# Potential of *Moringa oleifera* and Okra as Coagulants in Sustainable Treatment of Water and Wastewater

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**Abstract.** Chemical/synthetic coagulants are widely used to remove suspended solids and organic loads from water, but they pose several environmental and public health issues due to their chronic toxicity. The study evaluated the performance of these natural coagulants individually and in blended combinations with a synthetic coagulant, Alum, in terms of the percentage removal of turbidity, TSS, BOD, and COD after water treatment at optimum dosages. The blended use of all three coagulants in equal proportion showed the best performance (turbidity removal = 91.91%; TSS removal = 51.18%; BOD removal = 41.67%; and COD removal = 55.56%), but increased the pH of treated water from 7.10 to 7.95. The treatment cost analysis showed that Alum had the lowest treatment cost (Rs. 0.78 per 1,000 L); while the blended use of *Moringa oleifera* and Okra (*Abelmoschus esculentus*) at the optimum dosage of 120 mg/L had the lowest cost (Rs. 31.20 per 1,000 L) among the natural coagulants. Despite higher cost of treatment, the use of natural coagulants in water and wastewater treatment provide sustainable solutions while reducing the negative impact of synthetic coagulants on the environment and public health.

**Key words:** coagulation and flocculation, *Moringa oleifera*, Okra, alum, water and wastewater treatment.

## 1. Introduction

Coagulation and flocculation are an essential and integral part of drinking water treatment as well as wastewater (municipal and industrial) treatment by providing a reliable process for removal of turbidity as they enable reduction in suspended solids and organic loads up to 90 percent. (Bratby, 2016; Greenwood, 2022). Natural and/or synthetic coagulating agents have been used in water treatment since ancient times. Ancient civilizations like the Egyptians, Romans, and Indians also recognized the benefits of coagulation and developed their own methods for water treatment. For example, the Egyptians used almonds smeared around vessels to clarify river water as early as 2,000 BC, and later applied chemical alum to remove suspended particles from water. Meanwhile, the Romans used alum as a coagulant in 77 AD (Bratby, 2016; Chua et al., 2019; Enzler, 2022), and the Indians utilized crushed seeds of the plant *Phyllanthus emblica* to coagulate water. In fact, Sanskrit literature from around 2000

BC mentions the use of crushed nuts from the Nirmali tree (*Strychnos potatorum*) for clarifying water – a practice still alive today in parts of Tamil Nadu, where the plant is known as Therran and cultivated also for its medicinal properties (Bratby, 2016).

Coagulation and flocculation are two separate processes, used in succession, for separating suspended particles in water to produce suspension free effluent by charge neutralization and various binding mechanism that includes interparticle bridging, sweeping coagulation, bridging, absorption and patch flocculation (Duan & Gregory, 2003; Ho et al., 2020; Kurniawan et al., 2020; Greenwood, 2022). While coagulation is a chemical process that neutralises the charges on the particles; whereas, flocculation is mechanical process that enables them to bind together and making them bigger, so that they can be more easily separated from the liquid phase.

The processes of coagulation and flocculation require the addition of compounds, synthetic/chemical or natural, called as coagulants and flocculants. The performance of coagulation/flocculation processes depends on several factors including the type of coagulant/flocculant used, dosage of coagulant/flocculant, the mixing processes (speed and time of rapid and slow mixing), the characteristics of the water to be treated and initial concentration of turbidity, operational pH, temperature, zeta potential and characteristics of the suspended particles in water (Kurniawan et al., 2020).

The coagulants and flocculants used in water and wastewater are mainly of two types – inorganic chemical or synthetic compounds, and organic natural compounds. The chemical coagulants used in water and wastewater treatment are mainly divalent positively charged compounds and negatively charged polymers of high molecular weight flocculants, such as aluminum salts, iron salts, hydrated lime, magnesium carbonate and polymers (aluminium chlorohydrate, polyaluminum chloride, polyaluminum sulphate and polyferric sulphate) (Kurniawan et al., 2020). Table 1 lists the characteristics of these coagulates along with their merits and demerits.

Despite several merits, the application of these widely used chemical/synthetic coagulants also poses several environmental and public health issues due to their chronic toxicity. One significant issue is water pollution, as residual chemicals from coagulants can seep into the environment and contaminate water sources. This can be harmful to aquatic life and affect water quality. Another issue is eutrophication, where the use of chemical coagulants can increase nutrient levels in treated water, causing excessive algae and aquatic plant growth that can suffocate other marine life. The use of chemical coagulants can also disrupt ecosystems by altering the pH and chemical composition of water bodies, affecting the balance of aquatic organisms. Moreover, chemical coagulants that are discharged into the environment can contaminate soil and impact plant growth and other soil organisms. Exposure to chemical coagulants can also have negative impacts on human health, including skin irritation, respiratory problems, and even cancer. To address these issues, alternative coagulants such as natural coagulants have been explored and studied by researchers. Several potential natural organic coagulants that have been identified and reported in studies, includes *Moringa oleifera*, *Dolichos lablab*, *Cicer arietinum*, *Azadirachta indica*, *Vigna unguiculata* and many more (Table 2), which provide sustainable water and wastewater treatment without any harmful impact on environment and human health. The primary goal of modern water and wastewater treatment processes is that the treatment process should be inexpensive, practical, simple and environmental friendly. Natural coagulants have the potential to achieve all these goals, and have advantages over chemical coagulants in treating water and wastewater. Table 3 presents a comparison of common synthetic and potential natural coagulants used in water and wastewater treatment.

