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ORIGINAL PAPER

A Preliminary Evaluation of Locally Used Plant Coagulants for Household Water Treatment

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Abstract Conventional chemical water treatment systems which involve a series of steps are not feasible in rural areas, where a dispersed population is found. Moreover, it is extremely costly for investment in developing countries. Hence, improving drinking water quality at a household level is believed to be effective in fighting waterborne diseases. For this purpose, we investigated the performance of indigenous plant species locally used for turbid water treatment in Ethiopia. Batch coagulation and microbial reduction experiments were carried out on surface river waters found in Ethiopia having initial turbidities of 20, 45, 46, 80, and 195 nephelometric turbidity unit (NTU) with the flocculent dosages of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 mg/l. Tubers of *Maerua subcordata* (Gilg.) DeWolf and seeds of *Moringa stenopetala* (Baker f.) Cufod. were used for this study, and they were able to achieve appreciable removal efficiency (up to 98 %) of turbidity at an optimum dose range of 20 to 80 mg/l in 6 h of settling time. About 99.9 % of microbial load removal were observed for both *M. subcordata* and *M. stenopetala*, which is comparable with chlorine disinfection. The experimental result revealed that these plant coagulants were able to meet World Health Organization (WHO) standards of drinking water quality (<5 NTU). This implies that with further optimization, *M. subcordata* and *M. stenopetala* can be used as an alternative to household-level water treatment in low-income countries.

Keywords Indigenous plants · Coagulation · Household water treatment · Microbial load · Turbidity

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Introduction

The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible, and affordable water for personal and domestic uses [1]. Nevertheless, unsafe drinking water is a great concern mainly in rural parts of developing countries due to the fact that 75 % of all diseases arise from consumption of untreated water. 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 waterborne diseases that cause loss of productivity [2]. Water quality is a major problem, as evidenced by frequent outbreaks of waterborne diseases in both rural and urban areas. It is also reported that millions of people are at risk of cholera in Ethiopia, where acute watery diarrhea has broken out in crowded and unsanitary conditions of urban and rural areas in 2009 [3].

Although piped water is an important long-term solution in providing safe water, it is very expensive and challenging to implement in rural areas of developing countries. Hence, improving quality of drinking water at a household level is believed to be effective in fighting infectious diarrhea [4, 5]. It is also reported that household-level water treatment can reduce diarrhea by 71 % [6].

Filtration (ceramic and biosand), chemical disinfection, and solar water disinfection (SODIS) appeared to be frequently used household water treatment techniques in developing countries including Ethiopia [7]. Chlorination appeared among the most promising in terms of effectiveness, affordability, and potential sustainability [8, 9] for microbial water treatment. There is no international standard for chlorine dosage in household water treatment, but 1.875 to 3.75 mg/l has been recommended for treatment of low- to high-turbidity water [10]. Until recently, the use of chlorine was believed to be safe and concerns about drinking water only focused on eliminating pathogens. However, the chlorine used to reduce the risk of infectious disease may account for a substantial portion of the cancer risk associated with drinking water by forming disinfection by-products (DBPs). More than 250 different types of DBPs have been identified [11]. Aluminum sulfate (Alum), a widely used chemical for coagulation and flocculation, is also reported to affect the nervous system and skeletal problems, with possible connections to several diseases, such as Parkinson's, Alzheimer's [12], and Lou Gehrig's [13, 14]. Alum also produces large sludge volume [15] and affects the natural alkalinity of water [16]. It is therefore advantageous to look for alternatives to this chemical coagulant with cost-effective, safe, efficient, sustainable, and environmental friendly natural coagulants to offset the aforementioned side effects.

Seed of *Moringa oleifera* Lam. is one of a widely studied natural coagulant and reported to be the most effective water treatment agent in treating low- to high-turbidity levels of surface water and groundwater [15–20]. Studies also indicated that *M. oleifera* can remove bacterial load in the range of 80–99 % [19, 21]. Apart from the extensively studied *M. oleifera*, various other plant materials were reported to have the capability of coagulation and disinfection [22–25]. For instance, [19] tested the coagulation and disinfection ability of *Jatropha curcas* and Guar gum on well water. The plants showed turbidity removal efficiency up to 71 % on different turbidity levels of well waters found in Malawi. There was also a remarkable reduction in the number of fecal coliforms treated by both plant species. [26] conducted a similar study on *J. curcas* but on surface water, and the plant coagulated about 60–90 % of suspended matters in the samples. In addition to the abovementioned plant-based coagulants, recent studies indicated coagulation potential of *Brassica napus* [27], *Cocos nucifera* [28], *Oryza sativa* [29], *Plantago ovata* [30], and *Vicia faba* [31].

