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Experimental Evaluation on Comparative Performance of Native Plant Species in Removing Turbidity and Microbial Load for Household Water Treatment

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Abstract
Unsafe drinking water is a paramount concern because of the fact that, 75% of all diseases in developing countries are arising from polluted drinking water especially in rural parts of developing countries. This work investigates on comparative performance of native plant species in removing turbidity and microbial load as compared to alum and chlorine for household water treatment. Water treatment using Maerua subcordata (Gilg) De Wolf and Moringa stenopetala (Bakj) Cufod were able to achieve appreciable removal efficiency in both turbidity and microbial load at an optimum dose range of 0.01gm/L to 0.03 gm/L in synthetic water and natural surface water samples. Plant coagulants showed relatively lower removal efficiency (≈70%) as compared to alum (≈80%) at low turbidity (20 NTU) in synthetic water. However, in natural water samples of low turbidity, plant coagulants showed high rate of turbidity removal efficiency (≈90%) like that of alum. Plant coagulants can also achieve maximum turbidity removal (≈97%) like that of alum in medium turbidity level (200 NTU) in both natural and synthetic water samples. The experimental result revealed that plant coagulants were able to meet World Health Organization standards of drinking water quality (< 5 NTU) in terms of turbidity. The microbial reduction experiment also revealed that plant coagulants can effectively disinfect water at low turbidity but becomes less potent disinfectant as turbidity increases.
Key words: Coagulation, Disinfection**,** Household water treatment, Native plants, Turbidity

INTRODUCTION

The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses (CESCR, GC 15, 2002). As water is basic human need for health indeed, without safe water and sanitation there will not be real development. Safe water is the doorway to health and health is the pre-requisite for progress, social equity and human dignity. Because of the essential role–played by water in supporting human life it also has, if contaminated, greater potential for transmitting a wide variety of diseases and illnesses.

In developing countries, access to safe water is a crucial issue; because water related diseases are one of the major health problems globally. About 75% of the present world lives in developing countries out of which, 1.2 billion people still lack of safe drinking water and more than 6 million children die from diarrhea every year (Action Aid, 2010). About 84% of the populations without access to an improved source of drinking water live in rural areas of developing countries (WHO and UNICEF, 2010). In Africa, one third of the population has no access to safe water, and almost two thirds have no access to sanitation, causing widespread suffering from malaria, typhoid, dysentery and many other diseases that cause loss of productivity (WHO and UNICEF, 2010).

Ethiopia is one of the countries in the world with respect to water resources. According to UNICEF and WHO joint report of (2012) access to safe water in Ethiopia is from improved 44% (urban 97%, rural 34%), unimproved 46% (urban 3%, rural 43%) and surface water (19%). Peoples in Ethiopia without access to safe water depend on surface water sources such as unprotected springs, ponds, streams and rivers in which most of them are located at great distances from their households (up to six hours in some rural areas) where the burden highly rests on women and children. Even in urban areas, where access to safe water is higher, the quality, quantity and irregularity of water supply is far from being adequate (WHO, 2011).

The use of sophisticated technologies and different chemicals in the context of developing countries for their water supply activities is inappropriate. Wright *et al*. (2003) commented that coagulation and rapid mixing, flocculation, sedimentation, filtration and disinfection are inappropriate in rural areas of developing countries. Moreover, since a large population of Ethiopia reside in rural areas scatter, it is difficult to attain piped water system for them. For these reasons, it is desirable a progressive replacement of these chemical coagulants with alternative coagulants preferably from natural and renewable sources.

Nowadays a number of effective coagulants of plant origin have been identified. Some of the common ones include *Moringa oleifiera*, *Solanum incunum*, *Ocimum* sanctum, *Azadirachta indica, Triticum aestivum, Phyllanthus emblica and Strychnos potatorum and others* (Kihampa *et al*. 2011; Sunil *et al*. 2011 and Yongabi *et al*. 2011) of the large number of plant materials that have been used over the years. The seeds from *Moringa oleifera* have been shown to be one of the most effective primary coagulants for water treatment especially in rural communities. Like elsewhere of the world, local people of Ethiopia use their indigenous knowledge to treat their raw water using plants like *M. subcordata* and *M. stenopetala.* So the main aim of this study was to

evaluate contaminant removal performance of *M. subcordata* and *M. stenopetala* in terms of turbidity and microbial load reduction in laboratory which were used by local people.

