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ORIGINAL ARTICLE

Turbidity removal by conventional and ballasted coagulation with natural coagulants

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Abstract

Kernel of *Moringa oleifera* and *Strychnos potatorum* (Nirmali) seeds has the potential for turbidity removal. However, potential of seed kernel naturally dried in trees and that of sun-dried and oven-dried seeds and other parts, such as coat and wing of *Moringa oleifera,* has not been explored. In the present study, various forms of kernel and parts of *Moringa oleifera* seed were used to assess the removal of turbidity aided with/without coagulant aid and ballasting agent. Low (< 12 NTU), medium (> 13 <= 24 NTU) and high turbidity (>= 25 <= 35 NTU) water samples were used in the present study. Micro-sand and powdered activated carbon (PAC) were used as ballasting agents along with *Aloe Vera* as a coagulant aid/natural polymer. The kernel from seeds naturally dried in *Moringa oleifera* tree was found to possess more coagulant property. The optimum dose of *Moringa oleifera* for medium and high turbidity was found to be 50 mg/L and 100 mg/L, respectively, with turbidity removal of 90.46% and 88.57%. The optimum dose of *Strychnos potatorum* was 0.2 mg/L, 0.6 mg/L, and 0.8 mg/L for low, medium and high turbidity, with turbidity removal as 71.42, 64.28 and 57.14%, respectively. *Aloe Vera* acts as a coagulant aid with the natural coagulants and increases turbidity removal. Ballasting agents micro-sand and PAC, with *Aloe Vera* and coagulants, increase turbidity removal and reduce the settling time.

Keywords *Aloe vera* · Ballasting · Micro sand · *Moringa oleifera* · *Strychnos potatorum* · *Turbidity*

Introduction

Surface water is the primary source of potable water supply systems in most of the cases. These sources are largely contaminated by surface runoff and wastewater. The turbidity imparted thereby necessitates treatment for its removal before supplied to consumers for potable use. Turbidity is a significant physical water quality parameter and largely contributed by non-settleable solids. Normally, municipal water supply and treatment systems have centralized water treatment system wherein the concept is to treat and supply. Typically, in such systems the raw water is treated with physical and chemical treatment viz. coagulation, flocculation, settling and filtration for turbidity removal. The centralized treat and supply systems have several limitations such as requirement of chemicals, sludge disposal problems, contamination/deterioration of water quality during distribution and requirement of energy-intensive mechanized systems. In this context, decentralized water treatment system (DWTS) based on the concept of supply and treat implemented through point of use (PoU) purifiers is a feasible option which caters to overcome the above limitations. PoU purifiers available in the market are more suitable for urban population in developing countries like India and are not cost-effective in terms of capital and recurring cost. However, there is a need to develop economically feasible technologies for turbidity removal in PoU purifiers which are more appropriate for rural population. The locally available plant materials, which have a potential to be used as a coagulant/coagulant aid, are useful to develop such technologies. The ballasted flocculation/coagulation which enhances turbidity removal efficiency can also be a part of PoU purifier. The plant-derived natural coagulants could create economic benefits, as cultivation of plants as a means of revenue

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generation would also provide new job opportunities for the local population.

Bhole and Shrivastava (1983), Raghuwanshi et al. (2002), and Swati and Govindan (2005) used *Strychnos potatorum* (Nirmali seed) as a coagulant/coagulant aid and reported their suitability for turbidity removal. Jahn (1986) studied the coagulant potential of different species of *Moringa oleifera* and reported that out of 14 species of *Moringacea*, only *Moringa oleifera* and *Moringa stenopetala* possess efficient coagulation properties. Muyibi and Evison (1995) carried out the optimization studies using *Moringa oleifera* for low, medium and high turbidity water and reported residual turbidity less than 10 NTU in all cases. Okuda et al. (2001) studied coagulation mechanism of salt solution-extracted active component in *Moringa oleifera* seeds. Narasiah et al. (2002) conducted a study on turbidity removal in synthetic turbid water under laboratory-controlled conditions using natural coagulant–flocculant *Moringa oleifera* seeds from Burandi, Central Africa, and from Mahajanga, Madagascar. The seeds from Burandi were found to be of superior quality than those of Madagascar. Other studies conducted to remove turbidity using *Moringa oleifera* include Raghuwanshi et al. (2002), Sudhirkumar et al. (2010) and Sarpong and Richerdson (2010). Montakhab and Gazali (2010) used *Moringa oleifera* seed powder extracted with $NaNO_3$. Dalen et al. (2011) studied the synergy between *Moringa oleifera* seed powder and alum in the purification of water. Gulmire and Munavalli (2017) used *Aloe Vera* as a coagulant/coagulant aid for turbidity removal and found 60–65% removal efficiency raw water turbidity of 20–30 NTU.