The availability of those plant species may differ from country to country, and it is advantageous to search for new candidate of biocoagulants which are abundantly available in a specified country [32]. This will have enormous advantages in reducing costs that need to be allocated for transportation of plant-based coagulants if the plant is only found in a particular region [20]. Indigenous people in various parts of the world use plant-based coagulants to treat turbid water at household level. For instance, seeds of *Vigna unguiculata* and *Parkinsonia aculeata* are used by local people of Tanzania [33], whereas indigenous people of Venezuela use seeds of *Cactus latifaria* and *Prosopis juliflora* for turbid water treatment [34].

Similar to other countries, local communities in Ethiopia use natural coagulants to treat turbid water at a household level for their drinking and domestic purposes. *Maerua subcordata*, *Moringa stenopetala*, *Sansevieria ehrenbergii*, and *Sansevieria forskaoliana* were the four plant species used by local people in Ethiopia; out of which, tubers of *M. subcordata* (Gilg.) DeWolf and seeds of *M. stenopetala* (Baker f.) Cufod. appeared to be effective and efficient for purification of low- to high-turbidity surface water [35]. However, the determination of optimum doses for different turbidity levels was the main drawback of using these natural coagulants at household level. Therefore, the main objective of this research was to investigate the coagulation and disinfection potential of locally used indigenous plants (*M. subcordata* and *M. stenopetala*) on surface water as to determine optimum doses that help to develop affordable and potent water clarifier with minimal or no human health risks for people in need.

Materials and Methods

Collection and Preparation of Coagulants

All the experiments were carried out from February to June 2014 in the laboratory of Environmental Health Science and Technology Department, Jimma University, Ethiopia. The plants used locally for water purification (tuber of *M. subcordata* and seed of *M. stenopetala*) were collected from Konso, Jinka, Arbaminch, and Yaballo districts of southern Ethiopia. The plant materials were cleaned by soaking and washing with deionized water (DW) and dried in an oven at 105 °C for 1 h. The oven-dried plant materials were powdered using a mortar and pestle and homogenized by plant grinder with pore size of 212 μm. The solution was then prepared by dissolving 5 g of powder in 100 ml of distilled water. Alum was obtained from Jimma town water treatment plant. About 5 g of

Table 1 The physicochemical and biological characteristics of rivers

Parameters of natural water	Surface water sample site name				
	Kero	Ofole	Dolollo	Samiche	Gibe
Turbidity (NTU)	20	45	46	80	195
Electrical conductivity (μS/cm)	179	121	550	195	657
pH	7.29	7.36	7.81	7.86	7.95
Temperature (°C)	24.7	26.1	29.2	29.1	27.0
TC (colony count per 100 ml)	179	167	173	178	189
FC (colony count per 100 ml)	152	164	168	159	168
E. coli (colony count per 100 ml)	166	158	160	153	156
HTBC (colony count per 100 ml)	139	118	129	117	126

FC fecal coliform, *TC* total coliform, *HTBC* heterotrophic bacterial count, *NTU* nephelometric turbidity unit

powder was added to 100 ml of distilled water, and the solution was used for turbidity removal test.

Sampling of Water

Water samples were collected from Kero, Ofole, Dolollo, Samiche, and Gibe Rivers found in Jimma, Oromia, Ethiopia (Table 1). All samples were collected using clean and sterile polyethylene plastic bottles. The samples were stored in an ice box, transported to the laboratory, and kept in deep freezers until analysis.

Batch Coagulation Experiment

The batch coagulation experiments were conducted using jar test apparatus that accommodates a series of six beakers (1 l in size) together with six-spindle steel paddles. We used both positive (turbid water treated with alum) and negative (turbid water without coagulants) controls. The other four samples were treated with different doses of coagulants of *M. subcordata* and *M. stenopetala* with a dose range of 10 to 100 mg/l. The coagulants were added before stirring, and the solutions were agitated at a rate of 170 rpm for 3 min and slowly at 40 rpm for 20 min. After stopping the agitation, the suspensions were allowed to settle for 30 min and the effective dose with the maximum turbidity removal was recorded. The supernatant of the water samples was taken using a pipette from the middle of the beaker for analysis of physicochemical parameters (pH, conductivity, temperature, and turbidity) after treatment. The turbidity for each of the water samples was measured after treatment and a 30-min settling period using a turbidity meter consecutively for 6 h. Residual turbidity was measured using a turbidimeter (Oakton T-100), and the pH, conductivity, and temperature were measured using multi-parameter probe (HACH). All tests were performed in duplicate at room temperature in the range of 20 to 25 °C.

