all data ± standard deviation

Table 4. Removal rate for algae by using *M. Oleifera* (2.5 mg/l) in settling basin

Algae group	Algal genus	Removal rate %
Diatoms	*Synedra*	(85 – 96)
	Asterionella	(87 – 98)
	Melosira	(90 – 97)
	Fragilaria	(88–100)
	Navicula	(94–100)
	Cyclotella	(90 – 97)
Green algae	*Chlorella*	(80 – 96)
	Scenedesmus	(75 – 97)
	Pediastrum	(87 – 95)
	Oocystis	(80 – 92)
	Actinastrum	(85 – 95)
	Spirogyra	(90 – 99)
Blue-green algae	*Oscillatoria*	(97-100)
	Anabaena	(99–100)
	Microcystis	(99–100)
	Anacystis	(98–100)
	Coelosphaerium	(96–100)
	Chroococcus	(95–100)

DISCUSSION

Using a dose ranging from 1 to 10mg of *M. Oleifera*/l, *Moringa Oleifera* seeds represents a practical substitute natural coagulant that improves the removal effectiveness for the five algal categories. Algal removal was accomplished between 92% and 97%. The results obtained are consistent with those of **Ibrahim *et al.* (2015)** and **Abouzied (2021)** who claimed that, *Moringa Oleifera* seeds are an effective natural coagulant replacement that increases the removal efficiency for algal groups and results in an algal removal rate of over 97%. The recommended dosage of MOS for both the color and turbidity of wastewater was 0.4g/500 ml. The highest levels of turbidity, color, and COD reduction achieved by *Moringa oleifera* in acidic wastewater were 98%, 90.76%, and 65.8%, respectively, while the highest levels achieved in basic wastewater were 99.5%, 97.7% and 65.82% **(Desta & Bote, 2021)**.

A very high microalgal biomass harvesting efficiency of 85% was demonstrated v ia the powdered seeds of *Moringa oleifera* **(Hasan *et al*., 2021)**. When operating under ideal circumstances, the blended powder of MOS eliminated turbidity (88.5%) and TDS (92.1%) according to **Kenea *et al*. (2023)**.

The use of appropriate low-cost technologies to purify drinking water in impoverished nations has received a lot of attention recently. The Nile River's abundance of different algae groups, particularly the problematic forms, has made it more important to reevaluate conventional treatment methods **(Abouzied, 2021; Koul *et al*., 2022**).

The removal of various species of algae was the main emphasis of this study modified or novel techniques. By abandoning the usage of alum and switching to natural seeds such as MOS for purifying the water, the treatment of the Nile water algae was altered. As a natural coagulant, *M. Oleifera* was also added in concentrations ranging from 1 to 10mg/ l. The percentage of algae removed from untreated raw Nile water using MOS under optimum circumstances ranged from 92% to 97%. The most effective coagulant, *M. Oleifera*, was found to be able to eliminate all algal groups from the raw Nile water without the need for pre-chlorination. These results are supported by the studies of **Ibrahim *et al*. (2015)** and **Al-Jadabi *et al*. (2023)**. Accordingly, it has been demonstrated that *M. Oleifera* seeds can be used as a coagulating agent in water and wastewater treatment after suitable purification of positive active proteins since they contain a coagulant protein that can replace conventional coagulants, such as aluminum salts in both domestic and larger scale water treatment operations **(Xuan-Thanh *et al*., 2019; Al-Jadabi *et al*., 2023)**.

The results revealed that powder made from *M. Oleifera* seed kernels has certain naturally occurring coagulating capabilities at loading dosages of 1, 2, 4, 6, 8, and 10mg/l and above that have a comparable impact to the traditional alum coagulation. This confirms past research that suggested water treatment operations used a powder made

from MOS as a natural coagulant **(Ibrahim *et al*., 2015; Delelegn *et al*., 2018; Xuan-Thanh *et al*., 2019)**.

The maximum protein concentration in MOS was between 53 and 44% in globulin and albumin. The primary protein domains have molecular weights of around 6.5 and 9.0 kDa, respectively, according to protein profile analyses. Therefore, experiments are used to increase the extraction of the coagulant active substances in *M. Oleifera* seeds, based on scientific knowledge **(Xuan-Thanh *et al*., 2019; Abouzied, 2021)**.

