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ASSESSMENT OF DRINKING WATER TREATMENT USING *MORINGA OLEIFERA* NATURAL COAGULANT

Värdering av *Moringa Oleifera* för fällning av dricksvatten

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Abstract

In this study, a comparison between *Moringa Oleifera* MO and aluminium sulphate was conducted for coagulation of turbide water using jar test. The optimum coagulant dosage was investigated for different levels of turbidity, and the impact on treated water properties monitored. Use of MO together with direct filtration was also investigated.

Coagulation with aluminium sulphate led to more efficient treatment but MO could also produce water of acceptable quality. On the other hand, treatment with MO did not change the chemistry of treated water and was more efficient for high initial turbidities. Highest removal efficiencies were obtained when MO was extracted using tap water as compared to distilled water and oil extraction. Coagulation with aluminium, followed by direct filtration led also to better performances but in both cases the treated water met WHO water guidelines. Prolonged sedimentation helped improve MO treatment efficiency for low initial turbidities.

MO is found to be a sustainable solution for coagulation in drinking water treatment. The possibilities of using MO together with direct filtration are good and provide a realistic alternative to conventional methods for small to medium size water supplies.

Key words – Moringa Oleifera, drinking water treatment, aluminium sulphate

Sammanfattning

Att minska turbiditeten är en central del vid beredning av dricksvatten från ytvatten, och sker oftast med koagulering och flockning, där polyvalenta metallsalter som aluminiumsulfat används. Studier indikerar att metallsalterna kan ersättas av ett naturligt koaguleringsmedel från det tropiska och subtropiska trädet *Moringa Oleifera* (MO). Dess frön har använts i småskalig dricksvattenberedning i Indien och Sudan i flera generationer. Koaguleringsmedlet är troligtvis ett eller flera protein som agerar likt katjoniska polyelektrolyter.

I denna studie har en jämförelse mellan MO och aluminiumsulfat genomförts i bägareförsök. Den optimala dosen av koaguleringsmedlet undersöktes för olika turbiditetsnivåer, och effekten på vattenkemin kontrollerades. Användning av MO tillsammans med direktfiltrering, samt möjligheterna att använda MO i vattenverk undersöktes också.

Den mest effektiva beredningen för alla turbiditetsnivåer återfanns vid användning av aluminiumsulfat. MO påverkade inte de fysikaliska egenskaperna och var mest effektiv för högre grumlighetsnivåer i råvattnet. Extraktionsmetod för MO-extrakt påverkade inte det beredda vattnets kemiska egenskaper. En förlängd sedimentationstid tillsammans med MO förbättrade reningen och försöket med direktfiltrering var lyckat. Rening med MO och direktfiltrering resulterade i mer effektiv rening än med aluminumsulfat i kombination med direktfiltrering. MO kan anses vara ett förnyelsebart och billigt koaguleringsmedel vid dricksvattenberedning. För bästa resultat bör MO användas tillsammans med direktfiltrering. Om vattenberedningen sker i liten skala är MO ett realistiskt alternativ till konventionella metoder, förutsatt att plantager etableras i tillräcklig omfattning.

1. Introduction

When surface water is used for drinking water production, turbidity removal is an essential part of the treatment process. It is generally achieved using coagulation with metal salts followed by aggregation of particles through flocculation and separation through sedimentation and filtration. Aluminium (e.g. $Al_2(SO_4)_3 \cdot 18H_2O$) and iron salts are mostly used as coagulant reagents. Recent studies (Ngabigengesere & Narasiah, 1998; Katayon et al., 2005) have indicated a number of serious drawbacks linked to the use of aluminium salts such as Alzheimer's disease associated with high aluminium residuals in treated water, excessive sludge production during water treatment and considerable changes in water chemistry due to reactions with the OH^- and alkalinity of water. In addition, the use of alum salts is inappropriate in some developing countries because of the high costs of imported chemicals and low availability of chemical coagulants (Schultz and Okun quoted by Katayon et al., 2005).

A number of studies have pointed out that the introduction of natural coagulants as a substitute for metal salts may ease the problems associated with chemical coagulants (Katayon et al., 2005). Using natural coagulants such as the seeds from the *Moringa Oleifera* MO tree instead of aluminium salts might give advantages, such as smaller costs of water production, less sludge production and ready availability of reagents. There are also some disadvantages such as increased concentration of nutrients and COD in the treated water due to the organic nature of this type of coagulants.

In this paper, the potential of using *Moringa Oleifera* as an alternative to aluminium sulphate for drinking water treatment in Mozambique is evaluated, its limits analyzed and the optimal use and dosage assessed. Standard Jar-test experiments performed with solutions prepared from aluminium and MO seeds were used to compare the efficiency in turbidity removal and the impacts on the water chemistry. Filtration experiments in a coarse to fine media filter were used to compare filtration efficiency of suspensions prepared through coagulation with Al and MO.

The more specific objectives for this study were to:

- Evaluate the optimum dosage of MO for different levels of turbidity, and its removal efficiency at each level.
- Compare the treatment efficiency of MO to that of aluminium sulphate, regarding both treatment efficiency and influence on water quality and characteristics.
- Find a suitable method of preparation for the MO coagulant, and establish a procedure manual for the preparation, use and dosage of MO in order to use it for drinking water treatment.
- Investigate the possibilities of using MO on an industrial scale, regarding availability and reliability of production and distribution.

2. Background

In nature, water is always contaminated with various types of pollutants. Some of them are harmless and sometimes even desired in water whereas others need to be removed before the water can be used for drinking purposes. Physical properties such as turbidity, colour and solids impact the aesthetic appearance of water and its acceptability for consumption. The microbiological quality has a large effect on the taste and smell of water and can sometimes be a large problem in river water. Eutrophication of surface water sources due to nutrients disposal (e.g., from agriculture and wastewater) and physical properties such as pH and temperature, favours algae and bacteria growth and can cause health risks. Bacteria in water can cause illnesses such as typhoid (Salmonella typhus), cholera (Vibrio cholera), and diarrhoea (Giardia lamblia). Faecal coliforms and streptococci indicate contamination from human or animal faeces.