Microbial Culture Test

The samples were serially diluted up to 10^{-3} mg/l for natural surface water. Then, 0.1 ml of each diluent 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 following the standard protocols as described by [36]. Incubation was carried out at 37 °C for 24 h for total coliforms and at 44.5 °C for 24 h for fecal and *E. coli*, and the plates were read following standard microbiological procedures [37].

Results and Discussion

Performance of Plant Coagulants on Turbidity

The optimum dose found to purify Kero (Fig. 1a) river water by extracts of *M. subcordata* was 70 mg/l with a turbidity reduction of 75 %. Tuber extracts of *M. subcordata* reduced turbidity from 20 to 5 nephelometric turbidity unit (NTU), which was in the range of drinking water guideline set by [38]. However, it was impossible to achieve 5 NTU using seed extracts of *M. stenopetala*. The extracts of *M. stenopetala* reduced turbidity of Kero river by 62.5 %, at an optimum dosage of 20 mg/l.

Ofole river water (Fig. 1b) had an initial turbidity of 45 NTU, and both plant species reduced turbidity to 3 NTU with the optimum dosage of 30 mg/l. The residual turbidity was in the range of drinking water guideline set by [38]. However, dosage above 60 mg/l reduced turbidity removal efficiency of *M. stenopetala*, where residual turbidity exceeded the maximum permissible limit of drinking water.

Dolollo (Fig. 1c) had an initial turbidity of 46 NTU, and *M. subcordata* reduced its turbidity to 11 NTU with the optimum dosage of 60 mg/l, whereas *M. stenopetala* reduced the turbidity to 5 NTU with optimum dosage of 20 mg/l. *M. stenopetala* was superior to *M. subcordata* on Dolollo river

