Application of the Purified Moringa Oleifera Coagulant for Surface Water Treatment

J.K. Abaliwano
K.A. Ghebremichael
G.L. Amy
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Authors: Abaliwano, J. K., Ghebremichael, K. A., Amy, G.L.
The WaterMill Working Paper Series

The WaterMill Working Paper Series is part of the WaterMill project (Water Sector Capacity Building in Support of the Millennium Development Goals), which has been implemented by the UNESCO-IHE Institute for Water Education in Delft, the Netherlands, since 2004. The WaterMill Project is a capacity building project for the Water Sector responding to the targets as laid down in the Millenium Development Goals and by the Commission on Sustainable Development. The project offers several advanced training programmes at the post-graduate level to 72 professionals originating from the partner countries of the Netherlands.

As part of their training each of the 72 professionals had undertaken a 6-month research project which focuses on the achievement of the MDGs in their home country. The WaterMill working paper series presents the research outputs of these projects.

Contact information

For more information regarding the WaterMill project and the WaterMill Working Paper Series please contact Prof. Dr. Pieter van der Zaag (email: p.vanderzaag@unesco-ihe.org).
Abstract

The treatment of water with the common inorganic coagulants such have a number of disadvantages such as cost of chemicals (especially for developing nations), concern for human health, sludge management among others. The *Moringa Oleifera* is one of the natural coagulants that have been tested over the years as an alternative to the use of inorganic and synthetic coagulants. It has been found to be effective for high turbidity waters. The crude form has been used for water clarification on small scale in some parts of the developing world. The main drawback of the crude extract is that it adds organic and nutrients to the treated water. This has hindered the use of the *M. oleifera* in large scale water treatment. In an attempt to overcome these drawbacks a purification protocol has been developed and tested on a lab scale. Aside from improving the coagulating properties of the *M. oleifera*, the new protocol can be adapted for conventional water treatment. In addition limited studies on the characterization of natural organic matter and removal by the *M. oleifera* coagulant have been done.

This study investigated the effectiveness of the *M. oleifera* coagulant for the removal of turbidity, bacteria, and natural organic matter (NOM) from natural surface water. The results obtained were compared with inorganic coagulants of alum and ferric chloride. Two sources of water were used in jar test experiments (the River Meuse and Delft Canal waters). The results showed the effectiveness of *M. oleifera* for turbidity removals of up to 97% for high turbid waters and lower removals of 86% for low turbid waters. Turbidity removal was comparable to that of the inorganic coagulants especially for high turbid waters. The effect of mixing intensity and time was investigated and slow mixing time found to have the highest effect on the treated water quality with higher removals of both turbidity and DOC with increased slow mixing time. The use of *M. oleifera* coagulant in combination with alum and ferric chloride showed that reduced usage of inorganic salts to an average of 60% could be achieved. Bactericidal activity seemed to be evident through analysis of *E. coli* viability in the water and sludge treated by the *M. oleifera* coagulant.

**Keywords:** Moringa Oleifera; coagulation; aluminium sulphate
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1 Introduction

In many developing countries, access to clean and safe water is a major problem. According to the UN, 1.1 billion people still do not have access to an adequate supply of drinking water and these people are among the worlds poorest. Poor water quality is a key cause of poor livelihood and poor health with 80% of all diseases in developing countries being water related (OECD, 2006). The Millennium Development Goal number 7 and target 10 addresses the need to find better solutions/alternatives to halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation. Due to limited alternatives, surface water either from rivers or rain fed ponds has become one of the main sources of water supply. This water is vulnerable to various forms of pollution generated from different sources mainly households, agriculture and industries.

The most widely applied conventional water treatment technology consists basically of aeration, coagulation, flocculation, sedimentation, filtration and disinfection. When particles are slow to settle or are non-settling, the process is speeded up by coagulation and flocculation through the addition of certain chemicals known as coagulants. These processes are effective at removing fine suspended particles that attract and hold bacteria and viruses to their surface. They can remove up to 99.9% of the bacteria and 99% of the viruses from water supplies (CRC, 2003).

