Comparative studies of Alum, Maerua subcordata root tuber powder and juice extract as Coagulation/Flocculation Agents

Article *in* International Journal of Biological and Chemical Sciences · April 2016

4 authors, including:

Erastus Gatebe
Jomo Kenyatta University of Agriculture and Technology
41 PUBLICATIONS 695 CITATIONS

Godfrey Omare Mauti
Kampala International University (KIU)
23 PUBLICATIONS 189 CITATIONS

Eliakim Mbaka
Kenyatta University
18 PUBLICATIONS 132 CITATIONS

INTERNATIONAL JOURNAL OF PHARMACEUTICAL, CHEMICAL AND BIOLOGICAL SCIENCES

Available online at www.ijpcbs.com

Research Article

COMPARATIVE STUDIES OF ALUM, *MAERUA SUBCORDATA* ROOT TUBER POWDER AND JUICE EXTRACT AS COAGULATION/FLOCCULATION AGENTS

Keno David Kowanga[1]*, Erastus Gatebe [2],

Godfrey Omare Mauti[3] and Eliakim Mbaka Mauti[4]

[1]Unit of Science, Jordan University College, Morogoro, Tanzania.
[2]Chief Research Scientist, Kenya Industrial Research and Development Institute, Nairobi, Kenya.
[3]Health Sciences Department, Kampala International University College, Dar es Salaam.
[4]School of Pure and Applied sciences, Biochemistry and Biotechnology Department,
Kenyatta University, Nairobi, Kenya.

ABSTRACT

Turbidity is a great problem in water treatment. Comparative study was done on alum a commercial coagulant; *Maerua subcordata* root powder and juice extract a locally available natural coagulant to reduce turbidity and other water parameters. The tests were carried out using turbid river water with conventional jar test apparatus. After dosing, *Maerua subcordata* root powder and juice extract reduced turbidity 3.73±0.09 NTU, 0.02±0.03 NTU and 0.12±0.02 NTU for alum, from 86.77±0.52 NTU. Total coliforms and feacal coliforms were reduced to 15 MPN and 4 MPN by alum, to 14 MPN and 7 MPN by *Maerua subcordata* root powder and to 15 MPN and 4 MPN by juice extract. The study observed that both *Maerua subcordata* root powder juice extract showed a good alternative coagulant reducing water parameters to values below maximum permissible limits by WHO. Using *Maerua subcordata*, suitable, easier and environment friendly options for water treatment was observed.

Keywords: Natural coagulant, *Maerua subcordata*, Turbidity, nephelometric turbidity unit (NTU).

INTRODUCTION

Water is vital element in the natural resources and in many developing countries, access to clean and safe water is a privilege for the rich[1]. According to Ghebremichael, 2004, more than six million people die annually due to water-borne diseases caused by polluted water. It has as well been observed that in developing countries to import chemicals for water treatment is very expensive[2,3]. Water from any source must be purified before consumption. There are numerous methods for purification of raw water and the method applied normally depends on the character of the raw water. The major drawback for treatment of surface water is the large seasonal variation in turbidity[4]. Commonly used chemicals for treatment of water are synthetic organic and inorganic substances. In most of the cases, they are expensive as they are required in high doses this led to lack of cost effectiveness and these chemicals are also associated with human health and environmental problems[1,5]. Hence, the need to develop cost-effective, easier, and environmental friendly process of water clarification. Natural coagulants have been used for water purification since time in memorial; natural organic polymers have been in use for more than 2000 years in Africa, India and China[6]. These natural organic polymers are interesting because, comparative to synthetic organic polymers which containe acrylamide monomers, there is no human health danger and the cost of these natural coagulants are expensive than the conventional chemicals since they are locally available in most rural communities. Various coagulants from plant origin have been identified namely:- Nirmali, Okra, red bean, sugar and red maize[7], *Moringa oleifera*[8,10], *Cactus latifera*, and seed powder of *Prosopis juliflora*[9]. Natural coagulants have bright future hence the concerned by many researchers. The aims of the present study was to reduce the level of turbidity physical, chemical and bacteriological parameters using *Maerua subcordata* root tuber powder and *Maerua subcordata* juice extract.

2.0 MATERIALS AND METHODS

2.1 Sampling

Maerua subcordata root tubers were collected from Marigat District, Baringo County, Kenya. Turbid raw water samples were sampled from Ndarugo river as described by[10]. The samples were then transported to Civil Engineering Department, Environmental laboratory at J.K.U.A.T. for coagulation/flocculation process using jar test apparatus.