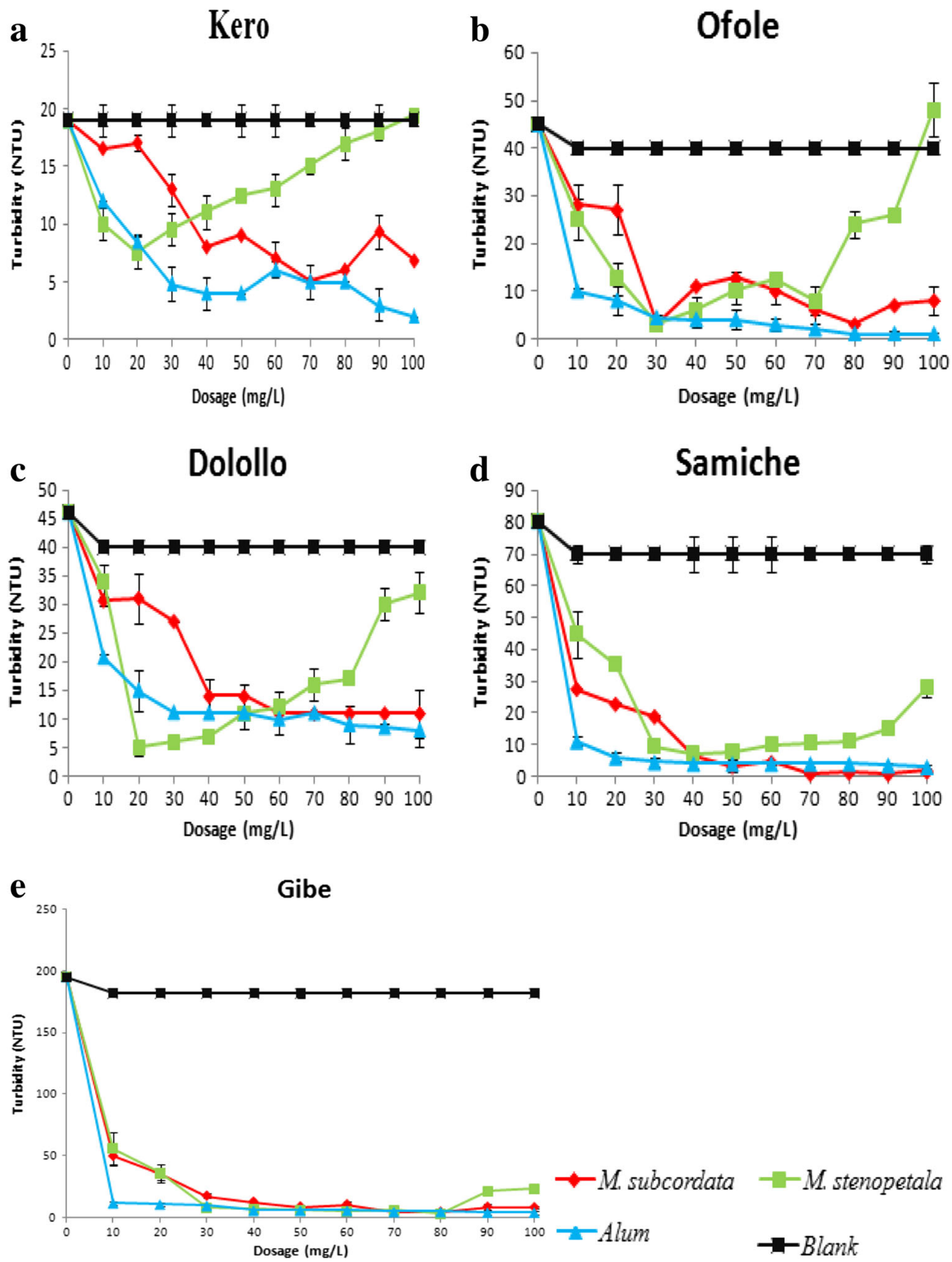

Fig. 1 Change in turbidity of river water with different doses of coagulants

water. The presence of color in this water sample might affect the efficiency of *M. subcordata.*

Samiche river water (Fig. 1d) had an initial turbidity of 80 NTU, and *M. subcordata* reduced its turbidity to 3 NTU with optimum dosage of 50 mg/l. The same water source treated with *M. stenopetala* with an optimum dose of 40 mg/l had residual turbidity of 7 NTU, which is above the World Health Organization (WHO) [38] guideline.

Gibe (Fig. 1e) river water showed the highest initial turbidity with 195 NTU, and *M. subcordata* reduced its turbidity to 5 NTU with the optimum dosage of 70 mg/l. *M. stenopetala* reduced turbidity to 3.5 NTU with an optimum dosage of 80 mg/l. The best percentage reduction results for both plant species were obtained with this Gibe river water, where residual turbidity fall within the WHO [38] drinking water guideline.

The coagulation and flocculation processes were significantly affected by the doses of coagulants, one of the most important parameters to consider for optimization. Basically, suboptimum dosage would result in a poor performance in flocculation and consequently lead to failure to meet the water quality targets [39]. Above optimal amount, coagulant leads to an increase of treatment cost and therefore is not economically viable [40]. Overdosing results in the saturation of the polymer bridge sites and cause re-stabilization of the destabilized particles and hence would also disturb particle settling [41]. This phenomenon happens if the mechanism of turbidity

Table 2 Removal of total coliform from surface water using *M. subcordata*, *M. stenopetala*, and chlorine as a positive control

River	Initial turbidity (NTU)	Initial microbial load (cfu/100 ml)	Microbial load after treatment (cfu/100 ml)					
			Positive control		*M. stenopetala*		*M. subcordata*	
			Average	SD	Average	SD	Average	SD
Kero	20	179	0	0	0	0	0	0
Ofole	45	167	0	0	0	0	0	0
Dolollo	46	173	1	1.4	0	0	0	0
Samiche	80	178	1	1.4	2	2.8	2	2.8
Gibe	195	189	2	1.4	4	2.8	3	2.8

removal is through adsorption and bridging. Overdosing may also lead to charge reversal and subsequent re-stabilization of destabilized particles if the mechanism of turbidity removal is linked with adsorption and charge neutralization. In the current study, we considered optimum dosage where residual turbidity was in the range of WHO guideline or the lowest residual turbidity even though the guideline could not be met. For instance, the lowest residual turbidity of Samiche river water treated with extracts of *M. subcordata* was 0.54 NTU with a dosage of 90 mg/l, but it was possible to achieve 3 NTU with a dosage of 50 mg/l. Thus, we considered 50 mg/l as an optimum dosage to treat Samiche river water using extracts of *M. subcordata*. Having this in mind, overdosing did not significantly affect the performance of *M. subcordata* unlike *M. stenopetala*, where increasing dosage above optimal further augmented residual turbidity. The presence of lipids may contribute to the poorer performance of *M. stenopetala* with increasing dosages in addition to the phenomenon of re-stabilization of destabilized particles.