The aim of drinking water treatment is to remove impurities and bacteria in order to meet the quality guidelines for drinking water (WHO, 2004). The design of water treatment process varies between different treatment plants. It also depends on the quality of raw water and the requirements regarding treated water quality. Surface water generally requires more treatment than ground water, since the former is more easily contaminated.

Conventional treatment is mostly used for surface water treatment. It generally involves chemical coagulation followed by flocculation, sedimentation, filtration and disinfection. Common coagulants are aluminium sulphate, ferric chloride, polyaluminium chlorides and synthetic polymers. All of these coagulants have in common the ability of producing positively charged ions when dissolved in water, which can contribute to charge neutralization (Degrémont, 1979; Hammer et al., 2004). The dosage of coagulant depends on several parameters such as type and concentration of contaminants, pH and temperature. The optimal dosage for specific water is defined as the dosage which gives the lowest turbidity in the treated water. Dosage beyond the optimum point will, apart from obvious disadvantages such as increased aluminium/iron content in the treated water, also lead to an increase in turbidity.

If the sedimentation step is omitted, and the flocculated water is led directly to filtration, the process is called direct filtration (McConnachie et al., 1999). A pre-requisite is that the raw water is of seasonally uniform quality with turbidity routinely less than 5NTU. If

Figure 1. *The Moringa Oleifera tree (left) and dried and shelled seed (above).* *© M. Begman.*

otherwise, pre-treatment is required. This includes pre-treatment with contact basins, flocculation chambers and roughing filters with flocculation processes. The latter can be designed either with a horizontal flow direction (HRF), up-flow (UPRF) or down-flow (DFRF). In all cases, coarse media of decreasing size in the direction of flow is used (Sánchez et al., 2006).

If flocculated water is filtered first in an up-flow roughing filter prior to its final treatment in rapid sand filters the processes is called up-flow-down flow filtration. This method is claimed by researchers (Ingallinela et al., 1998; McConnachie et al., 1999) as capable of producing treated water of quality equal to that of standard coagulation-flocculation followed by sedimentation and filtration, but, at lower investment and operational costs. Surface water treatment can also be treated by slow sand filtration-SSF. In this case, pre-treatment is always needed because SSF cannot handle high turbidity values of the raw water. For pre-treatment roughing filters are mostly used.

When conventional coagulation is used, chemical coagulants such as iron and alum salts are needed but, natural coagulants such as the seeds from the *Moringa Oleifera* tree can also be used. Traditionally, surface water has been treated with the help of herbs as natural coagulants for centuries in India. Ripe seeds of *Strychnos potatorum*, wiry roots of the rhizome of *Vetiveria zizanioides*, seed coats of *Elettaria cardamomum* and leaves from *Phyllantus emblica* have all been recorded to be used for water treatment in past and present times (Sadgir, 2007).

The *Moringa Oleifera* (MO) tree (Figure 1) is a perennial plant that grows very fast, with flowers and fruits appearing within 12 months after planting. The tree grows up to a height of 5–12 meters with branches extending between 30 and 120 cm (Lilliehöök, 2005).

With its origin in India and Pakistan the *Moringa Oleifera* plant was brought to the Africa continent and Sudan, in particularly during the colonial era for ornamental purposes. The natural coagulant found in MO is present in 6 of the 14 species of MO growing in Africa, Madagascar, India and Arabia. Knowledge that MO seeds can purify water is not new; the seeds have been used for water treatment for generations in countries like India and Sudan. For example, the women of Sudan have used the seeds from the MO three for water treatment since the beginning of the 20th century (Schwartz, 2000) through a technique that comprehended the swirling of seeds in cloth bags with water for a few minutes and let it settle for an hour.

Scientifically, the coagulation properties of MO seeds were first confirmed by the German scientist Samia Al azharia Jahn (Schwartz, 2000). The active agent is believed to be a protein, but the exact form of the protein is not yet known. Recent research has identified proteins of sizes ranging from 3 to 60 kDa, all possessing coagulating ability. The protein(s) act as a cationic polyelectrolyte, which attaches to the soluble particles and creates bindings between them, leading to large flocs in the water. Stirring and mixing accelerates the electrostatic flocculation, and the flocs condense the contaminants (Göttsch, 1992).

Extraction of the active agents can be done in several ways but most techniques follow the pattern: dried seeds grained or powdered with or without shells; powder mixed with a small amount of water and, the solution is stirred and filtrated (Ndabigengesere & Narasiah, 1998; Muyibi & Alfugara, 2003; Ghebremichael et al., 2005). The filtered solution is called "crude extract" or "stock solution" and can be used for water treatment without further preparation. Several studies have shown that the use of salt water and/or tap water is more efficient as solvent than e.g. distilled water. Okuda et al. (1999) showed for example that the crude coagulation capacity was up to 7.4 times higher when the active agents were extracted with salty water as compared to distilled water. The reason for this is assumed to be that the coagulating protein is more soluble in water with high concentration of ions (Okuda et al., 2001a). Other studies have focused on purifying the active agent as much as possible and producing a stable protein powder without excessive organic matter. Two separate studies show that the active agents could be purified from the extract using a cation exchanger column, leading to reduced levels of COD in the treated water (Ghebremichael, 2005; Ndabigengesere & Narasiah, 1998). However, a more low-tech way of reducing the organic content is to extract the oil from the seeds with an organic solvent (Ghebremichael, 2005).

The treatment efficiency is dependent on the turbidity of the raw water, as revealed in previous studies by Katayon et al., (2004). MO has also been proven to produce significantly less sludge than aluminium sulphate, which is an advantage especially if the sludge is to be dewatered or treated in some other way before disposal (Ndabigengesere et al., 1994). MO can also be used in combination with other coagulation salts, such as aluminium sulphate (Sutherland et al., 1994).