2.2 Preparation of Maerua subcordata

Juice extract juice was extracted from peeled and chopped tubers. Extraction was accomplished by the use of a ram press and brownish juice obtained was filtered off to remove suspended particles. The remaining tubers were peeled, cut into small pieces, dried in sunlight and ground using a 3 phase plant mill located at the mechanical Engineering workshop in J.K.U.A.T. The powder was then sieved with a sieve with an aperture of 0.5mm.

Fig. 1: *Maerua subcordata* juice extract and ground root powder (Picture, by Author)

2.3 Evaluation of Optimum Dosages of the Coagulants

The jar test was done on raw water of initial turbidity 86.77±0.52 NTU as described by[10] with different dosages of aluminum sulphate (alum), *Maerua subcordata* root powder and juice extract.

2.4 Analysis of Physical Parameters

Measurement of turbidity, pH, total dissolved solid (TDS) and conductivity as done as described in[10].

2.5 Analysis of Chemical Parameters

Determination of sulphates, chloride, phosphates and nitrates were done as per spectroscopic procedure by[11] while determinations of metals was done as described by[10].

2.6 Bacteriological Analysis

Bacteriological tests were done at Food Microbiology Laboratory in J.K.U.A.T. using Multiple Tube Technique arranged in three parts namely: - presumptive, confirmed and completed tests as described by[10].

3.0 RESULTS AND DISCUSSIONS

3.1 Alum: After coagulation and flocculation, the effective dosage was established at 50 mg/L which gave residual turbidity of 3.73±0.09 NTU representing 95.70% reduction in initial turbidity. Above the optimum dosage, the colloidal particles in water showed a tendency to restabilize, table 1.

Table 1: Jar Tests on Alum Coagulant.
(Optimum Dosage 50 mg/L, Beaker 4: Jar Test Conditions: Coagulation time; rapid mixing speed, 160 rpm, 60 s; slow mixing speed, 25 rpm, 20 min.; flocculation process, 1 hr)

Beaker	Initial Turbidity (NTU) (mean±S.D)	Dosage Alum (mg/L)	Final Turbidity (NTU) (mean±S.D)	% Removal of Turbidity
1	86.77±0.52	20	16.27±0.38	81.25
2	86.77±0.52	30	11.40±0.41	86.86
3	86.77±0.52	40	8.47±0.33	90.24
4	**86.77±0.52**	**50**	**3.73±0.09**	**95.70**
5	86.77±0.52	60	6.43±0.37	92.59
6	86.77±0.52	70	12.54±0.54	85.55

Alum resulted in producing treated water with turbidity less than 5 NTU and the flocs produced were white, large, rigid and settled well in less than 10 minutes; the supernatant was clear after 20 minutes settling. This finding is in agreement with[12]. World Health Organization recommend that treated water should have turbidity of less than 5 NTU before the water can be effectively disinfected with chlorine[13].

3.2 Maerua subcordata

Root powder and juice extract showed optimum dosages 100 mg/L and 0.94 mL/L with residual turbidity of 0.02±0.05 NTU and 0.12±0.31 NTU representing 99.97% and 99.88% reduction in initial turbidity, table 2. The residual turbidities obtained were well below WHO guidelines[13].

Table 2: Jar Tests on *Maerua subcordata* root tuber
(Optimum Dosage for *Maerua subcordata* Powder, 100 mg/L, Beaker 3; Optimum Dosage for *Maerua subcordata* juice extract, 0.94 mL/L, Beaker 2)

Beaker	Initial Turbidity (NTU) (mean±S.D)	Dosage M.s.P (mg/L)	Final Turbidity (NTU) (mean±S.D)	% Removal of Turbidity	Dosage M.s.J (mL/L)	Final Turbidity (NTU) (mean±S.D)	% Removal of Turbidity
1	86.77±0.52	88	5.74±0.06	93.381	0.63	1.39±0.15	98.398
2	86.77±0.52	94	0.30±0.13	99.654	**0.94**	**0.12±0.02**	**99.866**
3	**86.77±0.52**	**100**	**0.02±0.03**	**99.973**	1.25	0.46±0.07	99.474
4	86.77±0.52	106	0.48±0.34	99.443	1.56	0.88±0.01	98.990
5	86.77±0.52	113	2.64±0.41	96.954	1.88	1.43±0.19	98.352
6	86.77±0.52	119	4.27±0.07	95.083	2.19	2.46±1.01	97.165

M.s.P = *Maerua subcordata* Powder, M.s.J = *Maerua subcordata* Juice extract: Standard deviations were calculated from 3 replicate jar tests.