METHODS

Water sample

Experimental study was carried out in the laboratory of Environmental health Science and Technology Department, Jimma University. The experiment was carried out using synthetic water and natural surface water. The natural surface samples were collected in and around Jimma town. The samples were divided into six: two samples were used as a control (one is turbid water without coagulants and positive control or Alum) and the other four samples were with different dose of coagulants of *M. subcordata* and *M. stenopetala* to test their performance in coagulation.

Preparation of Synthetic Water

Kaolin clay used for synthetic turbidity water preparation was collected from Awash Melkassa Aluminum Sulfate and Sulfuric acid factory private PLC. Synthetic turbid water was prepared by adding 10g of kaolin (clay suspension) to 1 liter of distilled water. The suspension was stirred for about 1 hour to achieve a uniform dispersion of kaolin particles. Then it was allowed to settle for 24 hours for complete hydration of the kaolin. After 24 hrs of settling, the turbid-water supernatant was decanted and used as a stable stock solution. This suspension was used as the stock solution for the preparation of turbid water samples desired to use by varying turbidity level for coagulation tests (Okuda *et al.* 2001). In this study, four turbidity ranges were considered for the experiment, namely; low turbidity (20 NTU, 50 NTU), medium turbidity (100 NTU, 200 NTU), high turbidity (300 NTU, 400 NTU) and very high turbidity (500 NTU, 1000 NTU) considering the turbidity ranges used by Miller *et al.* (2008).

Preparation of Native Plant Coagulants

The plants used traditionally for water purification (tuber of *M. subcordata* and seed of *M. stenopetala)* by local community were collected from selected rural areas found in SNNPR (Konso, Jinka and Arbaminch) and Oromia Regional State (Yaballo) by the experts based on their existence. The plant materials were identified by comparison with the already preserved specimens kept at the Herbarium in the Department of Biology, Addis Ababa University. The identified plant materials were prepared by soaking into distilled water for an hour and washed by distilled water then dried in an oven at 105 ^{0}C. After that plants were powdered using a mortar and pestle then grained by plant grinder with the pore size of 212 micrometer in diameter to make it similar size and stored in sterilized container for future use.

Jar Test Operation

Jar test is the most widely used experimental method for coagulation. A conventional jar test apparatus was used to achieve uniform agitation rate throughout the experiment for both synthetic water and natural surface water with powder native plant species coagulants. It was carried out as a batch test, accommodating a series of six beakers together with six-spindle steel paddles. For natural surface water, before operating the jar test the natural surface water sample was mixed homogenously. Then, the water samples ought to be measured for physico-chemical; to represent an initial concentration. After the desired amount of coagulant is added to the water sample, agitation was takes place, which consisted of (170 rpm) for two minute followed by 40 rpm for 20 min. After the agitation being stopped, the suspensions were allowed to settle for 30 minutes and effective dose at which the maximum turbidity removal achieved was recorded. The supernatant of the water sample were withdrawn using a pipette from the middle of the beaker for physico-chemical parameters (pH, conductivity, temperature and turbidity) after treatment. All tests were performed at an ambient temperature in the range of 20 – 25 °C and for different turbidity ranges.

Culture Test Procedure

The sample was serially diluted up to 10^{-3} mg/L for both synthetic water and natural surface water and then, 0.1 ml of each diluents of 10^{-1} to 10^{-3} mg/L was plated aseptically onto nutrient MacConkey agar for total coliform, M-FC Broth for fecal coliform and eosin ethylene blue agar for *Escherichia coli* counts (Cheesbrough, 1984). Incubation was carried out at 37 °C for 24 h for Total coliforms, 44.5 ^{0}C for 24 h for fecal and *E. coli* and the plates were read following standard microbiological procedures. The bacterial counts were enumerated using Gallemp 20 colony counter and recorded accordingly. The average counts from 10^{-1} to 10^{-3} mg/L dilutions were recorded (Yongabi *et al.* 2011). For heterotrophic bacteria, spread plate method was used using R2A agar medium and incubated at 20-28 °C for 5-7 days or 35 °C + 0.5 °C for 48-72 + 2 hours.

Quality Control

The procedure of the experiments was done consistently through the whole study to minimize the sources of error and all equipments were calibrated. Triplicate analysis of each parameter was done following the standard protocol in order to get satisfactory result. Moreover, positive and negative controls were used for every triplicate analysis of each parameter during all the experiment.