Shahnawaz et al. (2002) carried out the bench- and pilot-scale studies using sand-ballasted flocculation and conventional coagulation and reported the effectiveness of sand as ballasting agent. Other studies on ballasted flocculation include Young and Edwards (2003) (factors affecting ballasted flocculation), Blumenschein et al. (2004) (performance of sand-ballasted high-rate clarification), and Ghanem et al. (2007) mode of transport of ballasting agent from bulk liquid).

The literature review shows that the kernel extracts of *Moringa oleifera* and *Strychnos potatorum and* gel of *Aloe Vera* have potential for their usage as coagulant for turbidity removal. But the potential of various forms of kernel (naturally and artificially dried) and parts of (seed coat/wings/pod) of *Moringa oleifera* seed has not been assessed for turbidity removal. The use of *Aloe vera* as a coagulant aid along with *Moringa oleifera and Strychnos potatorum* is also not studied. It can also be seen from the literature review that sand-ballasted flocculation was used effectively along with Alum and synthetic polymer as a coagulant for turbidity removal. In this context, the present study contributes to existing knowledge on use of natural coagulants for turbidity removal in the following ways:

Coagulation study with various forms of kernel and parts of *Moringa oleifera* seed.

1. Sand-ballasted flocculation with natural plant-derived coagulants (*Moringa oleifera and Strychnos potatorum*) and *Aloe Vera* as a binder (polymer).
2. Use of powdered activated carbon as a ballasting agent in ballasted coagulation study.

Materials and methods

Preparation of turbid water

River water was used in the study. The composition of a typical raw water sample collected from river has: turbidity 5–50 NTU, hardness 120–140 mg/L as $CaCO_3$, pH 7–7.6, TDS 300–400 mg/L and alkalinity 200 mg/L as $CaCO_3$. The turbidity of settled raw water collected was less than 35 NTU. Low (<12 NTU), medium ($>13 <= 24$ NTU) and high turbidity ($>= 25 <= 35$ NTU) water samples were used in the present study. The water sample with required value of turbidity for the coagulation study was prepared by either remixing with alluvial soil (<75 µm) or by diluting it with less turbid settled water. Series of such samples were prepared, and turbidity was ascertained through measurement by nephelo-turbidity meter. Thus, in the present study, the water samples used were contributed by suspended solids normally found in river water.

Moringa oleifera seeds

The pods of *Moringa oleifera* were collected from various locations in Sangli district, India (M.S.). These collected pods included matured green/partially dried and completely dried on the tree. The kernel of seed from completely dried pod collected from *Moringa oleifera* tree is referred as naturally dried seed kernel in the study. The coat of such seeds was also used in coagulation study. The matured green/partially dried pods were either sun-dried or oven-dried. One week period was used for sun drying. Temperature of 103 °C for 2 h was used for oven drying. The kernel of seed from pods which were sun-dried was referred as sun-dried seed kernel, and the kernel of *Moringa oleifera* seeds which were used oven-dried was referred as oven-dried seed kernel in the present study.

The kernel of seeds was used to prepare extract. The dried kernels were crushed and ground in domestic mixer to lowest possible size. One gram of pulverized kernel was mixed with 100 mL of distilled water, and the contents were blended in the mixer at highest possible speed for 60 s. The suspension was filtered and used as 1% stock solution. The fresh stock solution was prepared as and when required fresh for use. An extract of coat of naturally dried *Moringa oleifera* seeds was also prepared similarly.

Strychnos potatorum **(Nirmali)**

Strychnos potatorum seeds were procured from the market. The coating of seed was removed, and kernel was pulverized to powder. A stock solution of 0.1% strength was prepared following same procedure as discussed previously for *Moringa oleifera* seed kernel.

Aloe Vera

The leaves of locally available *Aloe Vera* plant were collected. The outer skin of the leaves was removed, and pulp/gel was separated. The gel was blended in a mixer to get uniform liquefied paste. One gram of such fresh liquefied paste was mixed in 100 mL of distilled water and blended in mixer at more than 100 rpm to get 1% solution.

Ballasting agents

Standard sand (quality defined by Bureau of Indian Standards IS650, grade-III) was used in the study as a ballasting agent. The size of sand between 90 and 150 µm and specific gravity of 2.65 was used. Powdered activated carbon (PAC) manufactured by Thermo Fisher Scientific India Pvt. Ltd., having size 75–90 µm and density of 360 kg/m^3 was used as another ballasting agent alternative to sand.