However there are constraints encountered in the use of chemical coagulants, such as scarcity of foreign currency for importation and inadequate supply of chemicals. Although aluminium is the most commonly used coagulant in the developing countries, studies have linked it to the development of neurological diseases (e.g. pre-senile dementia or Alzheimer’s disease) due to the presence of aluminium ions in the drinking water (Jekel, 1991). More so, large non-biodegradable sludge volumes are produced containing residual aluminium sulphate needing treatment facilities to prevent further contamination into the environment.

As a consequence of the above mentioned drawbacks, there was a need to develop alternative, cost effective and environmentally friendly coagulants. A number of effective coagulants from plant origin have been identified: Nirmali (Tripathi et al., 1976); Okra (Al-Samawi and Shokralla, 1996); red bean, sugar and red maize (Gunaratna et al., 2007), M. oleifera (Jahn, 1988) and a natural coagulant from animal origin; chitosan. Natural mineral coagulants have also been used including fluvial clays and earth from termite hills. Of all plant material investigated, seeds of M. Oleifera are one of the most effective sources of coagulant for water treatment.

In laboratory and field tests, seed of M. Oleifera have shown promise as a coagulant in the clarification of turbid water (Folkard et al., 1999; Kalibbala, 2007; Ndabigengesere et al., 1995; Sutherland, 2001). The seeds contain water soluble positively charged proteins that act as an effective coagulant however the crude moringa extract (though efficient in removal of turbidity) increased the organic load in the treated water (Ndabigengesere and Narasiah, 1998). The current research deals with purification of the coagulant and treatment of natural waters with the use of the purified M. Oleifera seed coagulant.
1.1 Impact of this Research on the MDGs

At the United Nations Summit in September 2000, 189 UN Member States adopted the Millennium Declaration, from which emerged the Millennium Development Goals (MDGs). The MDGs form a set of political commitments aimed at tackling the major development issues faced by the developing world within a fixed deadline.

Over the years, efforts have been made to attain Target 10 of the MDGs for water supply and sanitation (‘halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation’). Water is life for people and is a basic need, however for the world’s poorest citizens, the right to safe water and adequate sanitation remains a promise unfulfilled. At least 1.1 billion people lack access to safe water and 2.6 billion lack access to basic sanitation (WHO, 2000). According to the World Health Organisation, each and everyday 3,900 die because of poor quality water or poor hygiene. With 7 years to go until 2015, a dramatic increase in access to safe drinking water and basic sanitation services for poor women, men, and children in developing countries will be required, if the MDG number 7 is to be met.

The UN Millennium Project Task Force on Water and Sanitation identified 10 key actions as essential to meeting the MDGs and among them are:

- Efforts to reach the water and sanitation target must focus on sustainable service delivery, rather than construction of facilities alone.
- Governments and their civil society and private sector partners must support a wide range of water and sanitation technologies and service levels that are technically, socially, environmentally, and financially appropriate.
- Institutional, financial, and technological innovation must be promoted in strategic areas.

The promotion and development of *M. oleifera* as a natural coagulant offers many advantages to many countries of the developing world: sustainable, appropriate, effective and robust water treatment; declined reliance on the importation and distribution of treatment chemicals; the creation of new cash crops for farmers and employment opportunities (Folkard and Sutherland, 2002).

The use of *M. oleifera* can have an effect on several other MDGs apart from Goal number 7 of the MDGs. The different parts of the plant have been used for various purposes which are of benefit to human life and the environment. The leaves of the plant are widely eaten as vegetables. The high concentration of essential amino acids, minerals and vitamins makes *M. Oleifera* an ideal nutritional supplement (Fuglie, 2001). Regular intake of Moringa can prevent anaemia and most forms of malnutrition. This is important especially in the effort to reduce the rate if infant mortality. In other areas, the leaves are eaten by women during pregnancy and after child birth. This is done to provide proteins, vitamins and minerals to both the mother and child.