RESULTS AND DISCUSSION

Dose optimization

For the desired turbidity value (20 NTU, 50 NTU, 100 NTU, 200 NTU, 300 NTU, 400 NTU, 500 NTU and 1000 NTU) using synthetic water in the laboratory the effective dose and contact time of *M. subcordata* and *M. stenopetala* at which the lowest contact time and maximum turbidity removal efficiency was identified by using doses of 0 gm/L (negative control), 0.01 gm/L, 0.03 gm/L, 0.05 gm/L, 0.07 gm/l and 0.09 gm/L for each turbidity range comparing with positive control (Alum) for each experiments. For each turbidity range, the dose of *M. subcordata* and *M. stenopetala* required for removal of turbidity was different.

The Relative Performance of Indigenous Plant Species as a Coagulant

Effectiveness of *M. subcordata* and *M. stenopetala* have been examined in synthetic water at low (20, 50 NTU), medium (100, 200 NTU), high (300, 400 NTU) and very high (500, 1000 NTU) turbidity ranges. They were also applied on natural surface water at low (22, 45 and 46 NTU) and Medium (195 NTU) turbidity level. Other authors tested the effectiveness of Different plant species in synthetic water (Sarah *et al*. 2008 and Asrafuzzaman *et al*. 2011) and natural water (Lea, 2010 and Yongabi *et al*. 2011). *M. stenopetala and M. subcordata* powder reduced turbidity both in synthetic and natural surface water by their optimum dose. Both plant species work well in medium and very high turbidity water than lower. Turbidity reduction increases with increasing doses, similar to the findings reported by Sarah *et al.* (2008) and Asraffusman *et al.* (2011). The optimum dose used for this research was ranged from 0.01 mg/L to 0.07 mg/L and turbidity reduction efficiency ranges from 79 % to 99.9 % for *M. subcordata* Whereas, the efficiency of *M. stenopetala* ranges from 72 % to 98.55 %. Dosage is one of the most important parameters that have been considered to determine the optimum conditions for the coagulation and flocculation. Basically, insufficient dosage or overloading would result in the poor performance in flocculation (Alsameraiy, 2012). Therefore, it was crucial to determine the optimum dosage in order to minimize the dosing cost and obtain the optimum performance in treatment. Over optimal amount coagulant could cause the aggregated particles to re-stabilize in the suspension and would also disturb particle settling (Diyaakaran and Sivasanakra, 2002 and Alsameraiy, 2012). In this experiment, the optimum dose found for low turbidity (20 and 50 NTU) was 0.01 mg/L and 0.03 mg/L by which (79% and 91%) turbidity reduction was achieved by powder of *M. subcordata*. Similar turbidity reduction (72% and 86.5%) was also exhibited by *M. stenopetala*.

Diaz *et al.* (1999) found similar result by which extract of *Prosopis juliflora* reduced initial turbidity of 30 NTU to 5 NTU with optimum dose of 40 mg/L. In the same fashion for initial turbidity of 300 NTU and 400 NTU the optimum dose found for both *M. subcordata and M. stenopetala,* powder was 0.05gm/L with turbidity removal efficiency of 98.3%, 97.69% and 98.9%, 98.55% respectively. This result is nearly in agreement with Gide and Malusare *et al.* (2011) in which the protein extraction of *Moringa oleifera* powder reduced 96.33 % of 150 NTU and 98.51 % of 450 NTU with the dose of 40 mg/L and 100 mg/L. A slight difference of findings may be because of difference in *Moringa* seed extract species that seeds from different sources (geographic locations) exhibit varying coagulation performance (Nwaiwu *et al*. 2012). Another study regarding *Moringa oleifera* showed the effectiveness of *Moringa oleifera* for turbidity removals of up to 97% for high turbid water and lower removals of 86% for low turbidity water (58 NTU) (Abaliwano et *al.* 2008).