A natural, affordable, and superior replacement for aluminum sulfate in the purification of water is *Moringa oleifera* seeds. Since alum is not needed for primary water treatment using MOS, this reduces the negative effects of alum remaining in the treated water. Furthermore, it has an economic benefit for nations with limited resources, and treatment using natural methods has a significant positive impact on consumer health. The effect of MOS on eliminating turbidity and algae was shown in the current study to be one of the major variables in water treatment and the creation of high-quality water that is safe for human consumption.

CONCLUSION

This study found that *Moringa oleifera* seeds are highly effective at removing turbidity and algae from the Nile water. Water treatment facilities must adjust their treatment strategy in accordance with ways that limit the negative impact of chemicals used in water treatment to provide a water supply that is acceptable for purposes of quality and biologically safe for consumer health. It is advised to utilize algal counts as a biological monitor to assess water quality and turbidity to apply natural water treatment techniques like MOS extract as much as possible since drinking water must also be free of blue-green algae, pathogenic algae, and their dangerous by-products. Subsequently, for the proper purification of positively active proteins, it has been demonstrated that MOS can be used as a coagulant in water and waste-water treatment, which can replace conventional coagulants like aluminum salts. The Jar test also used MOS as a natural coagulant for the reason that they contained coagulating proteins instead of alum. The study suggests using MOS to treat water due to its numerous benefits, including its high quality and lack of chemical residues from treatment processes such as alum, as well as its lower cost compared to the conventional methods and its safety for consumers' health.

REFERENCES

Abd El-Hady, H.H. (2014). Alternations in biochemical structures of phytoplankton in as wan reservoir and river Nile, Egypt, Journal of Biodiversity and Environmental Sciences (JBES), 4(2): 68-80.

Abouzied A.H. and Hassan H.A.S. (2021). Application of permanganate, copper sulfate to the coagulation dose and use of *Moringa oleifera* seeds as a natural

coagulant in water treatment plants to remove algae. Egyptian J. of Phycol. Vol.22, 2021.

Ahmed, A. H. A. (2016). Study the microbiological effects on chemical doses and water treatment engineering. M.Sc. thesis, faculty of science, Fayoum University.

Al-Jadabi, N.; Laaouan, M.; El Hajjaji, S.; Mabrouki, J.; Benbouzid M. and Dhiba D. (2023). The Dual Performance of *Moringa Oleifera* Seeds as Eco-Friendly Natural Coagulant and as an Antimicrobial for Wastewater Treatment: A Review. Sustainability, 15(5): 4280. https://doi.org/10.3390/su15054280.

APHA, American Public Health Association (2023). Standard methods for the examination of water and wastewater, 24th Edition.

Badawy, M.I.; Gad-Allah, T.A.; Ali, M.E.M. and Yoon, Y. (2012). Minimization of the formation of disinfection by products. Chemosphere, 89: 235-240.

Babel, S. and Takizawa, S. (2011). Chemical pretreatment for reduction of membrane fouling caused by algae, Desalination, 274: 171-176.

Desta, W.M. and Bote, M.E. (2021). Wastewater treatment using a natural coagulant (*Moringa oleifera* seeds): optimization through response surface methodology. Heliyon. 2021 Nov; 7(11): e08451. doi: 10.1016/j.heliyon.2021.e08451

Delelegn, A.; Sahile, S. and Husen, A. (2018). Water purification and antibacterial efficacy of *Moringa oleifera* Lam. Agriculture & Food Security, 7: 25.

DESWAL, S.; RAWAT, S.; KUMAR, S. and SANGWAN, V. (2023). Potential of *Moringa oleifera* and Okra as Coagulants in Sustainable Treatment of Water and Wastewater. Ecological Questions. Online. 21 June 2023. Vol. 34, no. 4, pp. 1-17. DOI 10.12775/EQ.2023.045.

Devrimci, H.A.; Yuksel, A.M. and Sanin F.D. (2012). Algal alginate: Apotential coagulant for drinking water treatment, Desalination, 299: 16-21.

Gao, S.; Du, M.; Tian, J.; Yang, J.; Yang, J.; Ma, F. and Nan J. (2010). Effects of chloride ions on electro coagulation-flotation process with aluminum electrodes for algae removal, Journal of Hazardous Materials, 182: 827-834.