**Table 1.** Characteristics of common synthetic coagulants used in water and wastewater treatment.

| Scientific Name; [Common name(s)] | Molecular Formula; [Molar mass in g/mole]; (pH at 1%) | Merits | Demerits | References |
|---|---|---|---|---|
| **Aluminum Sulphate** [Phitkari, Alum, Filter alum, Sulphate of alumina] | $Al_2(SO_4)_3{\cdot}18H_2O$ [474.39] (3-4) | Most widely used; simple to use; quite effective; and suitable for a wide pH range (6.5 – 8.5). | pH control important; increases permanent hardness; produce more sludge volume; carcinogenic in nature; and contributing factor in Alzhemer’s disease and related disorder. | Jagaba et al. (2018); Krupinska (2020); Greenwood (2022) |
| **Sodium aluminate** | $Na_2Al_2O_4$ [81.97] | Lower dose requirement; and eEffective in hard water. | High cost; not effective for hardness less than 120 mg/L; and often used with alum. | Kumar et al. (2022) |
| **Ferric Sulphate** | $Fe_2(SO_4)_3{\cdot}3H_2O$ [399.91] (3-4) | pH range of 4 - 6 and 8.8 - 9.2 are both effective; and denser floc than alum. | Add some dissolved salts to treated water; incrrases salinity of water; and heavier sludge. | Jiang and Lloyd (2002); Greenwood (2022) |
| **Ferric Chloride** | $FeCl_3{\cdot}6H_2O$ [162.22] (3-4) | Effective over a wide pH range (4-11); and faster sedimentation, especially in cold water. | Add a few dissolved salts to treated water; increases salinity and water’s corrosivity. | Aboulhassan et al. (2006); Greenwood (2022) |
| **Ferrous Sulphate** [Copperas] | $FeSO_4{\cdot}7H_2O$ [151.91] (3-4) | pH insensitive | Increases dissolved salts in treated water. | Parmar et al. (2011) |

**Table 2.** Characteristics of reported/studied natural coagulants used in water and wastewater treatment.

| Scientific Name | Common Name | Family | Plant Part used as Coagulant | References |
|---|---|---|---|---|
| *Moringa oleifera* Lam. | Drumstick Tree | Moringaceae | Seeds | Ghebremichael et al. (2005) |
| *Dolichos lablab* L. = *Lablab purpureus* subsp. *purpureus* (L.) Sweet | Dolichos bean | Fabaceae | Fruits | Zhang et al. (2006) |
| *Cicer arietinum* L. | Chickpea | Fabaceae | Seeds | Choubey et al. (2012) |
| *Azadirachta indica* A.Juss. | Neem | Maliaceae | Fruit | Sowmeyan et al. (2011) |
| *Vigna unguiculata* (L.) Walp. | Cowpea | Fabaceae | Seed | Choubey et al. (2012) |
| *Cactus latifaria* | Cactus | Cactaceae | Leaves | Diaz et al. (1999) |
| *Pisum sativum* L. | Peas | Fabaceae | Seeds | Hassan et al. (2012) |
| *Strychnos potatorum* L.f. | Nirmali | Loganiaceae | Seeds | Vijayaraghavan et al. (2011) |
| *Vigna mungo* (L.) Hepper | Urad | Fabaceae | Seeds | Sotheeswaran et al. (2011) |

**Table 3.** Comparison of synthetic and natural coagulants used in water and wastewater treatment (Sources: Pise, 2015; Greenwood, 2022; Kumar et al., 2022).

| Parameters | Natural Coagulants | Synthetic Coagulants |
|---|---|---|
| Cost | High unit cost. | Low unit cost. |
| Availability | - | Widespread. |
| Hazardous | Non-hazardous to the environment. | Hazardous to the environment. |
| Toxicity | Less. | High. |
| Sludge properties | Produces biodegradable and non-hazardous sludge. | Produces non-biodegradable and hazardous sludge. |
| Sludge quantity | Less. | More. |
| pH | Rarely or margionally change the pH of water under treatment. | Significantly alter pH of water under treatment. Necessitating pH control. |
| Storage | - | Corrosion resistant storage. |
| Stability | Environmentally stable. | Environmentally unstable. |
| Availability | More available. | Less available. |
| Charge Density | Relatively low charge density. Produce longer polymer chains that enhance micro-floc formation without metals or hydroxides. | May have high charge densities on relatively large molecules. May behave as a flocculent. |
| Floc volume | Small. | Large, rich in metals. To dispose of in environmentally appropriate manner add significant cost. |
| Floc density | Low, so does not always settle well. | Heavy floc. |
| Corrosive | Non-corrosive. | Corrosive. |
| Dose | High. | Low. |

This research study broadly aims to investigate the performance of natural coagulants i.e., *Moringa oleifera* Lam. and Okra (*Abelmoschus esculentus* L.) in treating water in comparison to most commonly used synthetic coagulant i.e., alum. However, the present study primarily focussed on evaluating the performance of these natural coagulants – both individually and in combination, and also blended with the synthetic coagulant, not only on in terms of efficiency (that is, removal of turbidity, and other parameters) but cost-effectiveness and environmental consequences as well which are generally not considered in most of the studies.

## 2. Materials and Methods

### 2.1. Coagulants

Two natural coagulants: *Moringa oleifera* and Okra (*Abelmoschus esculentus*) and one synthetic/chemical coagulant: Alum [aluminium sulphate, Al $(SO_4)_2 \cdot 18H_2O$] were evaluated in the experiments, and their performance was evaluated individually and in blended-combinations with varying ratio. The coagulants used were commercially available in local market.