The optimum dose found for initial turbidity of 500 NTU and 1000 NTU was 0.07gm/L for both *M. subcordata and M. stenopetala* powder with turbidity removal efficiency of 98.11%, 98.01% and 99.41%, 99.01% respectively. This result is in line with the finding of Zhang *et al.* (2006) where the optimum dosage of *opuntia spp*. used for turbidity removal of seawater (980 NTU) was 60 mg/L with removal efficiency of 99%. So, these natural coagulants (*M. subcordata* and *M. stenopetala*) might be considered as excellent option of traditional chemicals like alum and very efficient coagulants for high turbidity ranges. Gebremichael *et al*. (2009) also recommended the use of *Moringa* plant as coagulant in developing countries. For natural surface water the optimum doses of the coagulants were ranged between 0.01 gm/L and 0.03 gm/L for corresponding initial turbidities of 22, 45, 46, 84 and 195 NTU respectively. The average percentage turbidity removal of *M. subcordata, and M. stenopetala* powder were 74.89%, 67.39% to 97.52%, 96.89% for initial turbidity of 22 NTU and 195 NTU at optimum dose of 0.01 gm/L and 0.03 gm/L respectively. The finding is in agreement with the studies done by (Arnoldsson *et al*. 2007) which, found for medium and high turbidity levels in raw water (30–100NTU), optimum doses between 20 and 30 mg/L and to more or less increase with increasing raw water turbidity. In addition to this coagulation with *Moringa oleifera* extracted with distilled water results high removal efficiencies when raw water initial turbidity was high but poor in efficiencies when the raw water had low values of initial turbidity.

Turbidity removal efficiency of *M. subcordata* and *M. stenopetala* on natural surface water with initial turbidity of 22 NTU using the optimum dose (0.01gm/L) was 89.52% and 87.21%. When this value was compared with synthetic water with initial turbidity of 20 NTU it was greater in efficiency. This is may be due to the natural water was no interference which inhabited the performance of the coagulant. The performance of *M. subcordata* and *M. stenopetala* in natural surface water with initial turbidity of 45 NTU was 93.28% and 90.53% respectively. The turbidity removal performance of *M. subcordata* and *M. stenopetala* for synthetic water with

initial turbidity of 50 NTU was 91.26% and 90% respectively. When the two values were compared they were almost similar in turbidity removal performance.

Turbidity removal efficiency in percent of *M. subcordata* powder on natural surface water with initial turbidity of 46 NTU and synthetic water with initial turbidity of 50 NTU were 89.52% and 91.26%, respectively. In the same fashion turbidity removal efficiency of *M. stenopetala* seed powder on natural surface water for initial turbidity of 46 NTU and synthetic water with initial turbidity 50 NTU was 87.21% and 90% respectively where as the turbidity removal efficiency of positive control (Alum) on natural surface water at 46 NTU and synthetic water at 50 NTU initial turbidity was 90.12% and 92.52% respectively. This result revealed that the turbidity removal efficiency of *M. subcordata* and *M. stenopetala* powder in synthetic turbid water was better performance than on natural surface water. This phenomenon probably is due to the fact that the surface water is likely to contain different substances like color, organic and inorganic compound, etc., which may inhibit the coagulation performance. The turbidity removal performance of *M. subcordata* and *M. stenopetala* for natural surface water with initial turbidity of 45 NTU and 46 NTU was different using the same dose of coagulant (0.03gm/L). This phenomenon is may be due to the nature of the natural surface water, i.e. in natural surface water with 46 NTU initial turbidity there may be coagulation interference that decrease the efficiency of the coagulants to coagulate than natural surface water with initial turbidity of 45 NTU. The turbidity removal performance of *M. subcordata* and *M. stenopetala* for natural surface water with initial turbidity of 84 NTU and 195 NTU was 94.05%, 89.41% and 97.52%, 96.89% respectively. When this result was compared with synthetic water with initial turbidity of 100 NTU and 200 NTU almost they have similar performance.

Initial turbidity affects significantly both *M. subcordata* and *M. stenopetala* powder dose respectively. Increase of initial turbidity in natural surface water and synthetic water causes increased demand of *M. subcordata* and *M. stenopetala* powder dose. Furthermore higher turbidity removal was observed as initial turbidity of water sample increases with the increment dose required. This result was in agreement with the findings reported by (Katayon *et al.* 2006) optimum dosage of *Moringa oleifera* seeds extract was increased from 80 mg/L to 400 mg/L for increase in initial turbidity of the surface water sample from 35.4 NTU to 390 NTU respectively. No significant changes were seen on the pH, conductivity and temperature for the water sample treated with *M. stenopetala* and *M. subcordata*.