The results also showed that initial turbidity and optimum dosage are not directly related. For instance, the optimum dosage used to treat Dolollo river water (46 NTU) with extracts of *M. subcordata*, *M. stenopetala*, and alum were 60, 20, and 30 mg/l, respectively. However, 70, 20, and 40 mg/l were optimum dosages used to treat Kero river water (20 NTU) using the same coagulants. This evidence is different from those reported by Katayon et al. [18], as they documented that the optimum dosage of *M. oleifera* increased with increasing initial turbidity. This difference might be due to unlike experimental setups, namely, the type of water used. The present study was performed with natural surface water, while the previous one was conducted on synthetic water made up of kaolin. Surface water characteristics, type and size of particles, alkalinity, and other process variables may vary from river to river, which clearly affects the performance of coagulants, unlike synthetic water samples.

The present result also indicated that both plant species and alum had better coagulation efficiency on higher turbidity than low turbidity. At higher turbidity, less sedimentation time was required to coagulate turbid river water (data not shown). For instance, turbidity of Kero river (20 NTU) was reduced to 17 NTU after 2 h of settling time using extracts of *M. subcordata*. However, at higher-turbidity range (195 NTU), the turbidity was reduced to 14.7 NTU after 2 h of sedimentation time. This phenomenon is due to the fact that turbidity increases with suspended particles, which can readily form interparticle bridges that enable them to settle down easily [42]. Other plant coagulants were also reported to allow better turbidity removal efficiency at high-turbidity ranges than of low-turbidity waters in both synthetic and natural raw water samples [19, 26, 34, 40, 43]. For instance, [40] reported the removal efficiency of *Cicer arietinum* on higher turbidity (120 NTU)

Table 3 Removal of fecal coliform and *E. coli* from surface water using *M. subcordata*, *M. stenopetala*, and chlorine as a positive control

Rivers	Initial microbial load (cfu/100 ml)		Microbial load after treatment (cfu/100 ml)					
			Positive control		*M. stenopetala*		*M. subcordata*	
	Fecal coliform	*E. coli*	Fecal coliform	*E. coli*	Fecal coliform	*E. coli*	Fecal coliform	*E. coli*
Kero	152	166	0	0	0	0	0	0
Ofole	164	158	0	0	0	0	0	0
Dolollo	168	160	2 ± 2	0	1 ± 1	2 ± 1	0	1 ± 1
Samiche	159	153	2 ± 1	1 ± 0	0	0	1 ± 1	0
Gibe	168	156	1 ± 1	2 ± 2	1 ± 1	0	0	0

Table 4 Removal of heterotrophic bacteria from surface water using *M. stenopetala*, *M. subcordata*, and chlorine as a positive control

River	Turbidity (NTU)	Initial microbial load (cfu/100 ml)	Microbial load after treatment (cfu/100 ml)					
			Positive control		*M. stenopetala*		*M. subcordata*	
			Average	SD	Average	SD	Average	SD
Kero	20	139	0	0	0	0	0	0
Ofole	45	118	2	2.8	3	1.4	1	1.4
Dolollo	46	129	2	2.8	4	2.8	2	1.4
Samiche	80	117	3	1.4	4	2.8	3	2.8
Gibe	195	126	3	1.4	4	2.8	3	2.8

and lower turbidity (35 NTU) to be 94.1 and 60 %, respectively, with an effective dose of 100 mg/l. A study conducted by [19] on shallow well water, as found in Malawi, indicated that *M. oleifera* had a removal efficiency of 95 % at 24 NTU with the optimum dose of 250 mg/l. [40] reported 100 mg/l as an optimum dosage for *Dolichos lablab* at 100 NTU, where 89 % of turbidity removal efficiency were achieved.

Alum showed the highest coagulation activity within a short period of sedimentation time for all tested river water samples (data not shown); however, with increasing sedimentation time, extracts from both plant species became as effective as the alum counterpart. Plant coagulants were even slightly more efficient (93.5 %) than alum (90 %) on Ofole river water samples (46 NTU). Such result is possible and in agreement with previous work using extracts of *C. arietinum*, where natural coagulant also outperformed alum [34]. Alum equally reduced turbidity of all, except Dolollo, river water samples to below 5 NTU, which is the maximum permissible limit of WHO standard for drinking water.