The coagulation and flocculation ability of the seeds has been investigated in several different studies around the world (Ndabigengesere & Narasiah 1998; Bengtsson, 2003; Muyibi & Alfugara, 2003). These studies have shown that neither pH nor alkalinity nor conductivity was affected during water treatment, but an increase in COD, nitrate and orthophosphate has been observed. Other studies have indicated that treatment with MO is dependent on the pH of the raw water were optimum is above neutral (Okuda et al., 2001b) whereas others say it is independent of raw water pH (Schwartz, 2000).

Storage of seeds and extract and its influence on coagulation properties has also been investigated by Katayon (Katayon et al., 2004; Katayon et al., 2006). Seeds were dried, crushed and stored in different containers and at different temperatures. These studies concluded that the temperature and type of container did not have a significant effect on treatment efficiency but that the duration of storage did. The seeds stored for one month showed better treatment efficiency than seeds stored for longer periods (three to five months). Storage was also found to influence the coagulation properties of the extract and to decrease treatment efficiency with increased duration (Katayon et al., 2006). The study does not discuss the reason for this but it could be assumed that it is due to microbial degradation of the proteins. The study also concluded that the duration of storage of extract should not exceed 24 hours as degradation of active agents is assumed to occur within this time. As noted by Katayon et al., (2004) extract solutions stored for longer than 2 to 3 days had between 73.6 % and 92.3 % lower turbidity removals as compared to fresh solutions.

3. Methodos

3.1. Jar tests experiments

The equipment used for jar test experiments was a Janke & Kunkel jar test apparatus with 5 beakers of 2.0 l capacity each (Figure 2). Each beaker was filled with 1.5 l of test water with identical turbidity. Different volumes of coagulant reagent were added to 4 of the five beakers with the last used as the blank sample. Mixing of the coagulant with water was provided by flash mixing during approximately 3 minutes with propellers set at 120 rpm followed by slow mixing at 40 rpm during approximately 17 minutes. Then the propellers were stopped and the content of the jars left to settle for approximately 30 minutes. After sedimentation, samples were taken for water quality determination.

For each coagulant and turbidity level, three identical jar tests were performed in order to obtain statistically reliable results. However, some of the parameters were only measured during one of these three jar tests and/or

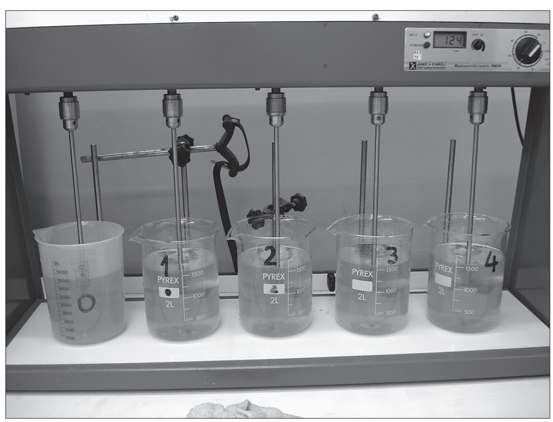

Figure 2. *Jar test equipment.*

in the jar with the optimal dosage, due to restricted time and economic means. If the optimal dosage was not found in the jar test, a new test with new dosage was carried out until the optimum was found.

3.2. Preparation of extract and test water

Dried and shelled MO seeds were obtained from IIAM (Agronomic research institute of Mocambique) via the Department of Chemical Engineering at Faculty of Engineering of Eduardo Mondlane University. The shells were ground to a fine powder using a mortar. The powder was then weighed and dissolved in distilled water to make a 50 g/l solution. The solution was stirred for 30 minutes using a magnetic stirrer, and finally filtrated through a Whatman filter no. 40. A fresh solution was prepared every day in order to avoid ageing effects. Two alternative preparation methods were used, one involving oil extraction from the seeds and the other using tap water instead of distilled water. To extract the oil, the ground seeds were first dissolved in cyclo-hexane, stirred for 30 minutes and then filtrated through a Whatman filter no. 40. The remaining solids in the filter ("press cake") were then dissolved in water, stirred and filtrated according to procedures described previously. The tap water preparation process was identical to the standard method, but with tap water as solvent instead.

Raw water from Umbeluzi river was used for all experiments. During the period of the experiments (September and October) the river water had low values of natural turbidity, therefore most experiments were performed with synthetic turbidity water. This was done by using ordinary clay, obtained from the Geology department of Eduardo Mondlane University. The clay was first ground with a mortar to make the particles as fine as possible, and then added to the water in sufficient amounts to produce the desired levels of turbidity.

3.3. Measurements and analytical methods

Turbidity, suspended solids, temperature, pH, EC (electrical conductivity), total dissolved solids (TDS), alkalinity, COD (chemical oxygen demand), and bacteria were the water quality parameters measured. Turbidity was measured using a 2100P turbidimeter from Hach. In order to increase reliability of measurements, water turbidity readings were tripled and that of settled water, doubled and the average values used as reference values.

Temperature was measured with a standard mercury thermometer (accuracy of ± 1°C) held for 1 minute in the water, and the observed values rounded to the nearest integer. pH and EC were measured using handheld digital meters from Wagtech International Ltd, and TDS was measured using an handheld digital meter TDScan Low-range (0–1990 ppm) from Eutech Instruments. All readings were taken with the digital meters held for 1 minute (or until a stable value was reached) in the sample water.

Alkalinity was measured with a simplified titration described in *Standard Methods* (1998). The samples were titrated with hydrochloric acid using an 725 Dosimat automatic titration equipment from Metrohm. The added volume of acid was noted at the colour changes (from pink to transparent for phenolphthalein and from blue to yellow for the mixed indicator).

COD and bacteriological analyses were conducted by the laboratory at the Ministry of Health in Maputo. For the bacteriological analysis, sterilized bottles were provided by the laboratory. During sampling, the bottles were filled completely to minimise the dissolution of air oxygen, and thereby aerobic degradation, in the samples. Microbial parameters analysed were total coliforms, *faecal* coliforms and *faecal* streptococci.