Moringa is a source of oil. The oil has a potentially high market value and become a source of income. It can also be used as firewood and in construction and since it is a perennial crop it is available throughout the year. This can also become a source of income and contribute to the alleviation of poverty.
2 Moringa Oleifera (M. oleifera)

M. Oleifera is the most widely spread species of the plant family Moringaceae. It is native to India but is naturalized in many other countries in the tropics. It is a small, fast growing, drought deciduous tree that ranges in height from 5-12m with an open umbrella shaped crown, straight trunk with corky, whitish bark. M. Oleifera is a multi purpose tree with most of its parts being useful for a number of applications.

The shelled M. Oleifera seeds have been found affective for the removal of heavy metals such as cadmium by adsorption (Sharma et al., 2006). The residue containing seed husks is regarded as waste but research has shown that a simple stream pyrolysis procedure can form high quality micro porous activated carbon from both the waste husks of M. Oleifera and the pods (Warhurst et al., 1997). With the use of artificially prepared turbid water and natural waters, laboratory investigations have confirmed the effectiveness of the M. Oleifera seed as a coagulant comparable to the much used inorganic coagulants in its effectiveness. Turbidity removals by M. Oleifera as a primary coagulant of up to 80-99%, both for raw and synthetic waters have been found (Kalibbala, 2007; Katayon et al., 2007; Muyibi and Okuofu, 1995; Ndabigengesere et al., 1995).

However researchers such as (Ghebremichael et al., 2005; Muyibi and Okuofu, 1995; Sutherland, 2001) found that M. Oleifera coagulant might not be an efficient coagulant for low turbidity water. They documented that the residual turbidity of samples increased with the decrease in initial turbidity at optimum dosage of M. Oleifera. In the case of low turbidity the M. Oleifera could be used as a coagulant aid (Ghebremichael et al., 2005). M. Oleifera as a coagulant aid has been tested in various studies and researchers found that when alum is used together with M. Oleifera as a coagulant aid, better performance of removal of colour and turbidity is achieved. (Kalibbala, 2007; Muyibi and Alfiugara, 2003). The M. Oleifera seed has also been found to have antibacterial activity (Broin et al., 2002).


3 Materials and Methods

3.1 Preparation of MO seed extracts

The MO seeds were obtained from Nigeria. Seeds were stored at room temperature. The seeds were shelled manually and the kernel ground to a fine powder using a kitchen blender. Oil was removed by mixing the seed powder in 95% ethanol (5%, w/v). This was mixed with a magnetic stirrer for 30-45 min and subsequently separation of the residue from the supernatant was done by centrifuging for 45 min at 3000 rpm. The supernatant was decanted and the residual solid was dried at room temperature. From the dried sample, 5% (w/v) was mixed with 1400ml of ammonium acetate (10mM, pH 6.8). The suspensions were stirred for 30 minutes using a magnetic stirrer and the separation of the solids from solution done by centrifuging at 3000 rpm for 45 minutes. The filtrate was termed as the crude extract.

3.2 Purification of the MO coagulant protein

The MO coagulant protein was purified using CM sepharose cation exchanger (IEX) with bead size 45-165um. Crude extract sample was added to the IEX matrix that had been equilibrated with ammonium acetate buffer and mixed. The seed protein was adsorbed to the IEX matrix. After settlement for between 1-2 hours, the supernatant was decanted and the IEX matrix washed with ammonium acetate three times to remove the non adsorbed protein and other impurities.

The adsorbed proteins were then eluted using a high molar concentration of NaCl (0.6M). A sodium chloride (NaCl) solution was added to the IEX matrix and mixed for approximately 30 minutes and settlement done for up to 1 hour. The supernatant was extracted using a pipette so as not to interfere with the settled particles. This was the purified coagulant from the 1st elution. A second elution was done after the first eluent.