It was observed that small amount juice extract was needed for effective coagulation process as compared to root powder, table 2. According Mavura *et al* 2008, *Maerua subcordata* has polysaccharides – amylopectin- in the roots. Juice extract had high concentration of amylopectin, these macromolecules formed bridges between colloidal particles, increasing their mass as a consequence, causing flocculation which dissolved in turbid water causing coagulation process to occur faster[14]. The overdosing of *Maerua subcordata* resulted in more presence of amylopectin molecules in flocculants repelling and causing restabilization of the stabilized flocs.

3.3 Synergy of Maerua subcordata root powder and juice extract with Alum

The best ratio for optimum dosage of alum and *Maerua subcordata* root powder was15 mg/L to 30 mg/L for alum to *Maerua subcordata* root powder which gave residual turbidity of 0.32±0.14 and reduced dosage of alum by 70%. Juice extract was 0.5 mg/L to 1 mL/L, resulting in residual turbidity of 0.30±0.48 and reducing dosage of alum by 99%, table 3.

Table 3: Effect of Natural Coagulants Aids on Alum
(Jar Test Conditions: Coagulation time; rapid mixing speed, 160 rpm, 60 s; slow mixing speed, 25 rpm, 20 min.; flocculation process, 1 hr)

Coagulants	Optimum Ratio and Dosage (mg/L) Alum : N.C	Residual Turbidity (NTU)	% Reduction in Turbidity	% Reduction in mass of Alum
Alum : M.s.P	1 : 1 10 : 10	0.90±0.28	98.97	80
	1 : 2 15:30	**0.32±0.14**	**99.63**	**70**
	2 : 1 20 : 10	1.63±0.04	98.12	60
Alum : M.s.J	1 : 1 1 : 1 (mL/L)	0.92±0.04	98.94	98
	1 : 2 0.5 : 1 (mL/L)	**0.30±0.48**	**99.65**	**99**
	2 : 1 1 : 0.5 (mL/L)	1.33±0.16	98.47	98

M.s.P = *Maerua subcordata* Powder, M.s.J = *Maerua subcordata* Juice, N.C = Natural coagulant, Standard deviations were calculated from 3 replicate jar tests, optimum dosage of alum was 50 mg/L, initial turbidity was 86.86±0.28 NTU

The use *Maerua subcordata* root and juice extract as coagulant aid in flocculation process decreased alum dosage significantly up to 99% in some instances and the residual turbidity dropped to as low as 0.30±0.48 NTU without filtration. There was an improvement in the floc size when *Maerua subcordata* root poweder and juice extract were used in conjunction with alum as compared to *Maerua subcordata* root powder, juice extract and alum alone, an observation also reported by[15].

3.4 *Analysis of Physical and Chemical Parameters*: The best turbidity, pH, conductivity, TDS and total hardness removal were obtained for water samples treated with Alum, *Maerua subcordata* root powder and juice extract reducing these physical parameters to values within the W.H.O and N.E.M.A guidelines, table 4.