Suspended solids were also determined using standard procedures described in the *Standard Methods* (1998). The concentration of suspended solids was measured for 6 different levels of turbidity and a calibration curve plot, in order to provide a relationship between turbidity and suspended solids. This was done since the measurement of suspended solids is very time demanding, up to 2 days for each set of measurements, whereas turbidity is measured in less than a minute. With the calibration curve, turbidity values could be easily converted into approximate values of suspended solids concentrations.

3.4. Filtration experiments

Filtration experiments were performed in a pilot scale plant consisting of an up-flow roughing filter followed by single media gravity rapid sand filter. Pre-coagulated water with MO was used as test water. The test water turbidity was of about 30 NTU, and the dosage of MO was set to 50 mg/l. The flow rate was set to 60 l/h through the roughing filter, and 40 l/h through the single media filter. Turbidity and head loss measurements were used to assess the pilot plant performance. Turbidity readings were taken as described previously and head loss readings were taken using a tube-type differential pressure gauge. Turbidity and head loss readings were taken at regular time intervals of 30 minutes.

3.5. Sources of error

The procedure of the experiments was done consistently through the whole study to minimise the sources of error. Possible errors in the study might arise from the lack of calibration for the equipment used in measuring

Table 1. *The range and average quality of the raw water used in this study.*

Parameter	Raw water		Test water[1]	
	Range (historical)	Range (study period)	Range	Average
Turbidity (NTU)	3.8–173	4.6–6.8	5.2–100	36.1
Temperature (°C)	21–27	22–24	21–25	23
pH	6.7–8.7	8.2–8.4	8.2–8.6	8.4
Alkalinity (mg $CaCO_3$/l)	140–160	209.6–211.1	206.4–215.2	212
TDS (mg/l)	370–410	480–490	480–500	490
EC.(µS/cm)	550–630	710–720	700–730	720

[1] synthetic turbidity water

turbidity, pH, conductivity and TDS. The dosage for the flocculation was not done at exactly the same time in each jar, leading to time differences for the mixing of the water. However, the main factors affecting the jar test results are believed to be differences in preparation of raw water and MO extract.

COD and bacteriological analyses were done at the Health ministry. The time passing between filling the bottles with samples and the actual analysis affects the result since organic matter can be degraded if stored too long. The large variation of the results (and large deviation from the values recorded in 2003 and 2006 in the Umbeluzi River) suggests that either the sampling method or analysis procedure were not satisfactory, and that the results are not reliable.

4. Results and discussion

4.1. Raw and test water physio-chemical characteristics

The general physio-chemical quality (range and average values) of the raw and test water is presented in Table 1. All variables were measured at the laboratory, prior to each jar tests experiment.

As shown in Table 1, the raw water quality did not vary much during the period of experiments but analysis of historical data suggests that large variation can be expected, particularly in relation to turbidity. It is also seen from Table 1, that measured values of conductivity, total dissolved solids and alkalinity were generally higher than given values from previous measurements. Since raw water samples were collected from a location just downstream the waterworks where aluminium sulphate and lime are used for coagulation and neutralization the observed increase in raw water pH and alkalinity could be explained by the disposal of sludge and waste water containing $Al(OH)_3$ from the plant. Also, downstream the waterworks, the river is sometimes affected by saltwater intrusion because of its proximity to the river mouth. This may explain the observed increases in EC and TDS. The sludge from the waterworks also contains large amount of ions, which also explains the increase in conductivity and TDS.

Most coagulants perform less effective when the water temperature is low or when the raw water pH and alkalinity experiences fluctuations. Unlike turbidity, these parameters show very small variations during the year. Therefore during preparation of test water these parameters were not changed but the raw water turbidity was. A calibration curve for converting turbidity readings into approximate levels of suspended solids was also developed and is presented in Figure 3.

Accordingly, an almost linear relationship between turbidity and suspended solids is observed particularly when the raw water turbidity is high (>10NTU). The reason for the bad correlation at low turbidity values is probably due to the fact that the total mass of suspended solids in a 200 ml sample when the turbidity is low (less than 10NTU) is very small, around 1 mg, which is dif-