Planning of experiments

The experiments were planned (1) to analyze raw and treated turbid water, (2) to carry out coagulation studies with *Moringa oleifera* and *Strychnos potatorum* as coagulant with and without *Aloe Vera* as coagulant aid, and (3) to conduct ballasted flocculation studies with clean standard sand and PAC. All the experiments of conventional and ballasted flocculation were performed with a standard jar test apparatus. The range of coagulant dose (10–100 mg/L for *Moringa oleifera* and 0.20–1 mg/L for *Strychnos potatorum*) and dose of coagulant aid *Aloe Vera* (10–100 mg/L) was used. These dosages were identified through trials and by referring the literature. The optimum pH was also determined for effective removal of turbidity. The coagulation studies were used as a reference to compare the results with that of ballasted flocculation. The maximum dosage of standard micro-sand and PAC used was 4 g/L and 0.50 g/L, respectively. In the ballasted flocculation study, optimum dose of *Aloe Vera* as a polymer was determined followed by determination of optimum dose of coagulant for particular ballasting agent dose. Therefore, series of experiments using *Aloe Vera* were planned. Five experiments were conducted for each dosage to assess the effectiveness of treatment, and average of these results was taken for discussions.

Experimental procedure

The jar test procedure was adopted to assess the effectiveness of *Moringa oleifera* and *Strychnos potatorum* with and without *Aloe Vera* as coagulant aid. The jar test procedure was referred to Bell-Ajy et al. (2000) and it consisted of rapid stirring at 120 rpm for 1 min, followed by a slow stirring at 40 rpm for 10 min and at 20 rpm for 10 min, consecutively; and finally settling for 30 min for a volume of 1 L synthetic sample.

The ballasted flocculation was carried out by initiating stirring, coagulating at 300 rpm for 2 min, injecting *Aloe Vera* (polymer) followed by 1 min stirring at 300 rpm, injecting appropriate dosage of ballasting agent, followed by stirring at 200 rpm for 2 min, and settling for 30 min. The settled sample was pipetted out a little (10 mm) below the surface of water for analysis in each of these jar test procedures. Raw and residual turbidity were measured.

All the procedures for analyzed parameters viz. pH, turbidity, alkalinity, and TDS were referred to Standard Methods for the Examinations of Water and Wastewater (1998). pH value of the samples was determined by pH meter. Turbidity was measured using a Hach 2100 series Nephelo-turbidity meter. The specific gravity of sand was determined by Pycnometer method.

Result and discussion

Effectiveness of kernel and coat of *Moringa oleifera* seeds for turbidity removal

Figure 1 shows the efficiency of turbidity removal by seed kernel (naturally dried, sun-dried and oven-dried) and coat of naturally dried seed. The results show that the coat of seed is relatively less efficient and naturally dried seed is more efficient in turbidity removal. Removal to an extent of 36% is possible with dosage of 10 mg coat of seed/L indicating that it has also some turbidity removal potential. This observation is significant as it can be used as coagulant aid due to its larger availability compared to kernel. However, naturally dried seeds can remove turbidity by 90% at a coagulant dosage of 50 mg/L. The comparison of turbidity

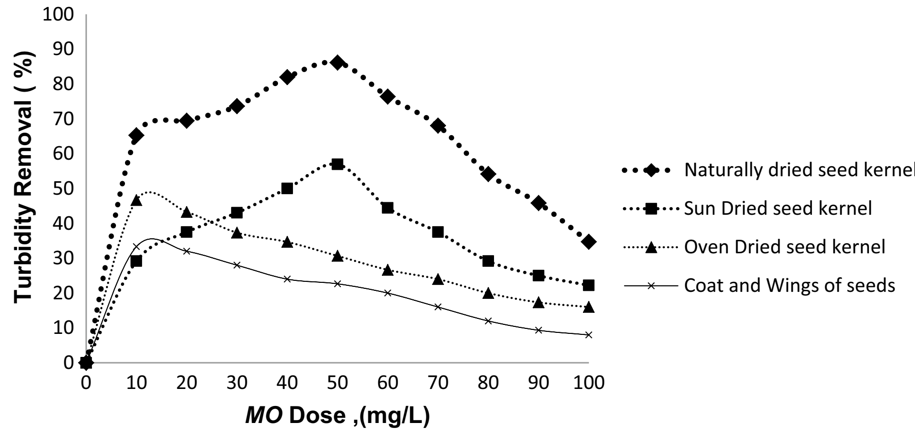

Fig. 1 Effect of coat and seed kernel of *Moringa oleifera* on turbidity removal

removal by sun-dried and oven-dried shows that sun-dried seeds are more efficient.