Table 4: Chemical and Physical Parameters of Raw and Clarified water

Coagulants		**Raw water**	**Alum at**	**M.s.P at**	**M.s.J at**
Optimum dosage		**-**	**50 mg/L**	**100 mg/L**	**0.94 mL/L**
Parameters	**Units**				
Turbidity	NTU	86.77±0.52	3.73±0.09 (95.70%)	0.02±0.03 (99.97%)	0.12±0.02 (99.87%)
pH	-log[H⁺]	7.1±0.2 -	6.8±0.1 (4.22%)	6.5±0.2 (8.45%)	6.7±0.2 (5.63%)
Alkalinity	mg/L (as $CaCO_3$)	245.94 ±0.31 -	176.45±0.97 (28.25%)	158.63±23 (35.50%)	163.95±05 (33.33%)
Conductivity	µS/cm	0.083 ±0.005	0.083±0.005 (0%)	0.073±0.005 (12.05%)	0.073±0.005 (12.05%)
TDS	mg/L	58.00±0.00	59.00±0.82	58.00±00	59.00±0.82
Ca^{+2}	mg/L (as $CaCO_3$)	248.63 ±0.51 -	111.45±0.59 (55.18%)	95.47±0.004 (53.46%)	105.38±0.52 (57.44%)
Mg^{+2}	mg/L (as $CaCO_3$)	235.37 ±1.64 -	212.07±0.94 (10.07%)	207.13±0.81 (12.05%)	216.70±2.13 (8.06%)
Total Hardness	mg/L (as $CaCO_3$)	484.00 -	323.52 (33.22%)	302.60 (37.44%)	322.08 (33.41%)
Nitrates ($NO_3^{2-}N$)	mg/L	12.68±0.77 -	5.46±0.33 (56.94%)	4.23±0.37 (66.64%)	2.22±0.12 (82.49%)
Sulphates (SO_4^{2-})	mg/L	1.899 ±0.023 -	1.232±0.031 (35.13%)	1.024±0.092 (46.08%)	1.016±0.037 (46.50%)
Phosphates (PO_4^{2-})	mg/L	20.01±0.25 -	13.24±0.05 (33.79%)	11.54±0.83 (42.30%)	10.27±0.41 (48.65%)
Chloride (Cl^-)	mg/L	98.71±0.57 -	61.38±0.12 (37.82%)	52.75±1.37 (46.56%)	49.44±0.62 (49.91%)
Chromium (Cr^{+2})	mg/L	0.400 ±0.016 -	0.075±0.043 (81.25%)	0.099±0.044 (75.25%)	0.112±0.073 (72.00%)
Cadmium) (Cd^{+2})	mg/L	0.025 ±0.058 -	0.008±0.000 (66.67%)	ND	ND

Lead (Pb^{+2})	mg/L	0.70±0.31 -	0.28±0.25 (60.00%)	0.18±0.00 (74.29%)	0.27±0.11 (61.435)
Nickel (Ni^{+2})	mg/L	0.367 ±0.121 -	0.167±0.027 (54.58%)	0.083±0.094 (77.38%)	0.143±0.061 (61.04%)
Copper (Cu^{+2})	mg/L	0.089 ±0.010 -	0.021±0.006 (76.36%)	0.013±0.000 (85.39%)	0.021±0.026 (76.35%)
Zinc (Zn^{+2})	mg/L	0.088 ±0.049 -	0.054±0.002 (36.64%)	0.027±0.033 (69.32%)	0.041±0.041 (54.41%)
Manganese (Mn^{+2})	mg/L	2.55±0.06 -	1.05±0.13 (56.82%)	0.76±0.37 (70.20%)	1.09±0.44 (57.25%)
Mercury (Hg^{+2})	mg/L	0.023 ±0.007 -	0.017±0.002 (26.09%)	0.005±0.001 (78.26%)	0.010±0.009 (34.78%)
Iron (Fe^{+2})	mg/L	1.133 ±0.011 -	0.467±0.013 (58.81%)	0.543±0.033 (52.07%)	0.681±0.034 (39.89%)

Standard deviations were calculated from 3 replicate measurements using three solutions, M.s.P = *Maerua subcordata* root tuber powder, M.s.J = *Maerua subcordata* juice extract, ND= Not Detected, (x %) = % Removal, detection limits: 0.0013 mg/L NO_4^{-2}, 0.003 mg/L PO_4^{-2}, 0.0043 mg/L SO_4^{-2}, 0.0075 mg/L Cr^{+2}, 0.0001 mg/L Cd^{+2}, 0.006 mg/L Pb^{+2}, 0.1 mg/L Ni^{+2}, 0.0158 mg/L Cu^{+2}, 0.0066 mg/L Zn^{+2}, 0.0063 mg/L Cl^{-}, 0.003 mg/L Hg^{+2}, 0.0248 mg/L Fe^{+2}, 0.15 mg/L Mn^{+2}

The removal of these parameters may have occurred during coagulation and flocculation process, as colloidal particles in water were destabilized by the coagulants to form flocs some of these ions are trapped in the flocs hence are deposited as sludge in the beakers, reducing their concentration in supernatant solution[16].

Chemical Parameters; Anions

Nitrates removal by the coagulants ranged from 56.94% for alum to 82.49% for *Maerua subcordata* juice extract. Phosphates removal ranged from 33.79% for alum to 48.65% to *Maerua subcordata* juice extract. Sulphates removal varied from 35.13% for alum to 46.50% for *Maerua subcordata* juice extract and chloride removal varied from 37.82% for alum to 49.91% for *Maerua subcordata* juice extract, table 4. The removal of these parameters may be attributed to adsorption and charge neutralization mechanism during coagulation and flocculation process[17].