*Moringa oleifera* Lam. (common names: horseradish tree or drumstick tree) is a plant species belonging to the *Moringaceae* family. It is a tropical native to tropical Asia but has also been naturalized in Africa and tropical America. This plant has greyish and thick bark and often grows to around 12 m tall. *Moringa oleifera* is a valuable and rich source of proteins, vitamins (C, B2, B3 and A) and minerals (Ca, Mg, K and Iron) in comparison to common food items and has numerous health and beauty benefits. *Moringa oleifera* seed powder has been suggested as effective natural coagulant for water purification, particularly to reduce turbidity.

*Okra* (or ladies' fingers) having botanical name *Abelmoschus esculentus* L. is an herbaceous hairy plant belonging to the *Malvaceae* family. It is a well-liked vegetable crop cultivated all over the world in tropical, sub-tropical and warm temperate regions. The global production of okra was over 10.8 million tonnes in 2021, led by India (about 60%). This plant often overgrows to around 2 m tall. Okra is low-calorie, nutrient-dense and antioxidant-rich food having numerous health benefits. Okra seed extract has been suggested as effective natural coagulant to remove turbidity in water treatment.

Alum (or Phitkari or Filter alum or Sulphate of alumina) having chemical name Aluminum Sulphate is a mineral salt and is most widely used inorganic chemical coagulant used in water and wastewater treatment. It is a colourless, clear, odourless, crystalline mass or granular powder having a sweetish astringent flavour widely found in India, Egypt, Italy and Germany. Despite having potential medicinal properties, such as antibacterial, anti-inflammatory, antiplatelet, anti-obesity and anti-haemorrhagic; studies have reported that usage of alum, as coagulant, in water and wastewater treatment may be a contributing factor in the development of Alzhemer's diesease and related disorder, and is carcinogenic in nature (Jagaba et al., 2018; Krupinska, 2020).

## 2.2. Preparation of Stock Solution of Coagulants

*Moringa oleifera* seeds procured from local market were thoroughly cleaned with tap water and then dried in sun-light for seven days to remove moisture content. The dried seeds were then grounded into a fine powder using mortar and pestle. The seeds powder was sieved through a sieve of 600 µm to obtain a very fine powder of the size suitable for solubilization of the ingredient of seeds. Thereafter, a 2% suspension solution of *Moringa* oleifera was prepared by adding 5 g of *Moringa oleifera* seed's powder to 250 ml of distilled water. The solution was shaken for 30 min with the help of a magnetic stirrer, followed by filtration using Whatman filter paper No 42. The filtrate was used designated as 2% suspension solution of *Moringa oleifera* and used in the experiments.

Okra seeds were also procured from local market, and a 2% stock solution of Okra was prepared by following a similar procedure as adopted for 2% stock solution of *Moringa oleifera*, and used in the experiments. Both, *Moringa oleifera* and Okra stock solutions have problem of aging effect with time; so every time before the experiments, fresh 2% stock solutions were prepared and shaken well before experimental use.

A 2% stock solution of Alum was prepared by adding 5 g of alum powder to 250 ml of distilled water. The solution was mixed slowly with glass rod and left to mix thoroughly.

## 2.3. Water Samples Used for Coagulation

The experiments have been conducted with the use of water collected from a natural pond (Bhisma Kund) in Dayalpur Village near National Institute of Technology Kurukshetra, Haryana, India. The pond is a collection point for storm-water and household wastewater (except sewage); and is being used by livestock and irrigation purposes. The average values of selected indices of physical-chemical composition of raw water are presented in Table 4.

**Table 4.** Raw water quality characteristics.

| **Indicators / Parameters** | **Unit** | **Average Value** |
|---|---|---|
| pH | - | 7.1 |
| Turbidity (T) | NTU | 47.0 |
| Total solids (TS) | mg/L | 1,036.0 |
| Total suspended solids (TSS) | mg/L | 254.0 |
| Total dissolved solids (TDS) | mg/L | 782.0 |
| Alkalinity (Alk) | mg/L | 97.0 |
| Chloride (Cl) | mg/L | 100.0 |
| $BOD_3$ at 27°C | mg/L | 48.0 |
| COD | mg/L | 259.2 |

### 2.4. Experimental Procedure of Coagulation

Jar tests were carried out by using 1 L (≡ 1 $dm^3$ ≡ 0.001 $m^3$) six-place paddle stirrer (Technolab Instruments, India). Coagulation was performed in water samples of 1 L. Rapid mixing through 2 min at a speed of 120 rpm. Flocculation through 20 min with an intensity of mixing of 30 rpm. After coagulation-flocculation, the samples were subject to sedimentation process for 30 min. Thereafter, samples were taken about 5 cm below the water surface from each jar using a pipette and examined for pH and turbidity. The jar tests were repeated three times and the presented results are the average values. The doses of coagulants are expressed in mg/L and varied from 20 to 360 mg/L.

### 2.5. Scheme of Experimentation

Jar tests were performed for determining the optimum doses of *Moringa oleifera* (MO), *Okra* and Alum individually, and in blended-combinations with varying ratio as – MO:Okra (1:1), MO:Okra (2:1), MO:Okra (1:2), MO:Alum (1:1), MO:Alum (2:1), Okra:Alum (1:1), Okra:Alum (2:1) and MO:Okra:Alum (1:1:1). The evaluation of optimum dose was carried out in terms of residual turbidity and % turbidity removal. The pH variation at varying doses was also studied.

After determining the optimum doses, the performance of coagulants (individually and blended-combinations) was evaluated and compared with respect to removal of turbidity (T, in NTU), total suspended solids (TSS, in mg/L), 3-day biochemical oxygen demand at 27°C ($BOD_3$, in mg/L), and chemical oxygen demand (COD, in mg/L). Thereafter, the cost analysis was carried out for various combinations.

## 3. Results and Discussion

To evaluate the performance of the coagulation and flocculation processes with the type of coagulants used, the dosage of coagulants needs to be optimized with respect to the measured turbidity (or any other pollutant parameter).