The predominant mechanism for coagulation is adsorption between coagulation active components in *Moringa oleifera* and particles of suspension to permit inter-particle bridging, and is not charge neutralization (Muyibi and Evison 1995; Ali et al. 2016). The efficiency of adsorption depends on the adsorbent surface area, surface morphology, pore size distribution, polarity and functional groups attached to the adsorbent surface (Ali et al. 2016). This indicates that naturally dried *Moringa oleifera* seed extract contains more active ingredients with more surface area available for adsorption and inter-particulate bridging (Joseane et al. 2013). The morphological characteristics of the powder of above materials used in the study were carried out through scanning electron microscope (SEM) with different levels of magnification to ascertain extent of porous nature of materials. Figure 2 shows the results of SEM study.

It can be seen that the naturally dried *Moringa oleifera* seed kernel is amorphous in nature with hips of fine particles which indicate availability of more surface area for adsorption. Sun-dried seed has agglomerated grains resulting in a flocculent structure. Oven-dried seed kernel is

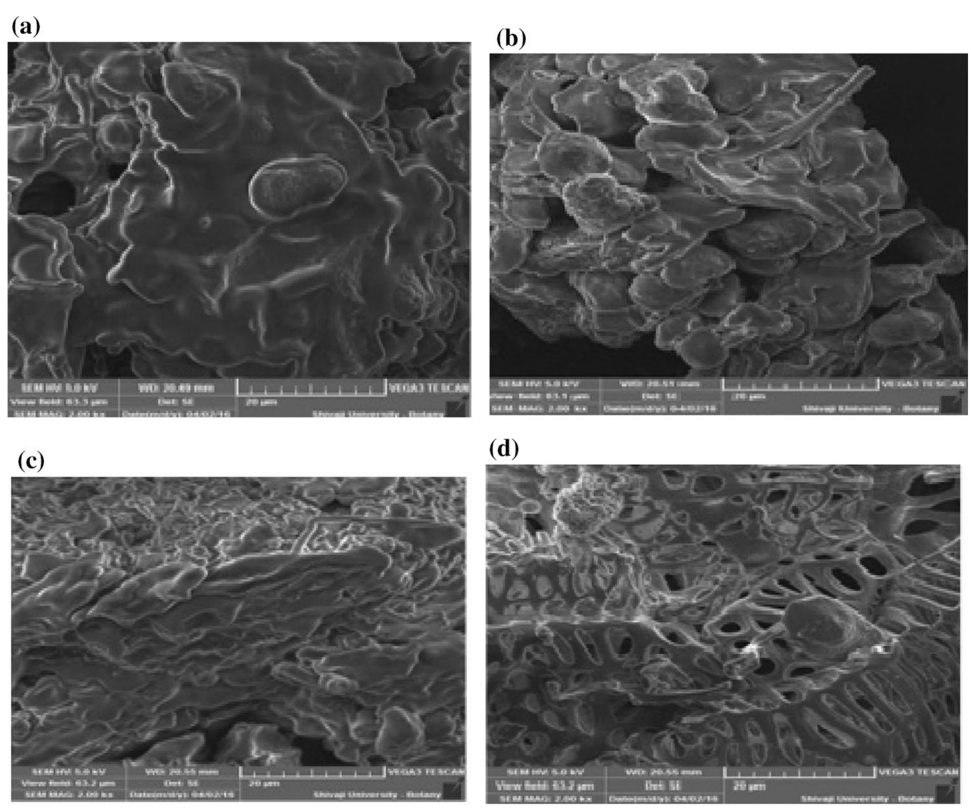

Fig. 2 Results of SEM study for **a** naturally dried; **b** sun-dried; **c** oven-dried; and **d** coat

relatively more porous compared to these two. Coat is highly porous with reticulated structure providing lesser sites for adsorption.

Further, the time required for drying of pods and its rate also plays a significant role in inducing quality ingredient (protein structure) and surface morphology of seed kernel. Sun-dried and oven-dried were subjected to 1 week and 2 h of drying time, respectively. Complete drying of pods in the tree naturally takes larger time and drying occurs gradually.

This surface morphology study and coagulation study reveal that naturally dried *Moringa oleifera* seed kernel has greater potential for turbidity removal. Hence, further study is carried out using naturally dried *Moringa oleifera* seed kernel.