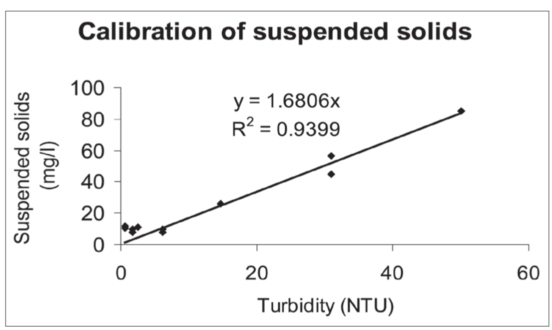

Figure 3. *Estimated relationship between turbidity and suspended solids.*

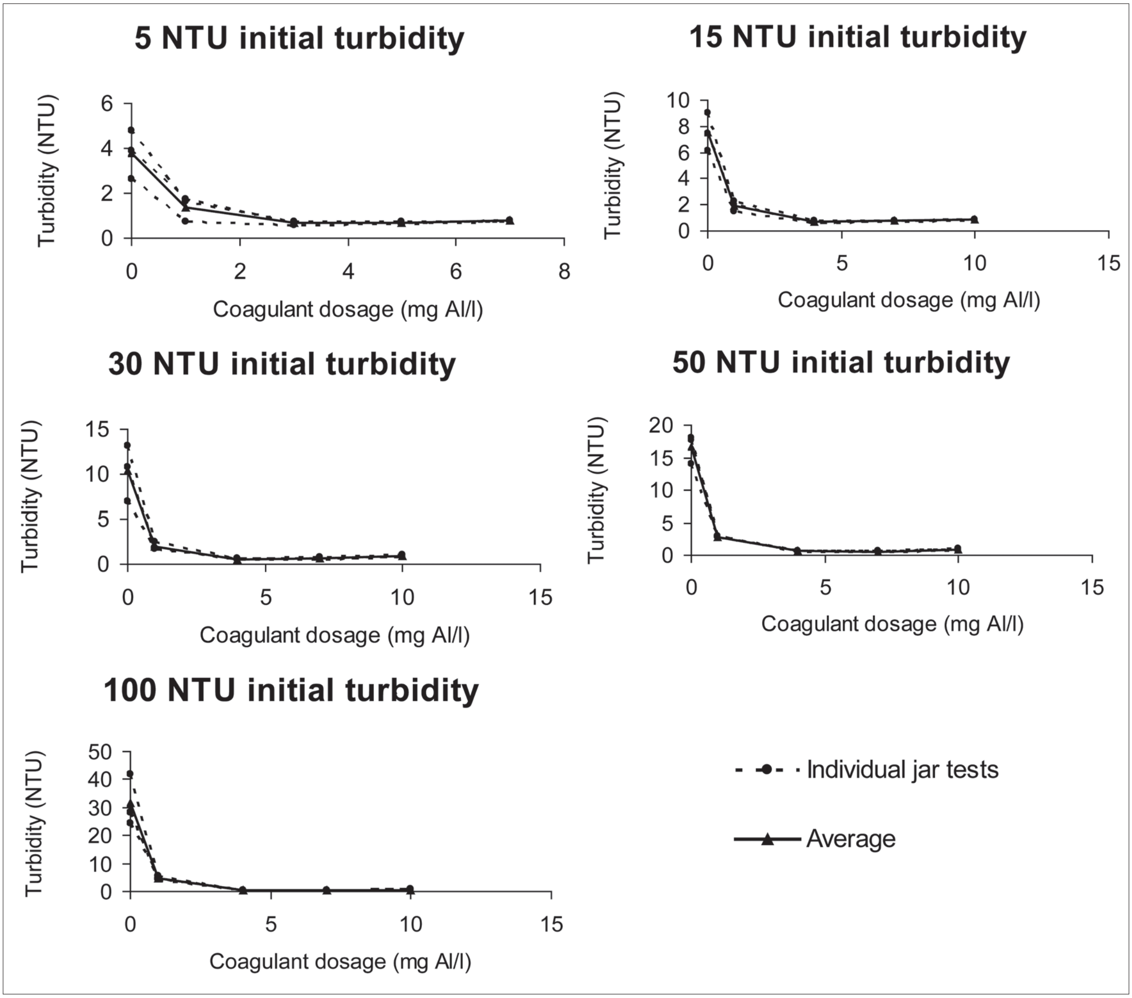

Figure 4. *Turbidity removal for raw water turbidity values in the range 5 to 100 NTU and aluminium sulphate as coagulant.*

ficult to measure with acceptable precision. A larger sample volume would increase the precision, but the measurements were already time consuming and unfortunately there was not enough time to filter larger volumes.

4.2. Optimum dosage and turbidity removal

4.2.1. Coagulation-flocculation with Alum sulphate

Results of optimum conditions of turbidity removal using Aluminium sulphate as the main reagent are presented in Figure 4 from which it is seen that coagulation with aluminium sulphate resulted generally in high removal efficiencies, irrespective of the raw water turbidity. The optimum dosage in all cases was between 3.0 and 4.0 mg Al^{3+}/l, corresponding to approximately 0.1g/l of solid $Al_2(SO_4)_3 \cdot 18H_20$. The coagulant formed large flocs that settled in 30 minutes and lead to a stable outgoing turbidity of 0.5–0.6 at the optimum dosage. The relative standard deviation for outgoing turbidity at optimum was 10–20 %, corresponding to approximately 0.1 NTU.

4.2.2. Coagulation with Moringa Oleifera

Coagulation-flocculation with *Moringa Oleifera* was done with reagent solutions extracted in three different ways. *Moringa Oleifera* extracts prepared with distilled water, was chosen as the standard preparation method to comply with earlier studies and also to reduce the number of unknown parameters in the tests. The other methods considered solutions prepared with distilled