SOME OF THE GRAPHS FROM EACH TURBIDITY RANGE

Low turbidity range (20 NTU and 50 NTU)

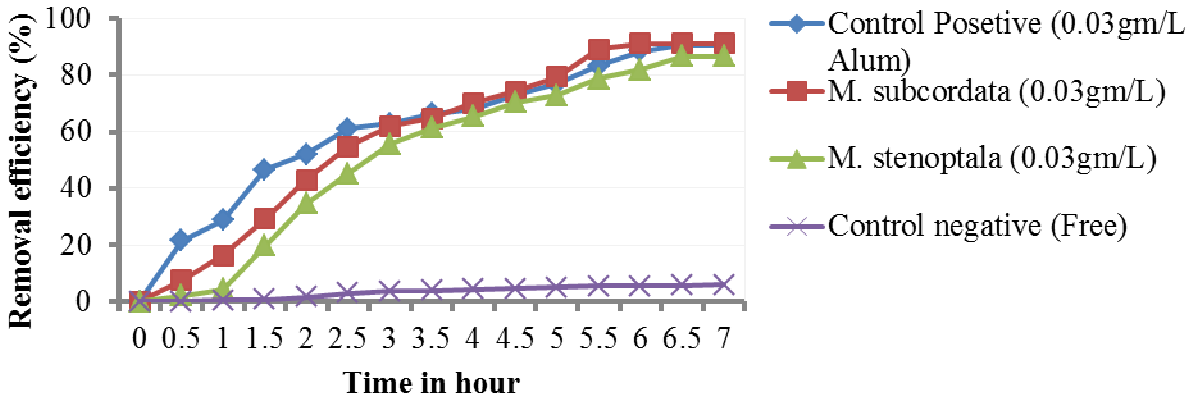

Figure 1. Removal efficiency of *M. subcordata* and *M. stenopetala* (0.03 gm/L) dose at initial turbidity of 50 NTU

Medium turbidity range (100 NTU and 200 NTU)

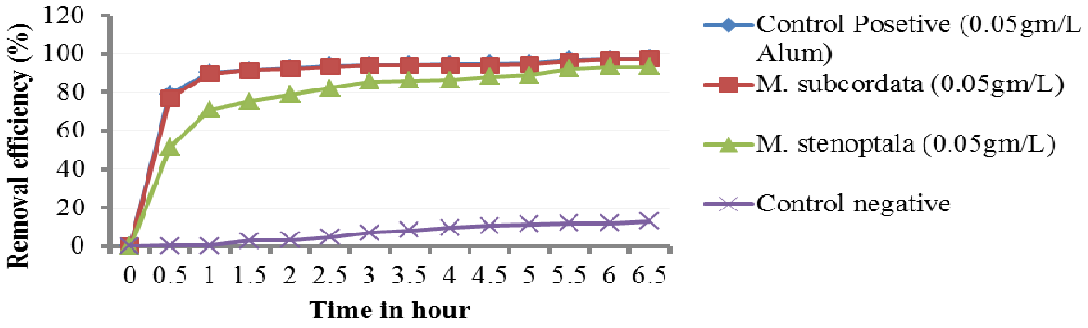

Figure 2. Removal efficiency of *M. subcordata* and *M. stenopetala* (0.03 gm/L) dose at initial turbidity of 200 NTU

High turbidity range (300 NTU and 400 NTU)

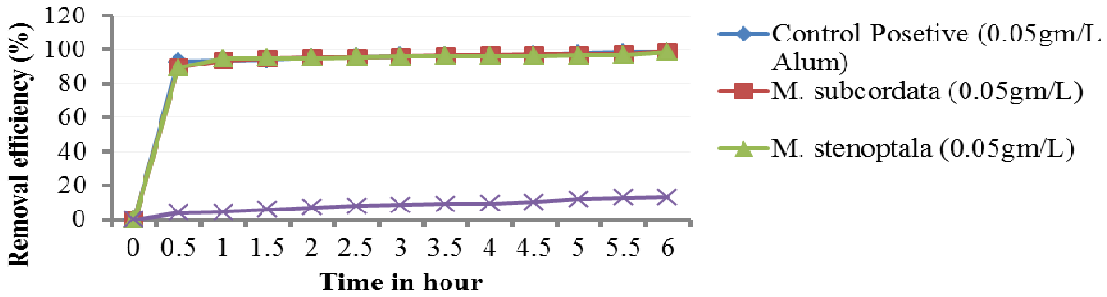

Figure 3. Removal efficiency of *M. subcordata* and *M. stenopetala* (0.03 gm/L) dose at initial turbidity of 400 NTU