Effect of Strength of *Moringa oleifera* and *Strychnos potatorum* extract on turbidity removal

The effect of varied strengths of *Moringa oleifera* extract was studied using 0.5, 1, 5, 10 and 15% extracts, for water sample of 26 NTU turbidity, and 100 mg/L dose of *Moringa oleifera*. Figure 3a shows the effect of *Moringa oleifera* strength on turbidity removal. It can be observed that although removal increases with increase in strength from 0.5 to 15%, the increase is not significant beyond 1%. Hence, 1% strength resulting in 88% removal was used for the further study. Figure 3b shows the turbidity removal with strength 1, 3, 5 and 8% of *Aloe Vera* for initial turbidity 32 NTU and *Aloe Vera* dose of 50 mg/L. It can be observed that *Aloe Vera* as a coagulant is not effective for turbidity removal. However, 1% strength is appropriate for *Aloe Vera* application as coagulant/coagulant aid. In case of *Strychnos potatorum* seeds, initial study for deciding dose range revealed that dose of 0.1–1 mg/L is sufficient for optimum turbidity removal. An extract of 0.1% was used considering the practical consideration of dose application. As lower dose application with higher strength extracts is not practicable, the strength effect study is not advisable for *Strychnos potatorum* seed extract.

Turbidity removal with *Moringa oleifera* and *Strychnos potatorum* seeds

Figure 4 shows the residual turbidity after applying varied dose of naturally dried seed kernel of *Moringa oleifera* for low, medium and high turbid water. It can be observed that for low turbidity water residual turbidity increases with added dose of *Moringa oleifera*. The colloidal and suspended solids concentration is less for low turbidity water, excess dose results in increase in residual turbidity due to uncombined coagulant, as sufficient particles are not available to combine with coagulant protein. The optimum dose

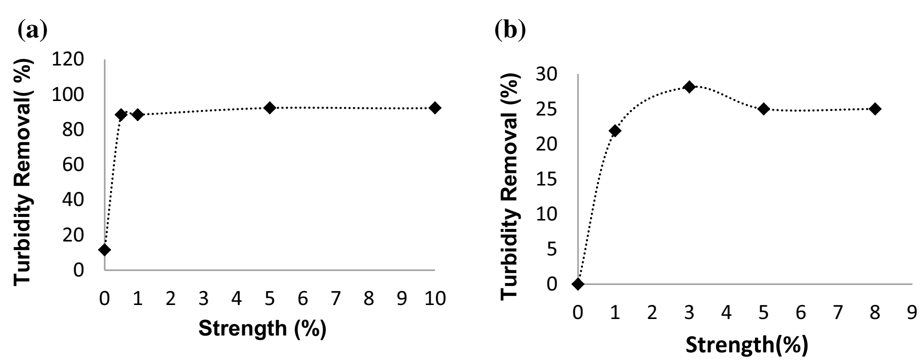

Fig. 3 Effect of strength of **a** *Moringa oleifera* extract and **b** *Aloe Vera* extract on turbidity removal

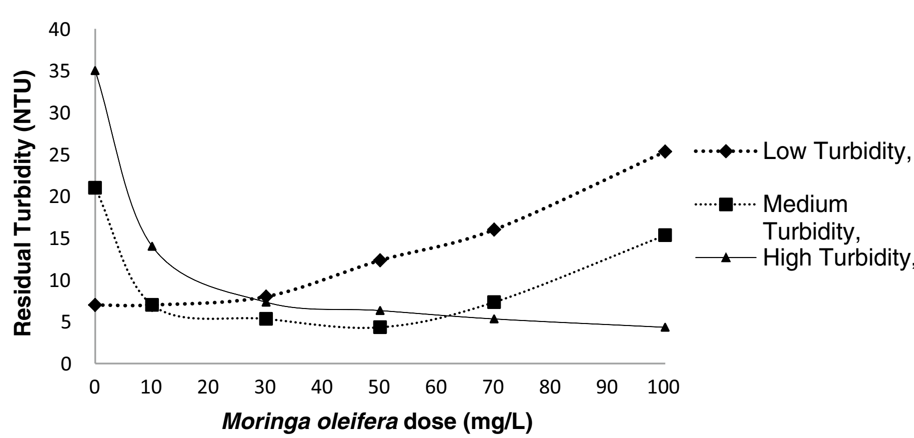

Fig. 4 Turbidity removal by naturally dried *Moringa oleifera* seed in (1) low, (2) medium and (3) high turbidity water

for medium and high turbidity samples was observed to be 50 and 100 mg/L, respectively, with turbidity removal efficiency of 80.95 and 88.57%. This indicates that coagulant dose required increases with initial turbidity for medium and high turbidity water, as more charged sites are necessary for adsorption and chemical bridging. After optimum dose the residual turbidity increases with added dose of coagulant, because of non-availability of sufficient number of particles for bridging with the charged sites of coagulant and turbidity increases due to suspended coagulant matter.