Cations (Heavy metals)

The highest heavy metals removal were as follows:- 81.25% for Cr (II) by alum, 96.00% for Cd (II) by *Maerua subcordata* juice extract, 74.29% for Pb (II) by *Maerua subcordata* root powder, 77.38% for Ni (II) by *Maerua subcordata* root powder, 85.39% for Cu (II) by *Maerua subcordata* root powder, 69.32% Zn (II) by *Maerua subcordata* root powder, 70.20% for Mn (II) by *Maerua subcordata* root powder, 78.26% for Hg (II) by *Maerua subcordata* root powder and 52.07% for Fe (II) *Maerua subcordata* root powder, table 4. The coagulants reduced these cations to values within the W.H.O and N.E.M.A guidelines. The removal of these cations occurred through coagulation and biosorption processes. The cations were either trapped in the colloidal particles and as flocs were formed; they were deposited as sludge at the bottom of the beaker reducing their concentrations in supernatant solution (coagulation process). Natural coagulants could have removed these cations by biosorption process through surface complexation, chemical precipitation, physical adsorption and ion exchange; this is explained in our other publications on biosorption studies[18].

3.5 Bacteriological Parameters

The results from presumptive test showed that total coliforms from raw water turbid was 230 MPN, this was reduced to 15 MPN, 14 MPN and 15 MPN representing 93.48%, 93.91% and 93.48% reduction by alum, *Maerua subcordata* root powder and juice extract respectively, table 5.

Table 5: Presumptive Test: Total Coliforms

Water Samples at Optimum Dosage	Test Tubes with Positive Reaction per Dilution				MPN /100 mL	% Removal
	10^0	10^1	10^2	10^3		
Raw Water Sample	3	3	0	0	230	-
Water purified with Alum (50 mg/L)	2	1	0	0	15	93.48
Water purified with M.s.P (100 mg/L)	2	0	1	0	14	93.91
Water purified with M.s.J (0.94 mL/L)	2	1	0	1	15	93.48

M.s.P = *Maerua subcordata* Powder, M.s.J = *Maerua subcordata* juice extract

The results for the confirmed test showed that feacal coliforms from raw water turbid were 28 MPN; they were reduced to 4 MPN, 7 MPN and 4 MPN this represented 85.71%, 75.00% and 85.71% reduction for alum, *Maerua subcordata* root powder and juice extract respectively, table 6.

Table 6: Confirmed Test: Feacal Coliforms

Water Samples at Optimum Dosage	Test Tubes with Positive Reaction per Dilution				MPN /100 mL	% Removal
	10^0	10^1	10^2	10^3		
Raw Water Sample	2	2	1	0	28	-
Water purified with Alum (50 mg/L)	1	0	0	0	4	85.71
Water purified with M.s.P (100 mg/L)	1	1	0	0	7	75.00
Water purified with M.s.J (0.94 mL/L)	1	0	0	0	4	85.71

* M.s.P = *Maerua subcordata* Powder, M.s.J = *Maerua subcordata* juice extract

Completed test, tested negative for all samples indicating that there was no *E. coli* in both turbid and purified water samples, table 7.

Table 7: Completed Test: *E. coli* Test

Water Samples at Optimum Dosage	*E. coli* Test
Raw Water Sample	Negative
Water purified with Alum (50 mg/L)	Negative
Water purified with M.s.P (100 mg/L)	Negative
Water purified with M.s.J (0.94 mL/L)	Negative

M.s.P = *Maerua subcordata* Powder,
M.s.J = *Maerua subcordata* juice extract

The removal of coliforms occurred during coagulation and flocculation process. *Maerua subcordata* antimicrobial effects as well attributed to their bactericidal activities. Roussy *et. al.,* 2005, reported a bridging mechanism for bacterial coagulation by natural coagulants; the coagulants get stack on the microbial cell surface, thereby forming an impervious layer around the cell that blocks the channels which are crucial for living cells[19].

CONCLUSION

The study showed that *Maerua subcordata* root powder and juice extract were better than alum as a coagulant. The optimum dosages of *Maerua subcordata* juice extract occurred at 0.94 mL/L reducing turbidity to 0.12±0.02 NTU, *Maerua subcordata* root powder was at 100 mg/L reducing turbidity to 0.02±0.03. *Maerua subcordata* showed that it was good coagulants aid. The best turbidity removal occurred when alum and *Maerua subcordata* juice extract were used in conjunction in the ratio of 1:2 it resulted in residual turbidity of 0.03±0.48 NTU reducing amount of alum by 99%. The results also showed that the natural coagulants were effective against total, feacal coliforms and *E. coli*.