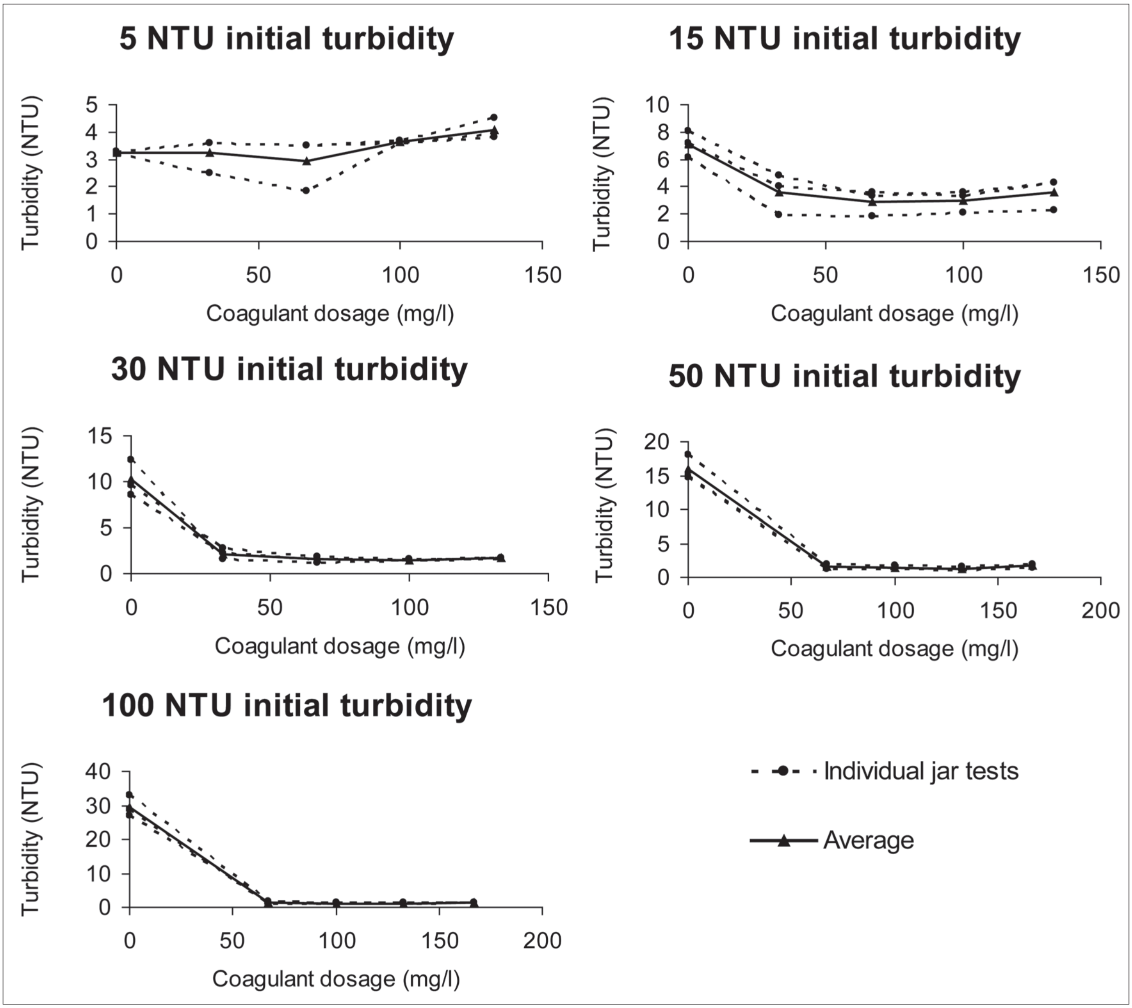

Figure 5. *Optimum dosage and turbidity removal at different levels of raw water turbidity using Moringa Oleifera extract prepared according to standard method.*

water and oil extraction and solutions prepared with tap water.

The results of optimum dosages and turbidity removal with MO prepared with the standard procedure are presented in Figures 5. The coagulant dosage indicates the mass of seeds that were used initially per litres of raw water, not the actual concentration of MO extract in the water. This difference is important to note since, a lot of the seed mass was separated during the filtration step when preparing the extract. The exact concentration of MO in the crude extract is therefore unknown.

For medium and high turbidity levels in the raw water (30–100 NTU), the optimum dosage was found between 40 and 70 mg/l and to more or less increase with increasing raw water turbidity. The outgoing turbidity at the optimum dosage ranged between 1–1.5 NTU. For low values of initial turbidity (5–15 NTU), the process was less effective since an optimum reagent dosage was generally not attained and the lowest outgoing turbidity remained around 3 NTU. Coagulation with MO extracted with distilled water resulted therefore in high removal efficiencies when the raw water turbidity was high but in poor efficiencies when the raw water had low values of turbidity (5 and 15 NTU). In the latter case, the treated water still had high amounts of suspended flocs even after 30 minutes of sedimentation. This indicates that flocs formed were either too small or not dense enough to settle within the 30 min-

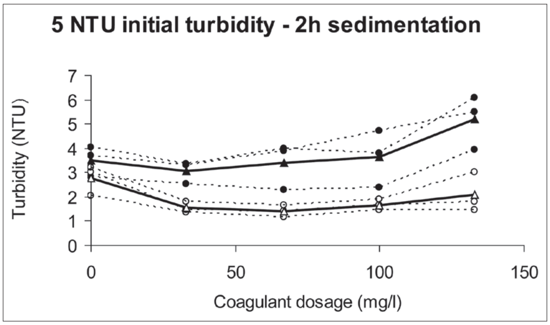

Figure 6. *Residual turbidity after 30 minutes (filled dots) and 2 h of sedimentation (empty dots) respectively, using an initial turbidity of approximately 5 NTU. Dotted lines show individual jar test results while solid lines indicate the average values.*

utes chosen for sedimentation. Complementary test with longer sedimentation time (Figure 6) confirmed this observation and resulted in significantly better removal efficiencies.

The prolonged sedimentation time resulted in an average outgoing turbidity of 1.4 NTU, a significant improvement. The extra sedimentation time indicates that coagulation of low turbid waters, using MO can only be effective if accompanied with long sedimentation times, which, in practical terms means large sedimentation basins.

The results of coagulation with MO prepared with distilled water and oil extraction as well as with tap water are presented in Figure 7. Two different levels of turbidity were tested; 15 NTU and 50 NTU. Preparation with oil extraction was conducted as recommended in previous studies (Ghebremichael, 2005; Narasiah & Ndabigengesere, 1998) which indicate that oil extraction helps prevent increases in COD of treated water. Preparation with tap water was used because it is more convenient for large scale production.

When solutions prepared with oil extraction were used, the average outgoing turbidity was 2.4 NTU, for 15 NTU initial turbidity and 1.9 NTU for 50 NTU initial turbidity at optimum dosage rates of 67 mg/l and 100 mg/l respectively (Figure 7, top). The relative standard deviation at optimum was 10 % for the low turbidity level, and over 50 % for the high turbidity. The latter was due to one jar test with much higher results than the other. The reason for this different result may have been bad coagulation properties of the seeds used to prepare the crude extract that day. The same extract was used in one of the jar tests at 15 NTU, and gave higher outgoing turbidities in that test as well, although not as extremely high as in the 50 NTU jar test. Another possibility is that the extraction process with cyclo-hexane removed