### 3.1. Optimum Dosages of Coagulants

The results of the jar test have been shown in Figure 1 by plotting the coagulant dosage (in mg/L) versus the Residual Turbidity (in NTU). The residual turbidity at the optimum dosage have been labelled in the said figure. The analysis of the obtained results showed that when the natural and synthetic coagulants were used individually, the optimum dosages obtained in case of *Moringa oleifera* (MO) and Alum was 60 mg/L; whereas, in case of Okra, it was 80 mg/L. The residual turbidity at the optimum dosages was minimum (6.74 NTU) with Alum, followed by MO (10.30 NTU), and maximum (11.30 NTU) with Okra. Thus, showing more effectiveness of Alum in reducing turbidity (85.66 %) in water treatment, in comparison to MO (78.09 %) and Okra (75.96 %). The optimum dosages of blended natural coagulants were obtained as 120 mg/L with MO:Okra (1:1), 180 mg/L with MO:Okra (2:1) and 240 mg/L with MO:Okra (1:2) having residual turbidity of 6.10, 6.53 and 7.50 NTU respectively (Figure 1). The comparative results of the two natural coagulants revealed that the optimum coagulant dosages of MO were not only lower – individually or blended with Okra, but also achieved lower residual turbidity after treatment.

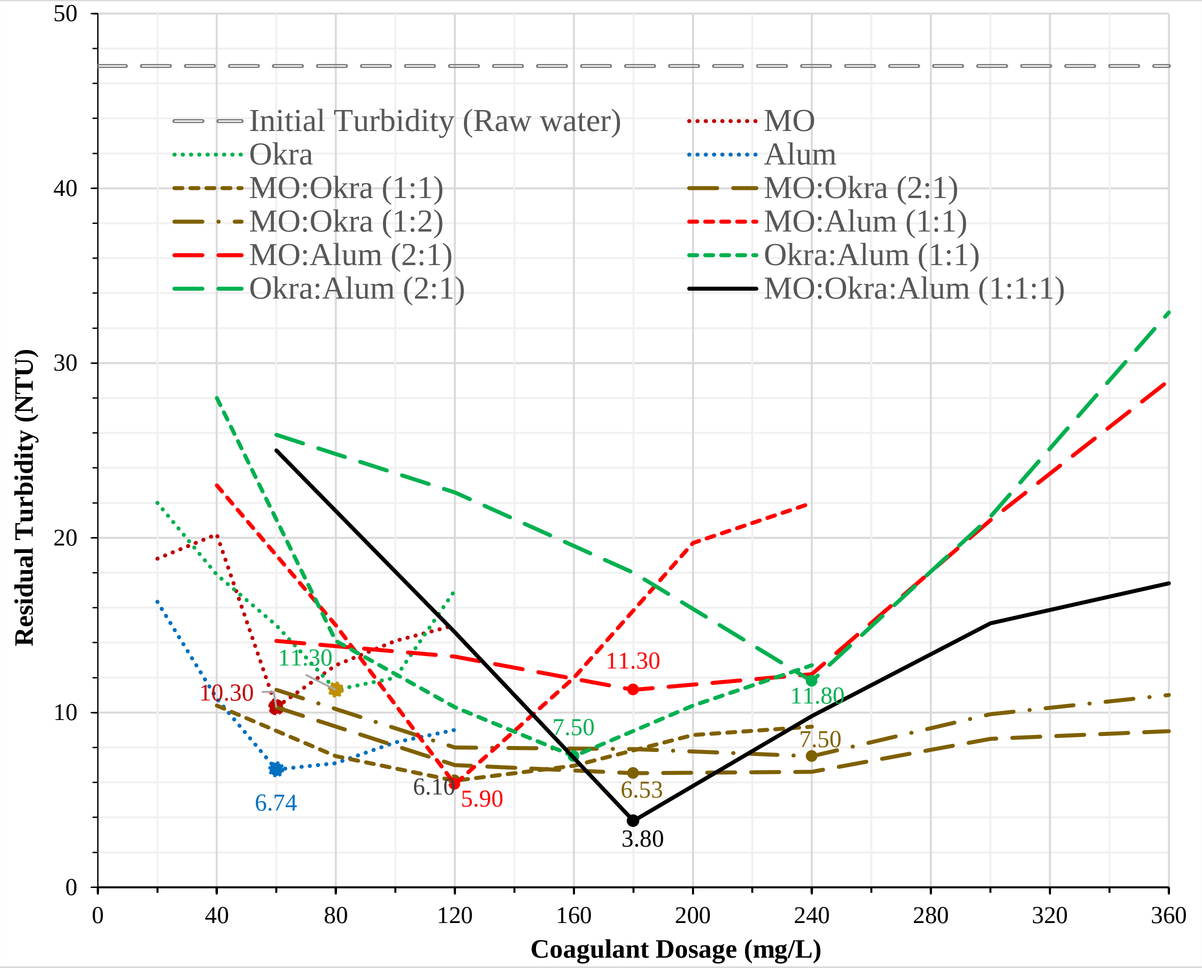


**Figure 1.** Optimum coagulant dosages with residual turbidity.

The optimum dosages of natural coagulants blended with Alum obtained were 120 mg/L with MO:Alum (1:1), 180 mg/L with MO:Alum (2:1), 160 mg/L with Okra:Alum (1:1), and 240 mg/L with Okra:Alum (2:1) having residual turbidity of 5.90, 11.30, 7.50 and 11.80

NTU. The results indicated that the natural and synthetic coagulants' blending in the ratio of 1:1 provided better results in terms of both – low coagulant dosages and higher turbidity removal. Further, the performance of blending MO with Alum was higher than blending Okra with Alum in terms of lower dosages coupled with lower residual turbidity.