3.3 Source water characterization

The sample water for this study was collected from River Meuse in the Netherlands. Water from the Delft canal was also used for comparison purposes. The samples once collected were stored at approximately 5 ºC in the UNESCO-IHE laboratory cold room to prevent bacterial activity. The raw water was analyzed for various water quality parameters, including pH, turbidity, conductivity and the presence and characteristic of NOM. In order to vary the turbidity of the sample water, spiking with clay suspension was done. This enabled us to study varying ranges of contaminant concentrations. Table 1 summarises source water quality and characterization of the River Meuse and Delft canal waters.

Surrogate parameters such as DOC, UV\textsubscript{254} and SUVA provided an indication of the NOM characterization and concentration. As shown in Table 1, DOC for samples from the River Meuse was in the range between 3 to 8 mg/l which falls within the typical range for river water. The DOC range for the Delft Canal water was between 14.7 and 17.4 mg/l. DOC in precipitation, ground waters and sea water is usually less than 1 mg/L, lakes and rivers most commonly vary from 2-10 mg/L whereas waters originating from wetlands and bogs may contain as much as 50 mg/L (Beckett.R. and Ranville, 2006).

Table 1: Source Water Characterization

<table>
<thead>
<tr>
<th>Water quality parameter</th>
<th>River Meuse</th>
<th></th>
<th>Delft Canal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>Turbidity, NTU</td>
<td>26 NTU</td>
<td>20-45 NTU</td>
<td>35 NTU</td>
<td>24-60 NTU</td>
</tr>
<tr>
<td>pH</td>
<td>8.0</td>
<td></td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>Electrical conductivity (EC)</td>
<td>635</td>
<td>40-700 µs/cm</td>
<td>829</td>
<td>750-900 µs/cm</td>
</tr>
<tr>
<td>DOC, mg/L</td>
<td>4.63</td>
<td>3-8 mg/l</td>
<td>15.84</td>
<td>14.7-17.4 mg/l</td>
</tr>
<tr>
<td>UV254, m-1</td>
<td>0.098</td>
<td>0.080-0.122</td>
<td>0.507</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>SUVA</td>
<td>2.25</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The SUVA values in Table 1 indicate that SUVA values for the River Meuse and the Delft Canal fall between 2 and 3. Natural waters with high SUVA values >4 L/mg-m, have relatively high contents of hydrophobic, aromatic and high MW NOM fractions, while waters with SUVA <2 contain mostly hydrophilic, non humic and low MW fractions (Edzwald and Tobiason, 1999). Based on the SUVA measurements, NOM in the River water may be dominated by hydrophilic, low MW fractions and lower aromacity. The Delft Canal water has a SUVA value of 3.2. The observed differences are consistent with the view that as DOC of water increases the majority of the additional organic matter is likely to be hydrophobic in character (Sharp et al., 2005).

3.4 Preparation of Synthetic water

Synthetic turbid water for the jar tests was prepared by adding kaolin (clay suspension) to tap water. About 5g of the kaolin was added to 1 liter of tap water. The suspension was stirred for about 1 hour to achieve a uniform dispersion of kaolin particles. Then it was allowed to settle for at least 24 hours for complete hydration of the kaolin. The synthetic turbid water was added to the sample water to achieve the required turbidity just before coagulation.

3.5 Coagulation test

The jar test is a widely used method to evaluate coagulation- flocculation processes (Kawamura, 1991). Coagulation tests were conducted using the jar test experiment of Phipps & Bird having a base floc illuminator. Six beakers were filled with 1 litre of the sample water and agitated at a rapid mixing speed of 120 rpm for 1 minute upon addition of the coagulant and slow mix at 40 rpm for 20 minutes. This was followed by 1 hour of sedimentation. Comparative tests were run under the same conditions as described above but using alum and ferric chloride.