Hasan, M.; Khalekuzzaman, M.; Hossain, N. and Alamgir, M. (2021). Anaerobic digested effluent phycoremediation by microalgae coculture and harvesting by *Moringa oleifera* as natural coagulant. Journal of Cleaner Production 292: 126042. https://doi.org/10.1016/j.jclepro.2021.126042.

Heng, L.; Jun, N.; Wen-jie, H. and Guibai L. (2009). Algae removal by ultrasonic irradiation. Coagulation, Desalination, 239: 191-197.

Henderson, R.; Parsons, S.A. and Jefferson, B. (2008). The impact of algal properties and pre-oxidation on solid. Liquid separation of algae, Water Research, 42: 1827-1845.

Ibrahim, W. M.; Essa, A. M.M. and Abouzied, A. H. (2015). Application of biological agent to determine the optimal coagulant dose in water treatment plants. The African Journal of Mycology and Biotechnology. Vol. 20 (1): 31-45.

Kenea, D.; Denekew,T.; Bulti, R.; Olani, B.; Temesgen, D.; Sefiw, D.; Beyene, D.; Ebba, M. and Mekonin, W. (2023). Investigation on surface water treatment using blended *moringa oleifera* seed and aloe vera plants as natural coagulants.

South African Journal of Chemical Engineering, Volume 45, July 2023, Pages 294-304. https://doi.org/10.1016/j.sajce.2023.06.005

Koul, B.; Bhat, N.; Abubakar, M.; Mishra, M.; Arukha, A.P. and Yadav D. (2022). Application of Natural Coagulants in Water Treatment: A Sustainable Alternative to Chemicals. Water 2022, 14(22): 3751. https://doi.org/ 10.3390/w14223751.

Lei, H.; Ziyuan, L.; Yingmu, W.; Xuejie, H.; Jiong, Z.; Maoquan G. and Jian, Z. (2021). Facilitating harmful algae removal in fresh water via joint effects of multi-species algicidal bacteria. J. of Hazardous Materials. 403: 123662.

Mohamed, F. M.; El-Deen, F. N. and Kamal, A. M. (2020). the Relationship between Algal Counting and Chemicals Consumption of Conventional Purification Systems at Qena Governorate, Egypt. Egyptian Journal of Aquatic Biology & Fisheries Zoology Department, Faculty of Science, Ain Shams University, Cairo, Egypt; Vol. 24(1): 161 – 172.

Nhantumbo, C.; Cangi Vaz, N.; Rodrigues, M.; Manuel, C.; Rapulua, S.; Langa, J.; Nhantumbo, H.; Joaquim, D.; Dosse, M. and Sumbana, J. (2023). Assessment of Microbial Contamination in the Infulene River Basin, Mozambique. Water 2023, 15: 219. https://doi.org/10.3390/ w15020219

Shen, Q.; Zhu, J.; Cheng, L.; Zhang, J.; Zhang, Z. and Xu X. (2011). Enhanced algae removal by drinking water treatment of chlorination coupled with coagulation, Desalination, 271: 236-240.

Wang, L.; Qiao, J.; Hu, Y.; Wang, L.; Zhang, L.; Zhou, Q. and Gao, N. (2013). Pre-oxidation with KMnO4 changes extracellular organic matter. s secretion characteristics to improve algal removal by coagulation with a low dosage of poly aluminium chloride. Journal of Environmental Sciences, 25(3): 452-459.

Xuan-Thanh, Bui; Chiemchaisri, C.; Fujioka, T. and Varjani, S. (2019). Water and Wastewater Treatment Technologies. Energy, Environment, and Sustainability. ISBN 978-981-13-3259-3 (eBook). https://doi.org/10.1007/978-981-13-3259-3.

Zhao, Y.; Lian, H.; Tian, C.; Li, H.; Xu, W.; Phuntsho, S. and Shih, K. (2021). Surface water treatment benefits from the presence of algae: Influence of algae on the coagulation behavior of polytitanium chloride. Environ. Sci. Eng. 2021, 15(4): 58.

Zeta-Meter, Inc. (1993). Coagulation and Flocculation. Zeta-Meter, Inc., Fourth Edition, April 1993.