ACKNOWLEDGEMENT

We acknowledge National Council of Science and Technology for providing funds to carry out this study. This manuscript was extracted from the author's M.Sc. Thesis "Clarification of Turbid River Water and Biosorption of Cu(II) and Pb(II) using Natural Coagulants: *Maerua subcordata, Prosopis juliflora* and *Moringa oliefera"*

REFERENCES

1. Miller R, Kopfter F, Kelty K and Strober L. The Occurrence of Aluminum in Drinking Water. Journal of American Water Works Asiation. 2004;76:84-91.
2. Ghebremichael KA. Moringa seed and pumice as natural alternative materials for drinking water treatment, Ph.D. thesis, KTH Land and Water Resources Engineering. 2004.
3. Gomes DJ. Waterborne illness: a real disaster in Bangladesh, in Proceedings of the Japan-Bangladesh Joint International Conference on Microbiology Education & the Prospect of Japanese Collaboration in Education and Research, December. 2005.

4. McConnachie GL, Folkard GK, Mtawali MA and Sutherland JP. Field trials of appropriate hydraulic flocculation processes, WaterResearch. 1999; 33(6):1425–1434.
5. Kaggwa RC, Mulalelo CI, Denny P and Okurut TO. The impact of alum discharges on a natural tropical wetland in Uganda, Water Research. 2001;35(3):795–807.
6. Kawamura S. Effectiveness of natural polyelectrolytes in water treatment, Journal of the American Water Works Association. 1991;83(10):88–91.
7. Gunaratna KR, Garcia B, Andersson S and Dalhammar G. Screening and evaluation of natural coagulants for water treatment, Water Science and Technology, vol. 7, no. 5-6, pp. 19–25.
8. Jahn S. A. A., 1988; Using Moringa seeds as coagulants in developing countries, Journal of the American Water Works Association. 2007;80(6):43–50.
9. Diaz A, Rincon N, Escorihuela A, Fernandez N, Chacin E and Forster CF. A preliminary evaluation of turbidity removal by natural coagulants indigenous to Venezuela, Process Biochemistry. 1999; 35(3-4):391–395.
10. Keno David Kowanga, Godfrey Omare Mauti and Eliakim Mbaka**.** Effect of crude and defatted *Moringa oliefera* seeds as natural coagulants in the removal of physical, chemical and bacteriological parameters from turbid river water**.** Journal of Scientific and Innovative Research. ISSN 2320-4818. J. of Sci. Inno. Res., 2016;5(1):19-25*.*
11. Bassett J, Denney RC and Mendham J. Vogel's Textbook of Quantitative Inorganic Analysis pages 1983;756, 510 and 754.
12. Ebeling JM, Sibrell P, Ogden S and Summerfelt S. Evaluation of Chemical Coagulation/Flocculation aids for The Removal of Suspended Solids and Phosphorus from Intensive Recalculating Aquaculture Effluent discharge. Journal of Aquaculture Engineering. 2003;12*:*19–20.
13. W.H.O., Water Quality Monitoring- A practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programs., Published on behalf of United Nations Environment Program and the World Health Organization,Geneva. ISBN 0 419 22320 7 (Hbk) 0 419 21730 4 (Pbk). 2006;
14. Mavura W, Chemeli M and Saenyi W. Investigation of Chemical and Biochemical Properties of Maerua Subcordata Plant Extract: A Local Water Purification Agent. Bulletin Chemestry Society of Ethiopia. 2008;22:143-147.
15. Divakaran R and Pillai VN. Flocculation of River Silt using Chitosan. Journal of Water Resource. 2002;36:2414-2418.
16. Schulz C. Suface Water Treatment for Communities in Developing Countries. John Wiley and Sons, UK. 2002;432-442.
17. Kegley SE and Andrews J. The Chemistry of Water; University Science Books Sausalito, California. 2008;592-602.
18. Fatoki OS and Ogunfowokan AO. Effect of Coagulant Treatment in the Metal Composition of Raw Water. Journal of Water. 2002;28(3):293-298.
19. Roussy J, Van Vooren M, Dempsey B and Guibal E. Influence of Chitosan Characteristics on the Coagulation and the Flocculation of Bentonite Suspensions. Jounal of Water. Resources. 2005; 39: 3247-3258.