Figure 5 shows the effect of varied dose of *Strychnos potatorum* on turbidity removal for low, medium and high turbid water. The results show that the removal efficiency increases from high to low turbidity water and for maximum removal optimum dose was observed to be 0.8, 0.6 and 0.2 mg/L for high, medium and low turbidity water, respectively. Thereafter, residual turbidity increases insignificantly. The turbidity removal for low, medium and high turbidity samples was 71.42, 64.28 and 57.14%, respectively.

This study reveals that *Moringa oleifera* is not effective for low turbidity water, but *Strychnos potatorum* seeds show good results. For medium, *Moringa oleifera* is more effective coagulant for high turbidity water, as compared to *Strychnos potatorum.*

Effect of *Aloe Vera* as coagulant aid and as polymer with ballasting agents in turbidity removal

The efforts were taken to improve the efficiency of coagulation process by using *Aloe Vera* as a natural coagulant aid with *Moringa oleifera and Strychnos potatorum* as natural coagulants. Table 1 shows the comparison of optimum dosage of *Moringa oleifera*, when used with and without *Aloe Vera*. The results show that *Aloe Vera* is more effective as coagulant aid when used with *Moringa oleifera* for low turbidity water and relatively less effective for medium and high turbidity water. *Aloe Vera* acts as a polymer which possesses charged sites, to which micro-flocs formed with *Moringa oleifera* get attached, and large settleable flocs are formed.

This table also gives the optimum combination of *Moringa oleifera*, *Aloe Vera* and micro-sand for turbidity removal. It can be seen that the use of ballasting agent (micro-sand) with *Aloe Vera* has enhanced the turbidity removal. The dosage of *Moringa oleifera* is also reduced for medium and high turbidity water. This is due to improved settling conditions with increase in weight of flocs. Addition of polymer leads to branched floc formation and sand provides surface area for floc formation. The micro-flocs formed lead to the formation of macro-flocs by attaching with micro-sand. The physical attachment and enmeshment followed by fast settling macro-flocs are the causes of enhanced turbidity removal.

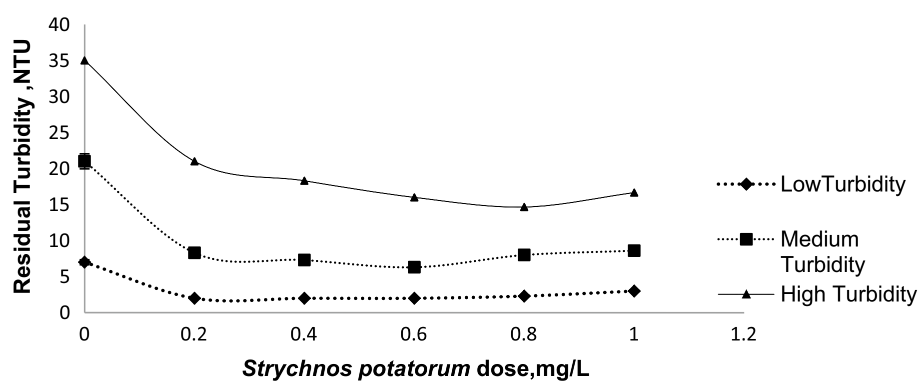

Fig. 5 Turbidity removal by *Strychnos potatorum* seed in (1) low, (2) medium and (3) high turbidity water

Table 1 Turbidity removal by *Moringa oleifera (MO)* with and without *Aloe Vera (AV)*; ballasted coagulation by *MO*, *AV*, and micro-sand

Initial turbidity	*MO*		*MO* + *AV*			*MO* + *AV* + micro-sand			
	Optimum dose (mg/L)	Res. turbidity (NTU)	Optimum dose (mg/L)		Residual turbidity (NTU)	Optimum dose			Residual turbidity (NTU)
			MO	AV		MO (mg/L)	AV (mg/L)	micro-sand (g/L)	
Low (7NTU)	10	7	10	10	4	10	10	0.5	3
Medium (21NTU)	50	4	50	10	3	30	10	1	2
High (35NTU)	100	4	100	10	3	70	10	1	2

Table 2 shows the comparison of optimum dosages of *Strychnos potatorum* with and without *AV*. The combination of *Strychnos potatorum* and *AV* did not give good results as compared with *MO* and *AV*. This may be due to *AV*, which bridges with some of the charged sites on coagulant protein, making them unavailable to the colloidal particles. At higher concentration of colloidal and suspended matter, the removal is more due to greater opportunity for contact to form large and readily settleable flocs. This table also shows that the use of micro-sand and *AV* as polymer with *Strychnos potatorum* improves turbidity removal for medium and high turbidity water, as compared with *Strychnos potatorum* alone. Although removal improves by this combination, post-treatment is necessary to reduce the turbidity below 1 NTU.