Very high turbidity range (500 NTU and 100 NTU)

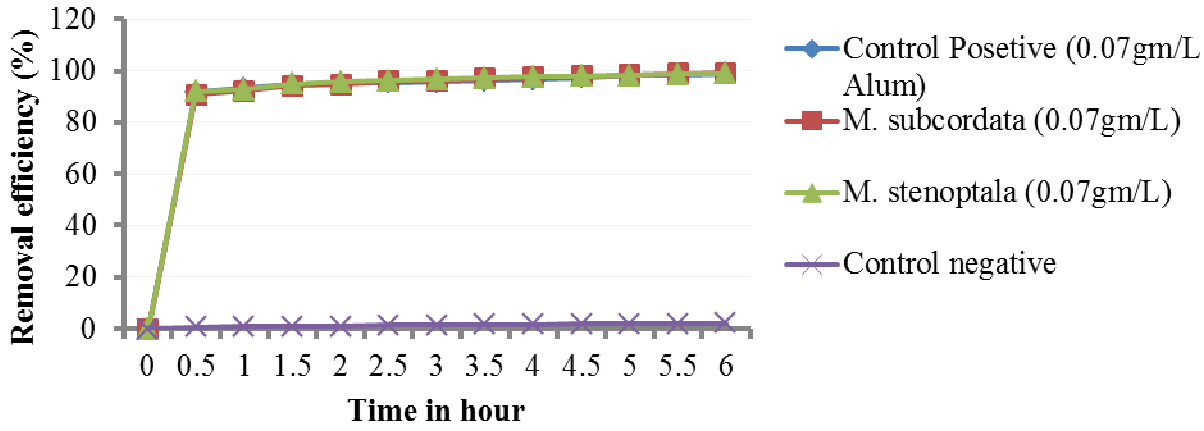

Figure 4. Removal efficiency of *M. subcordata* and *M. stenopetala* (0.03 gm/L) dose at initial turbidity of 500 NTU

The Relative Performance of Indigenous Plant Species as Disinfectant

With regards to microbial result the colony counts were drastically decreased with both *M. subcordata* and *M. stenopetala* powder treatments for both synthetic water and natural surface water (Table 1 and 2). As the results of average colony count of bacteria showed there was no significant difference between *M. subcordata* and *M. stenopetala* powder treatment with respect to all types of bacteria (Total coliform, feacal coliform, *E. coli* and heterotrophic bacteria) as chlorine treatment in both natural surface water and synthetic water. In percent about 99.9% of microbial load removal was observed for both natural surface water and synthetic water after treating the water using these two coagulants.The percentage microbial load reduction after treatment with *M. subcordata* and *M.stenopetala* for both synthetic and natural surface water was ranged from 97.6% to 99.9% for

the first 0.5 hour. This finding is in agreement with the finding of Bina *et al.* (2010) who found effect of *Moringa oleifera* crude protein extract on microbial to be 99.2% – 99.97% in the first 0.5 hour process. This might be due to the coagulation effect of *M. subcordata* and *M. stenopetala* powder thus microbes may settle with other particles. This was supported by findings of Atieno *et al.* (2011) that the process of coagulation by *M. oleifera* extract removes about 90-99% of bacteria which are normally attached to the solid particles.

Table 1 Removal of TC, FC and *E. coli* using *M. subcordata*, *M. stenopetala* powder and chlorine in colony counting form Synthetic water

Turbidity (NTU)	Microbial load before treatment in colony(initial)			pH of solution	Microbial reduction after treatment in colony															
					Negative control			pH of solution	*M. stenopetala* (shifera)			pH of solution	*M. subcordata* (gulf)			pH of solution	Positive control (Cl_2)			pH solution
	TC	FC	EC		TC	FC	EC		TC	FC	EC		TC	FC	EC		TC	FC	EC	
20	175	180	179	6.9	174	175	161	6.8	0	0	0	7.3	0	0	0	7.4	0	0	0	6.7
50	189	185	189	7.2	172	177	179	6.7	2	0	0	7.4	0	0	0	7.4	0	0	0	6.9
100	188	176	195	6.8	177	172	174	7.1	0	0	1	7.1	2	0	0	7.2	1	1	0	7.2
200	200	197	187	7.1	174	181	172	6.9	3	1	0	7.2	0	0	0	7.5	0	0	1	6.8
300	200	198	199	6.9	181	188	189	6.8	1	0	2	7.3	3	1	0	7.4	1	0	0	6.8
400	175	197	199	6.7	169	186	187	7.2	0	1	0	7.4	1	0	1	7.2	1	0	2	7.2
500	199	185	189	7.2	188	183	174	7.3	2	0	2	6.9	0	1	0	7.1	0	1	2	7.6
1000	200	180	180	7.3	197	179	178	6.9	4	1	1	7.2	3	0	1	7.3	4	1	1	6.9