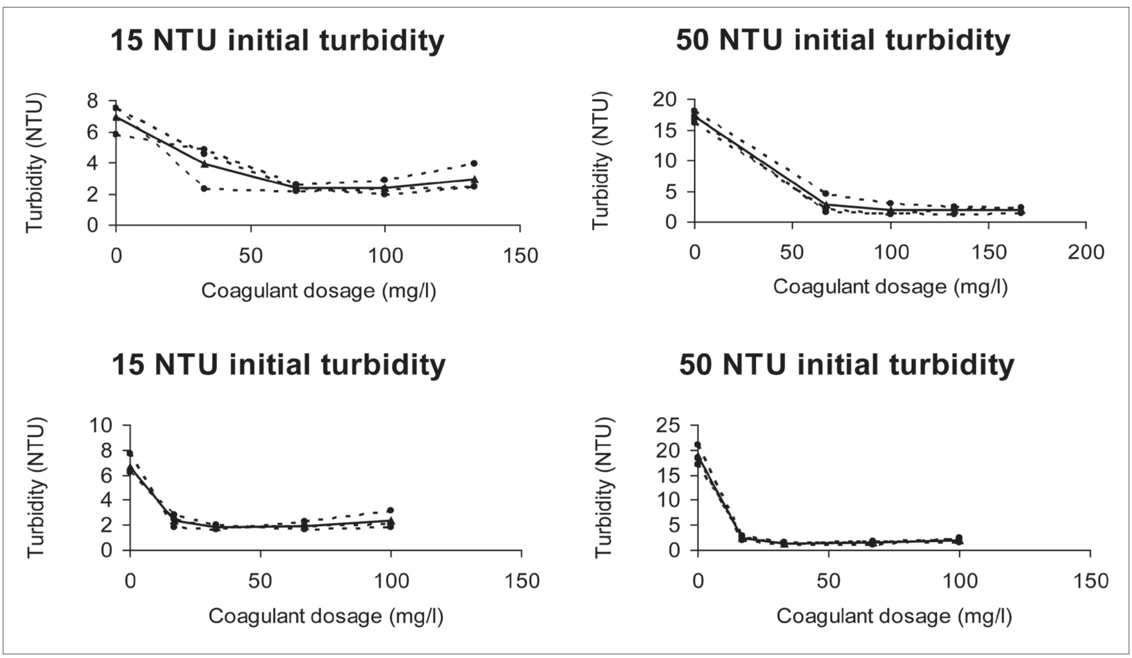

Figure 7. *Turbidity removal efficiency with Moringa Oleifera prepared with oil extraction (top) and tap water (bottom) and initial turbidity in the raw water of 15 and 50 NTU.*

some of the coagulating agents as well, thus lowering the coagulating ability of the crude extract.

When solutions prepared with tap water were used, the average outgoing turbidity was of 1.85 and 1.3 NTU for low and medium turbidity respectively (Figure 7, bottom). Optimum dosage rates were of about 33 mg/l for water with low (15 NTU) and medium (50 NTU) initial turbidity. The standard deviation at optimum was 10–15 %.

4.3. Effect on water quality

The effect of the reagents on some of the treated water quality, notably the water pH, alkalinity and EC is illustrated in Figure 8. As can be seen, coagulation with aluminium sulphate (Figure 8, right) led to a decrease in the water pH and alkalinity and to an increase in conductivity. These trends were confirmed statistically at 0.05 level of significance. These effects are also well known from previous studies (kemira, 2003) and use of aluminium sulphate throughout the world.

At an initial turbidity level of 15 NTU, the results from the COD analyses indicated a modest increase in COD from 1.6 to 2.4 mg O2/l. Bacterial contamination expressed as the number of total coliforms per 100 ml were reduced from >100 to 24. *Faecal* coliforms on contrary, increased from <1 to 18 counts per 100 ml while *faecal* streptococci were found to be >100 counts per 100 ml both before and after treatment. At 50 NTU initial turbidity, the COD decreased from 12.8 to 9.6