When both the natural coagulants and the synthetic coagulant were used in blended form as MO:Okra:Alum in the ratio 1:1:1, the optimum dosage obtained was 180 mg/L having residual turbidity of 3.80 NTU. The residual turbidity after the treatment in this case was significantly lower in comparison to other cases of individual or blended combinations of coagulants.

### 3.2. pH Variation

The pH invariably increased with coagulant dosage with all the coagulant combinations used in the study (Figure 2). The increase in pH as well as the pH at the optimum dosage (labelled in Figure 2) were observed to be higher in case of synthetic coagulant – Alum (7.40 to 7.78; 7.52), in comparison to natural coagulants – MO (7.12 to 7.20; 7.15) and Okra (7.13 to 7.27; 7.24).

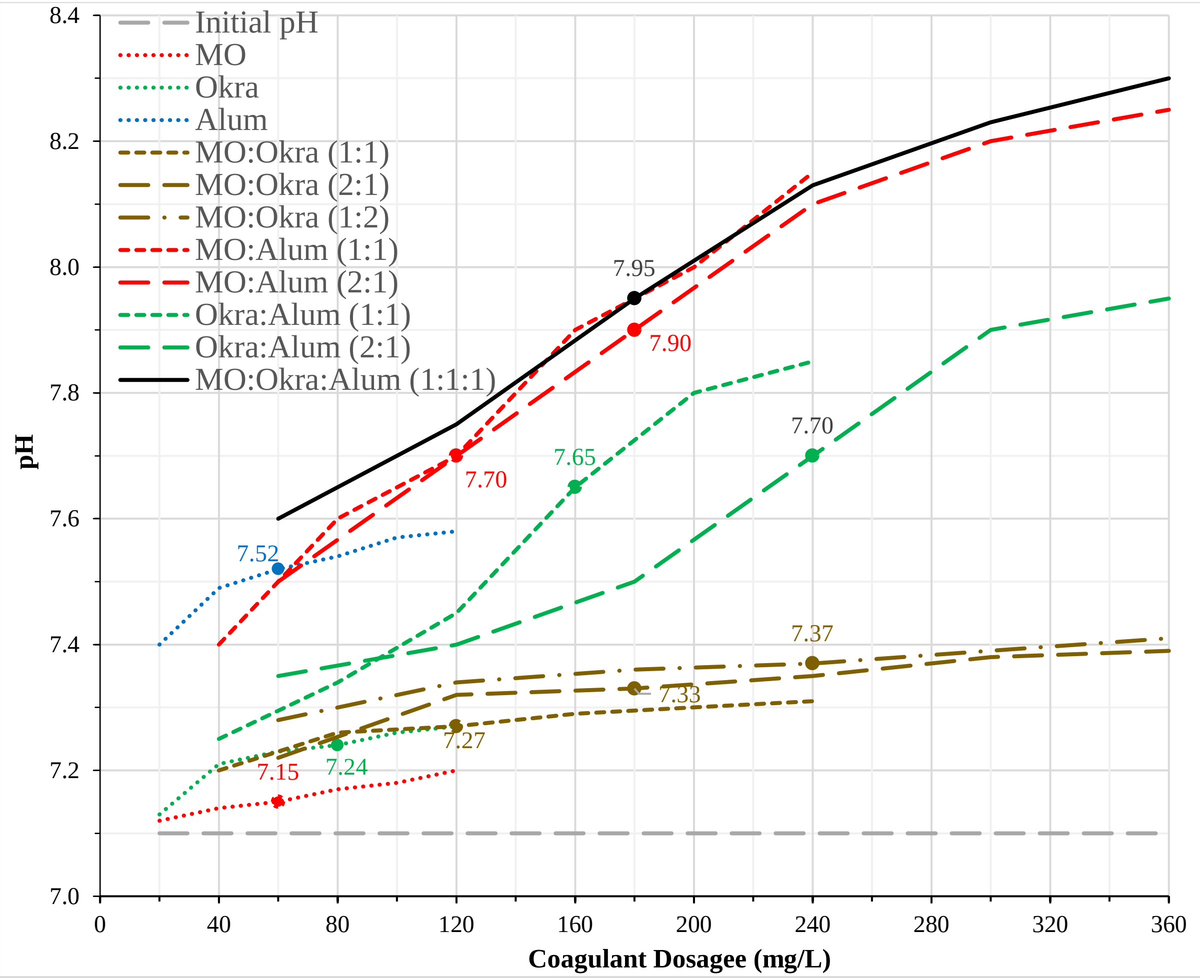


**Figure 2.** Variation of pH at coagulant dosages.

On similar line, in all the three blended combinations of natural coagulants, the increase in pH as well as the pH at the optimum dosage were observed to be lower than the values obtained with alum as shown and labelled in Figure 2. The results thus revealed that the rise in pH of the treated water was more in case of alum than natural coagulants, whether used individually or blended. Although, blended natural coagulants have higher increase in pH as well as pH at the optimum dosage in comparison to when natural coagulants used individually. Further, with blended natural coagulants, the increase in pH at higher dosages (>100 mg/L) was observed to be marginal.

When natural and synthetic coagulants were used in blended form, the pH of the treated water increased rapidly with increasing dosage, and also the pH at optimum dosage was higher. MO blended with alum imparted higher pH to the treated water in comparison to Okra blended with alum (Figure 2). The blending of MO, Okra and Alum, resulted in even higher ranges of pH (7.60 to 8.30) with increasing dosage in treated water, along with a pH of 7.95 at optimum dosage.