3.6 Analytical procedures

The following parameters were analyzed in the raw and treated water: pH value, turbidity, conductivity, sludge volume and dissolved organic carbon (DOC). Turbidity measurements were conducted using a turbidity meter (HACH 2100N). The pH value was measured with a calibrated METROHM-691 pH meter. Conductivity was measured using a conductivity meter which was also used to monitor the temperature. Sludge volume was measured using Imhoff cones. DOC was measured using a model 700 portable TOC analyzer. The DOC measurements were made after filtering the samples through 0.45 µm membrane filters.
4 Results and Discussion

4.1 Turbidity removal studies

The purified \textit{M. oleifera} coagulant protein (MOCP) and the crude \textit{M. oleifera} extract demonstrated adequate coagulation capacity. The formation of flocs and decrease in turbidity indicate coagulation activity of the \textit{M. oleifera} coagulants. Since the active agent of the \textit{M. oleifera} is believed to be positively charged cation, these results point to a mechanism whereby the positively charged part of the coagulant associates with and neutralizes negative charges on the surface of the particles in the river water. Thus the mechanism of charge can be described as neutralization and adsorption as suggested by (Ndabigengesere \textit{et al.}, 1995). Enhanced by mixing, particle interaction between the differently charged particles takes place and flocs are formed which settle out of the water.

![Fig 2: Comparison of MOCP, alum and ferric chloride](image)

4.2 Comparison of MOCP with Alum and Ferric chloride

The coagulation activities of \textit{M. oleifera}, alum and ferric chloride were compared using the jar tests apparatus. Results indicated that the coagulation activities of the alum, ferric chloride and \textit{M. oleifera} coagulant were similar for high turbid waters (>100 NTU). \textit{M. oleifera} was found to be less effective for low turbid waters.

MOCP did not significantly affect the pH-value which remained almost constant at 7.9 for all dosages tested. This is line with previous study which has shown that the use of \textit{M. oleifera} does not cause alteration in pH (Ndabigengesere and Narasiah, 1998). In contrast the pH value decreased for both alum and ferric chloride with increase in dosage due to a series of hydrolytic reactions which produce hydrogen ions and hence the pH of the water is reduced.

The EC of both alum and ferric chloride shows only a slight increase with increase in dosage. In contrast, the conductivity of the water treated with MOCP increased significantly with increase in dosage. This increase is attributed to the presence of NaCl ions used during the purification stage for the process of elution.

DOC was observed to increase with increased MOCP dosage. This is in contrast to previous research works which have found no increase in the DOC with the addition of the purified \textit{M. oleifera} coagulant at the optimum dosage (Ghebremichael, 2004; Ndabigengesere and Narasiah, 1998; Okuda \textit{et al.}, 2001). The DOC increases only slightly with MOCP dosages at the optimum
dose of 7mg DOC/L but as dosage increased beyond this the residual DOC value rises significantly. The rapid increase after a dosage of 7 mg DOC/L could be attributed to overdosing of coagulant and therefore having a residual of the coagulant protein in the treated water hence increasing the DOC value.

Inorganic salts like alum and ferric chloride have been found to leave a residual of alum and iron in the treated water. Driscoll and Letterman (1988) reported that approximately 11% of the Al input (through raw water and Al₃(SO₄)₃) remained in the finished water as residual Al and was transported through the distribution system without any significant loss. Mesdaghinia et al. (2005) found that residual metal concentration due to under or overdosing resulted in significant deterioration of water quality with respect to residual aluminium and iron concentrations.

Resultant sludge volume from sedimentation of M. oleifera treated water was approximately 5 times less than that of alum and ferric chloride. This is in correlation with research by Ndabigengesere et al. (1995) who found the sludge production of alum to be 4 to 5 times higher than that of M. oleifera. The cost of sludge disposal and treatment may be dependant on the volume of sludge. It can then be argued that MOCP sludge would be more economical to treat than either alum or ferric sludge. A further advantage is that MOCP sludge is biodegradable and can be reused as a fertilizer provided heavy metals are absent in the water being treated.