Table 3 shows the results of ballasted coagulation with *MO*, *AV* and powdered activated carbon (PAC). It can be seen that the use of PAC as ballasting agent with *MO and AV* has resulted in residual turbidity of 1 NTU or below 1 NTU for all types of turbid water. The larger surface area and surface texture of PAC particles, coating with *Aloe Vera*, formation of micro-flocs induced by *MO* with nucleus of PAC, and adsorption of colloidal particles contribute to improved turbidity removal. The results of ballasted coagulation by *SP*, *AV* and PAC given in Table 1 show enhanced turbidity removal but resulting residual turbidity is 2 NTU or below 2 NTU.

Table 2 Turbidity removal by *Strychnos potatorum (SP)* with and without *AV*; and ballasted coagulation by *SP*, *AV*, and micro-sand

Initial turbidity	*SP*		*SP*+*AV*			*SP*+*AV*+micro-sand			
	Optimum dose (mg/L)	Residual turbidity, NTU	Optimum dose (mg/L)		Residual turbidity, NTU	Optimum dose			Residual Turbidity, NTU
			SP	*AV*		*SP* (mg/L)	*AV* (mg/L)	Micro-sand (g/L)	
Low (7NTU)	0.2	2	0.2	10	5	0.4	40	1	3
Medium (21NTU)	0.6	6	0.6	10	11	1	50	0.8	3
High (35NTU)	0.8	15	0.8	20	7	0.6	10	0.6	2

Table 3 Turbidity removal by *MO*, *AV* and PAC; and *SP*, *AV* and PAC

Initial turbidity, NTU	*MO*+*AV*+*PAC*				*SP*+*AV*+*PAC*			
	Optimum dose			Res. turbidity, NTU	Optimum dose			Residual turbidity, NTU
	MO (mg/L)	*AV* (mg/L)	PAC (g/L)		*SP* (mg/L)	*AV* (mg/L)	PAC (g/L)	
Low (7NTU)	30	70	0.5	0	0.4	40	0.5	1
Medium (21NTU)	70	30	0.5	0	0.4	10	0.2	2
High (35NTU)	100	30	0.1	1	0.2	50	0.5	1

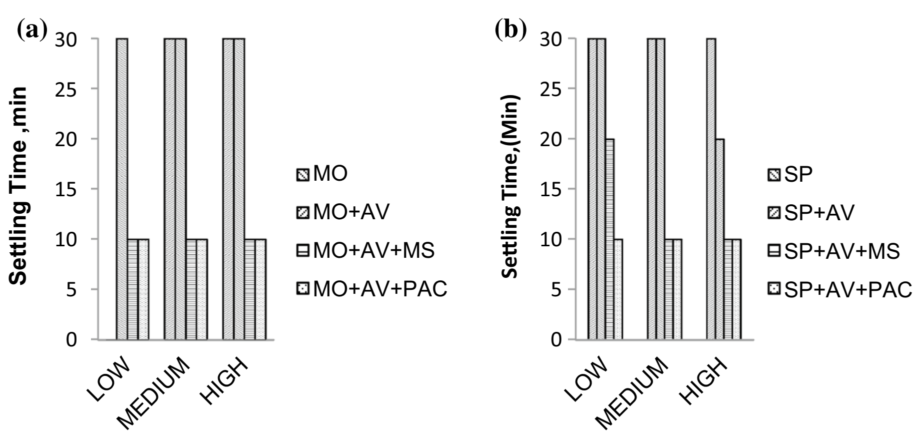

Fig. 6 Effect on settling time by use of **a** *MO*, **b** *SP* with and without micro-sand and PAC

Effect on settling time in ballasted coagulation

Figure 6 shows the effect on settling time in ballasted coagulation with micro-sand and PAC. The residual turbidity was measured after coagulation–flocculation for 10, 20 and 30 min of settling. It can be observed that the use of ballasting agents micro-sand or PAC reduces settling time from 30 to 10 min for obtaining residual turbidity below 4 NTU, as compared with *MO*, and *MO* + *AV* for all three categories of turbid water. Dose of *MO* increased the residual turbidity for low turbidity water, hence the effect on settling time was not considered.

Figure 6 also shows that the use of micro-sand and PAC reduces settling time to 20 min, and 10 min, respectively, for low turbidity water to reduce residual turbidity to 3 NTU. The settling time was reduced to 10 min for medium and high turbidity water by both micro-sand and PAC for obtaining residual turbidity of 6 NTU. Settling time was observed to be 30 min without the use of ballasting agents.

Addition of polymer in treatment leads to branched floc formation and addition of sand/PAC increases weight of the flocculated particles leading to faster settling of suspended solids. The polymer binds the sand/PAC to the floc, thereby avoiding dispersed floc. The reduction in settling time is significant as high-rate clarifiers such as tube/plate/lamella settlers can be used in separation.