### 3.3. Performance Evaluation of Coagulants

The performance of natural coagulants: *Moringa oleifera* and Okra and synthetic/chemical coagulants: Alum, individually and in blended-combinations with varying ratio, was evaluated in terms of percentage removal of turbidity, TSS, BOD and COD after water treatment with optimum dosages.

Alum, with an optimum dosage of 60 mg/L, showed higher percentage removal of turbidity (85.66%), TSS (38.58 5), BOD (31.25%) and COD (35.80%), followed by MO (turbidity: 78.09%; TSS: 31.50%; BOD: 20.83%; and COD: 22.22%) and Okra (turbidity: 75.96%; TSS: 18.90%; BOD: 16.67%; and COD: 11.11%) as shown in Figure 3. Although both the natural coagulants showed lower performance than alum, but the results exhibited the potential of using the natural coagulants - MO and Okra, in water treatments.

The blended use of MO and Okra as coagulants showed improved performance in the removal of all the four parameters particularly turbidity and TSS than using them individually, albeit with higher optimum dosages (Fig. 3). The performance of MO:Okra (1:1) was followed by MO:Okra (2:1) and MO:Okra (1:2) at optimum dosages of 120, 180 and 240 mg/L respectively. Further, the performance of MO:Okra (1:1), at the optimum dosage of 120 mg/L exhibited higher percentage removal of turbidity (87.02%) and TSS (41.73%) than alum but comparatively lower percentage removal of BOD (27.08%) and COD (33.33%).

The results of blended use of MO or Okra with alum revealed that – (i) the blending of MO with alum performed better than blending of Okra with alum in the removal of turbidity, TSS, BOD and COD; (ii) the blending ratio of 1:1 showed better results than the blending ratio of 2:1; (iii) MO:Alum (1:1) with an optimum dosage of 120 mg/L achieved removal of turbidity (87.45%), TSS (44.09%), BOD (33.33%) and COD (44.44%) higher than MO:Okra (1:1) and Alum as shown in Figure 3. The blended use of all the three coagulants as MO:Okra:Alum in equal proportion (1:1:1) at optimum dosage of 180 mg/L exhibited significantly enhanced and best performance in the removal of all measured parameters – turbidity (91.91%), TSS (51.18%), BOD (41.67%) and COD (55.56%), in comparison to all other blending combinations of natural and/or synthetic coagulants used in the present study. But, this blending of the three coagulants also results in the increased pH (7.95) of the treated water.