pH of the medium is 6.99 for TC=total coliform, 7.04 for FC=fecal coliform, 7.2 for EC=*E. coli*, (checked before sterilization).

Table 2 Removal of heterotrophic bacteria using *M. subcordata*, *M. stenopetala* and chlorine from Synthetic water

Initial turbidity (NTU)	Dose of *M. subcordata*(gulf) used(gm/L)	Dose of *M. stenopetala* (shifera) used(gm/L)	Dose of positive control (Cl_2) used (gm/L)	Microbial loads before treatment incolony(initial)	pH of solution	Microbial reduction after treatment in colony							
						Negative control	pH of solution	*M. subcordata* (Gulf)	pH of solution	*M. stenopetala* shifera	pH of solution	Cl_2	pH of solution
20	0.01	0.01	0.01	155	6.9	148	6.8	0	7.4	0	7.3	0	6.7
50	0.03	0.03	0.03	169	7.2	165	6.7	0	7.4	0	7.4	0	6.9
100	0.03	0.05	0.03	172	6.8	169	7.1	0	7.2	0	7.1	0	7.2
200	0.03	0.05	0.05	178	7.1	173	6.9	1	7.5	1	7.2	2	6.8
300	0.05	0.05	0.05	183	6.9	180	6.8	0	7.4	0	7.3	0	6.8
400	0.05	0.05	0.05	187	6.7	183	7.2	1	7.2	2	7.4	1	7.2
500	0.07	0.07	0.07	188	7.2	185	7.3	2	7.1	1	6.9	2	7.6
1000	0.07	0.07	0.07	189	7.3	187	6.9	4	7.3	5	7.2	2	6.9

pH of the medium is 7.05 (checked before sterilization)

Optimum conditions of indigenous plant species for coagulation and disinfection

The optimum dose of the coagulant found for effective removal of turbidity and microbial in synthetic water was seen in the range of 0.01 gm/L to 0.07 gm/L and for the natural surface water the dose ranged from 0.01 gm/L to 0.03 gm/L. The pH and temperature of the water after treatment using the effective dose of the two coagulants was ranged 6.89 to 7.04, 25 0C to 27 0C respectively which shows almost neutral. The stirring time used for coagulation in this study was 170 rpm for 2 min and followed 40 rpm for 20 min and measurement of turbidity was done for every 30 min consecutively for 6 hr for each turbidity range both in synthetic and natural surface water. This stirring time was agreed with (Wang, 2002.) which says synthetic water samples (600 ml) were stirred at 125 rpm for 2 min and coagulants were added into the samples during this time. Then the samples were stirred at 70 rpm for 30 min. After the agitation, the samples would stand for 30 min and then the turbidity of the supernatant liquors was measured using a turbid meter (HACH 2100P).

CONCLUSION

In general, the experimental result indicated that *M. subcordata* and *M. stenopetala* plants were very effective in reduction of turbidity and microbial load. The pH, conductivity and temperature of the water did not significantly changed as compared to chemical based coagulants when both *M. subcordata* and *M. stenopetala* coagulant was added for both synthetic and natural surface water after treatment. In addition, the results suggested that with further optimization of both *M.subcordata* and *M. stenopetala* could be valuable for the replacement of chemical coagulant at household water treatment (e.g., Aqua tab). As initial turbidity increase the removal efficiency of both coagulants were increased. Particularly, *M. subcordata* was most effective than *M. stenopetala* and it was also even more efficient than Alum in certain turbidity levels. However, the mechanism of turbidity and bacterial removal was not studied and hence further studies are need to address this and other related issue (e.g., toxicological experiments) in using *M. subcordata* and *M. stenopetala* for water treatment. Since indigenous plant species has similar performance with synthetic chemical in removing turbidity and microbial, it can be concluded that *M. subcordata* and *M. stenopetala* has the potential to be utilized for household water treatment applications.

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