Effect of Aloe Vera on dosages of *MO and SP* in ballasted coagulation

Figure 7a shows reduction in *MO* dose, with *AV* and ballasting agents. It can be seen that the dose of *MO* was reduced to 30 mg/L, 10 mg/L and 10 mg/L for high, medium and low turbidity water for obtaining residual turbidity of 4 NTU, respectively. The dose reduction is due to improved coagulation, flocculation and settling of particles, with the aid of polymer and ballasting agents.

Figure 7b shows reduction in *SP* dose, when used in combination with *AV* and ballasting agents to reduce the residual turbidity below 4 NTU. The ballasting agents are effective with coagulant and polymer, even for low turbidity water. The study shows that ballasting agents reduce the time and quantity of coagulant required for water treatment.

Conclusions

1. The coagulation study with various forms of kernel and parts of *Moringa oleifera* seed revealed that the naturally dried *Moringa oleifera* seed kernel has more potential for turbidity removal, with removal efficiency of 88.57%, when compared with sun-dried and oven-dried seed kernel and coat with removal efficiencies as 58, 48 and 36%, respectively.
2. The study on effect of naturally dried *Moringa oleifera* seed extract strength revealed that 1% extract gives 88% turbidity removal. Strength of 1% *Aloe Vera* leaf pulp solution was found to be more effective for turbidity removal; however, the study revealed that *Aloe Vera* is not an effective coagulant.
3. *Moringa oleifera* is not effective for low turbidity water, but it is effective for medium and high turbidity water. The optimum dose of *Moringa oleifera* for medium and high turbidity water was 50 and 100 mg/L, respectively, with turbidity removal of 80.95 and 88.57%.
4. *Strychnos potatorum* is effective for low, medium and high turbidity water, although the removal efficiency is less as compared with *Moringa oleifera* for medium and high turbidity water. The optimum dose of *Strychnos potatorum* for low, medium and high turbidity water was 0.2, 0.6, and 0.8 mg/L, respectively, with turbidity removal as 71.42, 64.28 and 57.14%.
5. *Aloe Vera* acts as a coagulant aid with *Moringa oleifera* and is effective for low turbidity water with removal up to 40%; however, its effect is lesser for medium and high turbidity water.
6. The ballasted coagulation with *Moringa oleifera/Strychnos potatorum*, micro-sand and *Aloe Vera* increases turbidity removal by 5–10% when compared to conventional coagulation with *Moringa oleifera.*

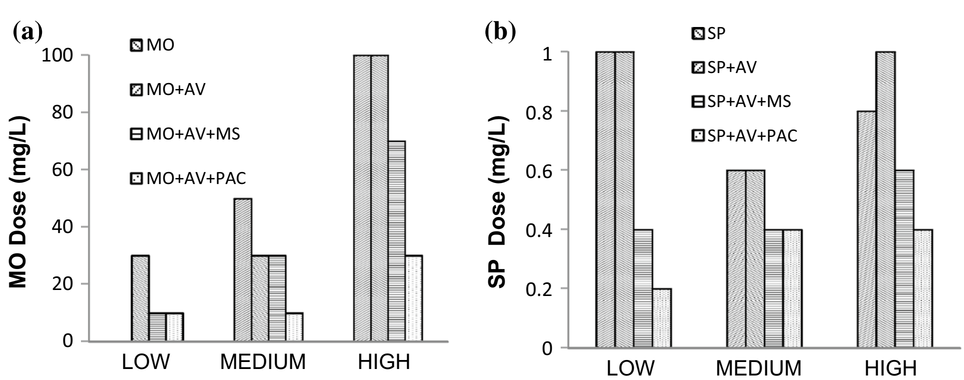

Fig. 7 Effect of *AV* and ballasting agents on dose of **a** *MO*, and **b** *SP*

7. The use of PAC as ballasting agent and *Aloe Vera* as natural polymer, with the coagulant *Moringa oleifera*, *or Strychnos potatorum* is most effective in reducing the turbidity of low, medium and high turbidity water samples below 1 NTU.
8. The use of ballasting agent as micro-sand or PAC reduces the settling time required for settling of flocs, by increasing the weight of flocs. The reduction in settling time is by 10–20 min. The ballasting agents reduce the coagulant dose by 20–70 mg/L with *Moringa oleifera* and 0.2–0.6 with *Strychnos potatorum.*
9. The study revealed that the coagulation with *Moringa oleifera* and *Strychnos potatorum* is a cost-effective alternative, particularly for rural area. The ballasting agents reduce the quantity of coagulant and time required for water treatment.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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