4.3 Factors affecting coagulation effectiveness of M. Oleifera

Several parameters were checked for their effect on M. oleifera coagulant performance. These included; rapid mixing intensity and time, slow mix time, pH and initial turbidity. The effectiveness of M. oleifera coagulant did not show significant changes with change in rapid mix intensity and time. However an improvement was noted when slow mix time was increased from 10 minutes to 20 minutes. Performance of the coagulant improved with decrease in pH as the net positive charge increased with the presence of H⁺ ions. Initial turbidity of the water was a factor in the performance of the coagulant. At high turbidity better removal efficiencies were noted compared to lower initial turbidity. The presence of a larger number of particles in the water raises the chances of collision and floc formation and hence better settlement of the denser flocs that are formed.

\[\text{Figure 2: } M. \text{oleifera as a coagulant aid (a) turbidity removal, (b) DOC}\]

\[M. \text{oleifera} \text{ was tested as a coagulant aid to alum and ferric chloride. The results in Fig 3 (a) and (b) give an indication of percentage turbidity removals and DOC reduction when } M. \text{oleifera was}\]
combined with alum. The order of addition was found to be significant. The addition of M. oleifera coagulant first before alum was more effective than addition of M. oleifera after alum. This is again attributed to the fact that M. oleifera performs better in high turbid waters as more particles are able to agglomerate making them denser so they can easily settle out of the water. The use of M. oleifera could lead to a 50% reduction in the use of inorganic chemicals.

### 4.4 Anti bacterial effect of M. oleifera

The ability of the *M. oleifera* coagulant to remove bacteria from water was tested in the jar test experiments with spiking of sample water (Delft canal) with *E.coli* bacteria. The results indicated a reduction in the bacteria count similar to that of alum. However the bacteria count in the sludge reduced significantly with increased *M. oleifera* coagulant dosage unlike alum where the bacterial count in the sludge remained fairly constant with increased dosage. This may be an indication of bactericidal activity of *M. oleifera* although further investigation is required to verify the mechanism of action. Previous study by Suarez *et al.* (2003) demonstrated the ability of a recombinant *M. oleifera* protein to decrease the viability of gram-negative or gram-positive bacterial cells and to mediate the aggregation of negatively charged particles in suspension, such as bacterial cells, clay or silicate microspheres.
5 Conclusion

The purpose of this study was to purify *M. oleifera* seed coagulant and use it for surface water treatment. The specific conclusions derived from this study are as follows;

1. The purification by ion exchange matrix showed better coagulation activity in terms of turbidity removal with dosages 5 times lower than the crude *M. oleifera* extracts. The MOCP could effectively remove more than 95% of turbidity for high turbid waters.

2. The use of MOCP for coagulation purposes investigated through a number of jar test experiments found the following factors highly significant; the initial turbidity of the water as percentage removals for high turbid waters (>100 NTU) were greater than those for waters of lower turbidity (<50 NTU). The performance was seen to improve with increased mixing time.

3. Increasing dosage of *M. oleifera* seed coagulant leads to decrease in turbidity up to the optimum dose after which the residual turbidity increases due to floc restabilization.

4. On the quality of water treated by *M. oleifera* seed coagulant, the following were noted; the pH of the water was not affected by the addition of the coagulant; The volume of sludge produced was considerably less as compared to alum and ferric chloride; there was a gradual increase in the EC of the water treated by MOCP as a result of the use of NaCl in the purification process; The DOC value increased significantly with the use of the crude *M. Oleifera*, the increase of DOC with the MOCP was not as significant up to the optimal dosage and then increased gradually with increased dosage due to an overdose of coagulant

5. The MOCP was found to be effective as a coagulant aid with alum and ferric chloride and its use could reduce the use of alum by almost 60%.

6. The bacterial quality of water treated with MOCP was similar to that with alum treatment although MOCP was seen to effect bactericidal activity.
6 References


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Contact information
For more information regarding the WaterMill project and the WaterMill Working Paper Series please contact Prof. Dr. Pieter van der Zaag
E-mail: p.vanderzaag@unesco-ihe.org