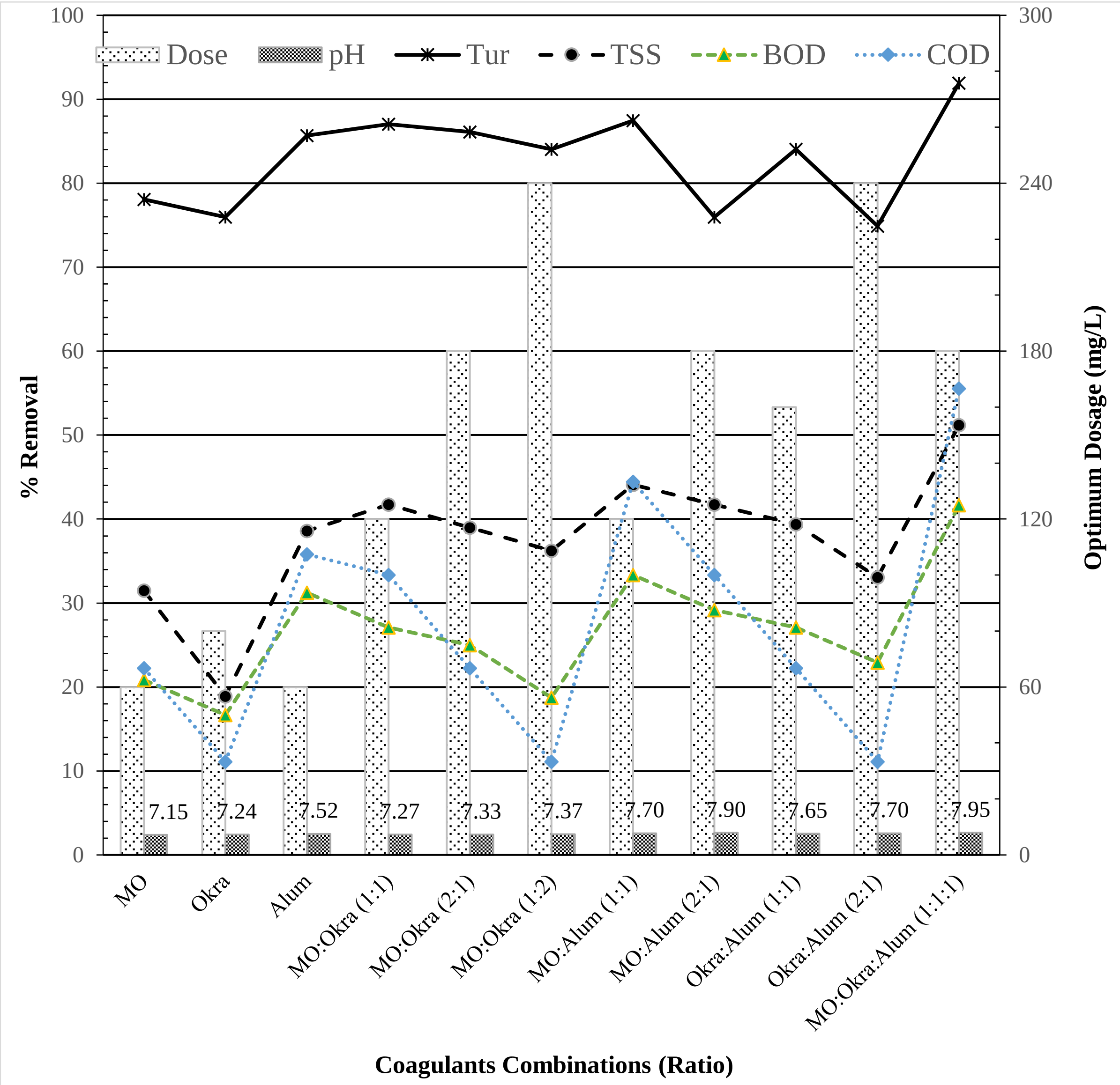


**Figure 3.** Performance of coagulants at optimum dosages.

The results of the present study have been compared with similar studies as well as with other natural coagulants as reviewed and summarized by Nisar & Koul (2021) and Koul et al. (2022). In case of *M. oleifera*, the reported turbidity, TSS and COD removal were in the range of 61.60 – 99.00%, up to 95.00% and 65.00 – 83.00% respectively in different studies; whereas, the removal of corresponding parameters in the present study were 78.09%, 31.50% and 22.22%. In case of Okra (*A. esculentus*), the reported turbidity and COD removal were in the range of up to 97.24% and 85.69% respectively in different studies; whereas, the removal of corresponding parameters in the present study were 75.96% and 11.11%. A comparison with other natural coagulants revealed that the turbidity removal of more than 75% (around or higher than *M. oleifera* and Okra) has been reported with *Cicer arietinum* L. (78.33%), *Opuntia indica* L. (78.54%), *Hibiscus sabdariffa* L. (87.18%), *Strychnos potatorum* L.f. (90%), *Carica papaya* L. (90%), *Jatropha curcas* L. Britton and Mills. (93%), *Julifora prosopis* var. *juliflora* (Sw.) DC (96%), *Citrus sinensis* L. (97%), *Tamarindus indica* L. (97.72 %) and *Musa acuminate* L. (98.50%); whereas, *Opuntia ficus* L. (49.56%), *Trigonella foenum* L. (58%), *Hibiscus rosa-sinensis* L. (60%), *Momordica charantia* L. (61.03%), *Parkia biglobosa* Jacq. (67.82%), *Cyamopsis tetragonoloba* L. (67.82%), *Dolichos lablab* L. (71.74%) and *Acacia mearnsii* De Wild. (75%) have turbidity removal ≤ 75%. In case of usage of blended combination of *M. oleifera* and alum, the reported turbidity, TSS, COD and BOD removal were up to 86.14%, 81.52%, 66.73% and 80.67% respectively in different studies; whereas, the removal of corresponding parameters in the present study were 87.45%, 44.09%, 44.44% and 33.33%. Although the above comparison has the limitations – including varying optimum dosage, state of coagulant, strength of raw water, and blended combination; however, the outcome of these reported studies indicate the potential of *M. oleifera* and Okra as coagulants in water treatment, and need of exploring blended combinations of natural coagulants.

The cost of the three coagulants used in the present study – namely alum powder, MO powder and Okra powder, in the local market in Indian Rupee (Rs.) was 13, 170 and 350 per kg respectively. Taking this in consideration, the treatment cost (Rs. per 1,000 L) at optimum dosage of individual and blended combinations of coagulants was determined and presented in Figure 4. The treatment cost with alum was minimum (Rs. 0.78/1,000 L) at optimum dosage of 60 mg/L, followed by MO (Rs. 10.20/1,000 L) at optimum dosage of 60 mg/L, and MO:Alum: 1:1 (Rs 10.98/1,000 L) at the optimum dosage of 120 mg/L; thereafter, the treatment cost with other blended coagulants increased substantially due to higher optimum dosages requirement and high cost of natural coagulants. Amongst the natural blended coagulant, MO:Okra (1:1) at the optimum dosage of 120 mg/L had the lowest treatment cost of Rs. 31.20/1,000 L.