Performance of Indigenous Plant Species as Disinfectant

Both *M. subcordata* and *M. stenopetala* exhibited excellent performance on the reduction of microbial load (total coliform, fecal coliform, *E. coli*, and heterotrophic bacteria) as shown in Tables 2, 3, and 4. About 99.9 % of microbial load removal

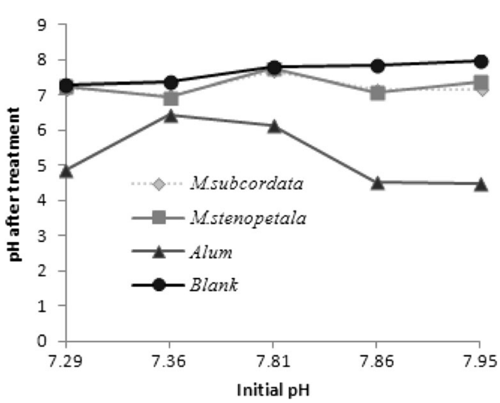

Fig. 2 Change in pH of river water samples treated with optimum doses of coagulants

were observed for both *M. subcordata* and *M. stenopetala*, which is comparable to chlorine disinfection. A higher percentage of microbial elimination could be observed for lower-turbidity (99.9 %) than higher-turbidity levels (96 %). This higher percentage of microbial load removal from low-turbidity water than high-turbidity water could be due to the increment of suspended particles in high-turbidity water which protect microbes from the action of extracts.

A similar study conducted by [40] showed efficient reduction (89–96 %) of total coliform from turbid water. [30] also reported a complete removal of coliforms from turbid water using seed extracts of *P. ovata*. As previously elucidated for other plant coagulants, the antimicrobial effect may be attributed to both flocculation [44] and bactericidal action [45]. The presence of alkaloids and tannins in plant species could contribute to antimicrobial activities [46]. Bacterial re-growth was raised as a big concern of natural coagulants and can be improved by purification of the active agent; thus, purification further eliminates additional nutrient and organic content [47]. Nevertheless, residual disinfection would be crucial to attain a level of zero colony-forming unit in treated water to meet the quality of the drinking water standards [19].

Effect of the Coagulants on pH

The coagulation of *M. stenopetala* and *M. subcordata* revealed no significant changes on the pH of river water samples (Fig. 2). However, the same river water treated with alum decreased from 7.29 to 4.51, which makes such treated water strongly acidic. When dissolved in water, the aluminum ions are hydrolyzed and it lowers the pH by increasing the concentration of H^+. Most likely, the naturally occurring coagulants from plant materials possess a buffering property. The study conducted by [15] and [48] indicated that water treated with *M. oleifera* and *V. unguiculata* did not alter pH of water, whereas pH of a water sample augmented with increasing doses of *M. oleifera* and *J. curcas* [43]. Thus, using plant extracts for water treatment may have an enormous advantage by omitting the need for application of lime or bicarbonate to subsequently raise the pH, and hence, it provides extra cost savings [19, 24, 48].

Conclusions

The batch experimental results indicated that extracts from *M. subcordata* tubers and *M. stenopetala* seeds were very effective in reduction of turbidity and microbial load. At optimum dose, large reductions of turbidity were achieved, but above the optimum dose, there was a reduced turbidity removal efficiency of *M. stenopetala*. The results revealed that different optimum dosages were needed to treat river water samples. For instance, 70 mg/l was an optimum dosage for *M. subcordata* tubers to treat Kero river water with initial turbidity of 20 NTU, whereas 20 mg/l was an optimum dosage to treat the same river water using seed extracts of *M. stenopetala*. The optimum dosage to treat the most turbid Gibe river water (195 NTU) was 70 and 80 mg/l using extracts of *M. subcordata* and *M. stenopetala*, respectively. The results revealed that turbidity removal efficiency of both plant species also varied from river to river under study. As a result, *M. subcordata* was more effective than *M. stenopetala* on Kero and Samiche river water, whereas *M. stenopetala* was more effective than *M. subcordata* on Dolollo and Gibe river waters. In general, extracts of both plant species showed comparable turbidity removal performance (up to 98 %) on high-turbidity waters. About 99.9 % of microbial load removal was also observed for both *M. subcordata* and *M. stenopetala*, which is comparable to chlorine disinfection. However, microbial removal efficiencies of plant extracts were insufficient to fall within guideline values. Extracts from both plant species did not affect pH of water samples unlike alum. Generally, both the microbial and turbidity reduction findings revealed that both plant species can meet the requirements of drinking water quality in terms of microbial standards and maximum permissible limit of turbidity (≤5 NTU) if they are used for household water treatment with further optimization.

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