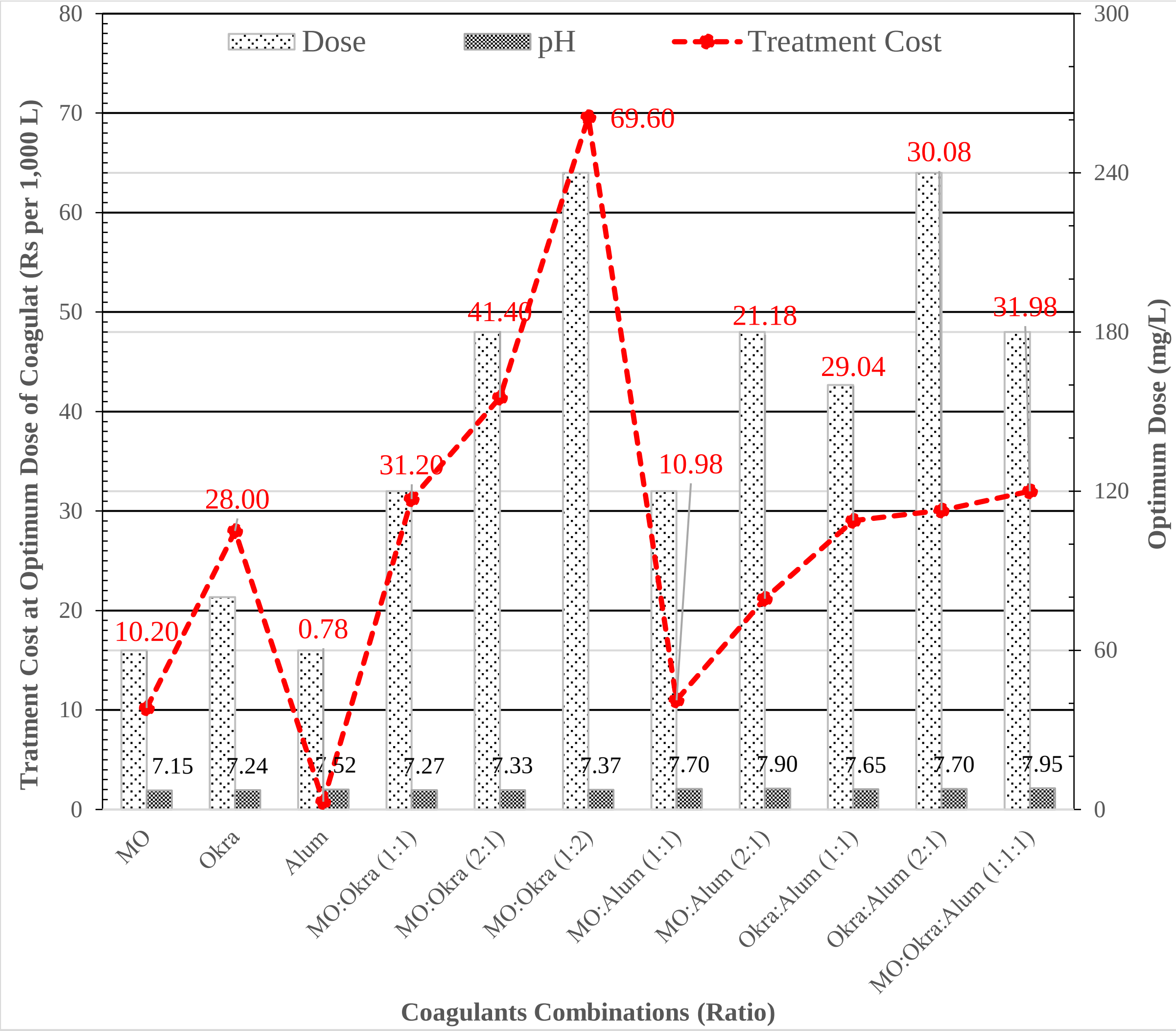


**Figure 4.** Treatment cost of coagulant at optimum dosages.

In view of the treatment efficiency (in terms of percentage removal of turbidity, TSS, BOD and COD), amount of optimum dosage (that in turn reflects the amount of sludge generation) and the treatment cost, the significant inferences from the results have been summarized as under: –

(i) The treatment cost with conventional alum has been minimum (Rs. 0.78/1,000L) at optimum dosage of 60 mg/L with percentage removal of turbidity, TSS, BOD and COD as 85.56, 38.58, 31.25 and 35.80 respectively and effluent pH of 7.52; however, there are environmental and health issues related to its usage.

(ii) The treatment performance of natural coagulants has been observed to be lower than alum, but encouraging – particularly that of MO with same amount of optimum dosage (60 mg/L) without any significant change in effluent pH (7.15). In case of MO, the percentage removal of turbidity, TSS, BOD and COD were 78.09, 31.50, 20.83 and 22.22 respectively; and there are environmental and health issues related to its usage, along with low quantity of sludge.

(iii) In the blended combinations of MO/Okra and alum, the blending of MO with alum has displayed better treatment performance along with lower dosages and cost of treatment. The blended combination of MO: Alum (1:1) has better treatment performance than alum alone with percentage removal of turbidity, TSS, BOD and COD as 87.45, 44.09, 33.33 and 44.44 respectively at lower pH of 7.70; but at higher optimum dosage of 120 mg/L and treatment cost of Rs. 10.98/1,000L, and the environmental and health issues related to alum usage remains as such.

(iv) The blended combination of natural coagulants – MO and Okra (1:1) has better treatment performance than alum alone and comparable with MO: Alum (1:1) providing percentage removal of turbidity, TSS, BOD and COD of 87.02, 41.73, 27.08 and 33.33 respectively with marginal variation in pH (7.27), and at optimum dosage of 120 mg/L (same as in case of MO: Alum) but at higher treatment cost of Rs. 31.20/1,000L; however, without any environmental and health issues, and low quantity of sludge.

(v) The blended combination of all the three coagulants – MO:Okra:Alum :: 1:1:1 has provided the best and significantly higher treatment performance with percentage removal of turbidity, TSS, BOD and COD of 91.91, 51.18, 41.67 and 55.56; but at higher optimum dosage of 180 mg/L with effluent pH of 7.95) and at a higher treatment cost of Rs. 31.98/1,000 L, and the environmental and health issues related to alum usage remains unresolved.

The above inferences from the present study, suggests that the usage of *Moringa oleifera* (MO) or the blended combination of MO: Okra (1:1) as coagulant in the water and wastewater treatment in view of environmental sustainability and public health.

## 4. Conclusion

The inorganic synthetic coagulants, particularly alum, has been widely used in water and wastewater treatment for turbidity removal due to high efficiency and low cost; however, usage of these chemical compounds poses several environmental and public health issues due to their chronic toxicity. The natural organic coagulants – *Moringa oleifera* and Okra (individually and in blended combination of 1:1) used in this study, have exhibited comparable performance in removing turbidity and other water quality parameters like TSS, BOD and COD with marginal pH variation and less sludge, albeit at higher treatment cost. Though, the higher treatment cost with natural coagulants can be brought down by commercialization of their cultivation in suitable areas. But most importantly, the natural coagulants are non-hazardous to the environment and public health. So, there is an urgent need to replace these chemical coagulants by natural coagulants (individually and/or blended combinations) to achieve environmentally sustainable treatment of water and wastewater despite having some limitations. Future research may be focused on suitable improvement in the usage of natural biodegradable coagulants in water and wastewater treatment at commercial scale.

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