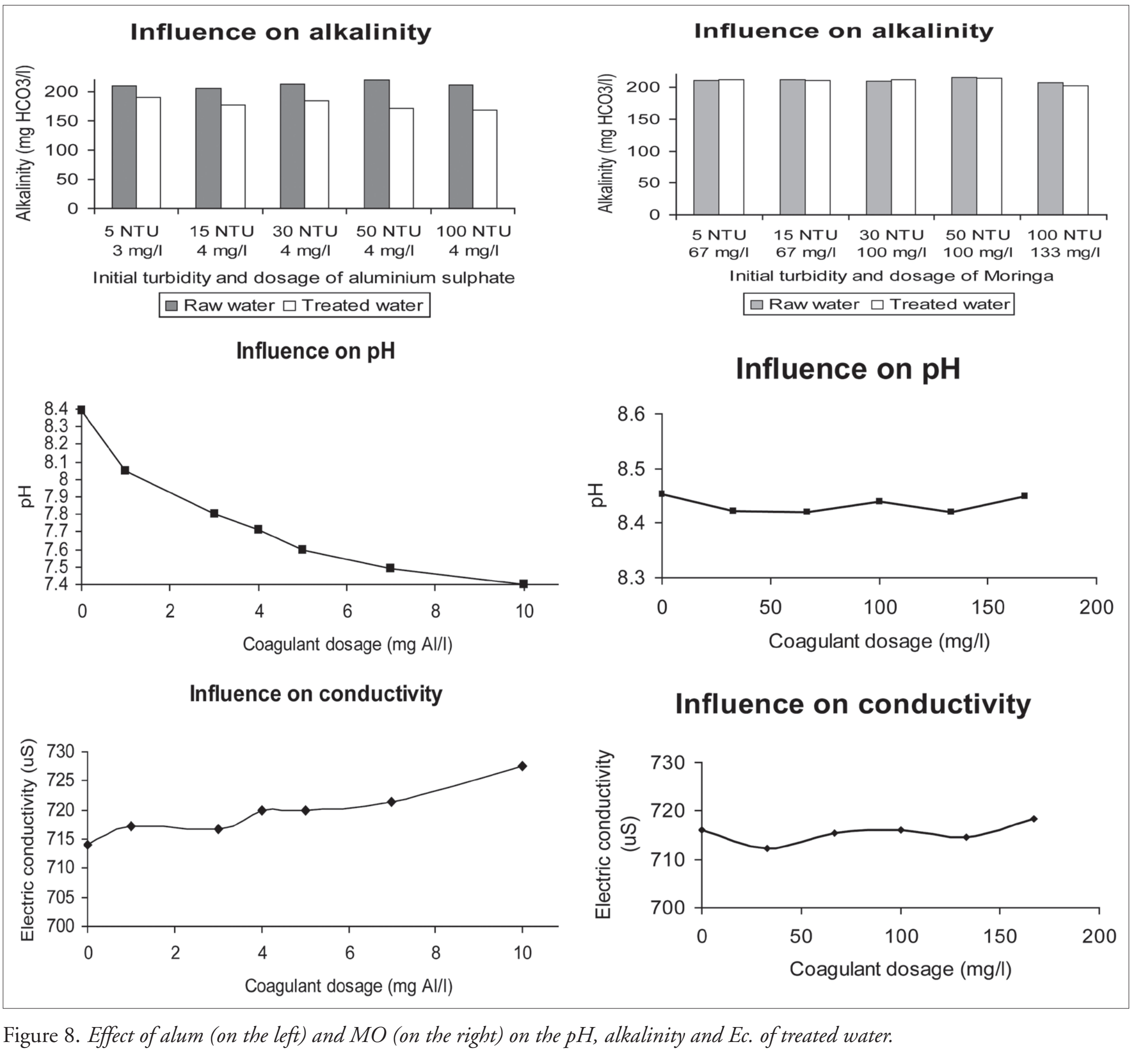

Figure 8. *Effect of alum (on the left) and MO (on the right) on the pH, alkalinity and Ec. of treated water.*

mgO_2/l. Altogether, these results are too few and too diverse to be reliable, and no conclusions can be drawn regarding the effect of aluminium sulphate on COD and on the microbial quality of treated water.

Treatment with *Moringa Oleifera* had no effect on the pH, alkalinity or conductivity of the treated water. The impact on COD levels and on the bacteriological quality of water was evaluated for initial turbidity of 15 and 50 NTU but the results are inconsistent. At 15 NTU, the COD results indicated an increase from 2 mg O2/l to 2.4 mg O2/l after sedimentation at optimum dosage, whereas at 50 NTU the result was a decrease from 40 mg O2/l to 7 mg O2/l. Considering the yearly variations of COD in the Umbeluzi river in 2006, where no value exceeding 9 mg O2/l was reported the high COD levels found in the samples indicates either that readings were misleading or that external sources of organic pollution (e.g. from the clay used to make artificial turbidity) existed.

The COD results from the 15 NTU turbidity level supports however the findings from previous studies (Ghebremichael, 2005; Ndabigengesere & Narasiah, 1998) that the use of MO leads generally to an increase in COD levels in the treated water. As for the bacteriological quality, the count in raw water resulted in >100 counts per 100 ml for all three bacteria types at 15 NTU turbidity level, and <1 counts per 100 ml for the equivalent at 50 NTU turbidity level. The amount of faecal streptococci were reduced to 3 after treatment at 15 NTU turbidity level, and the faecal coliforms were increased to 7 after treatment at 50 NTU turbidity level.

4.4. Comparison between coagulants and preparation methods

4.4.1. Optimum dosage and turbidity removal

Figure 9 provides a comparison of turbidity residuals after treatment at optimum dosage rates for all scenarios of raw water turbidity and coagulant reagent used. As can be seen, the efficiency of MO compared to aluminium sulphate was significantly lower in the jar tests. Aluminium sulphate led to outgoing turbidities of 0.5–0.7 NTU regardless of the initial turbidity, whereas MO never produced water with turbidity below 1 NTU. Treatment with aluminium sulphate resulted generally in a more stable effluent quality as is indicated by the relative standard deviation which was never more than 20 %, corresponding to 0.1 NTU.

In contrast, treatment with MO resulted in an effluent quality that varied considerably with the relative standard deviation reaching as high as 50 %. The relative standard deviation at optimum for high initial turbidity levels was however lower for MO than for aluminium sulphate. This could have resulted from the fact that,

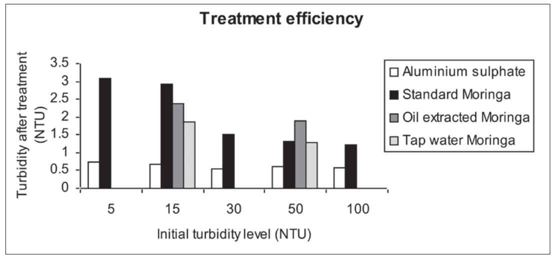

Figure 9. *Comparison of optimum dosage for different coagulants.*

when using Al for coagulation of water with high initial turbidity, high amounts of reagent are required which may lead to the formation aluminium hydroxide precipitates that increase turbidity levels in the effluent.

Overall, MO prepared with tap water was more efficient than the other two methods of preparation. The outgoing turbidity was lower, especially at high initial turbidity level, and the dosage needed to reach optimum was significantly lower. Coagulation with MO resulted also in smaller and lighter flocs than with aluminium sulphate. Small and light flocs settle more slowly therefore, they remain longer in the supernatant water. This explains the higher outgoing turbidity levels when MO was used as coagulant. Treatment efficiencies with MO could be improved by prolonging the sedimentation time to about 2 hours. While at laboratory scale these improvements are possible, at large scale operation, increasing duration of sedimentation means that larger investment is needed for construction of larger sedimentation basins. This is generally not feasible. Also, large scale operations flocs that do not settle during sedimentation will continue to subsequent stages of water treatment (filtration), where they may be removed at the expenses of higher costs of operation of filters.

4.4.2. Influence on water quality and characteristics

The effect of adding coagulation reagents on water quality and characteristics is illustrated in Figure 9. As can be seen MO coagulant shows a major advantage compared to aluminium sulphate; it does not affect neither pH and alkalinity nor conductivity and TDS, whereas aluminium sulphate influences all of these. No specific conclusion can be drawn regarding the effect on COD level and bacteriological quality of the water, due to lack of analysis results and large uncertainties in the existing results.

4.5. Filterability of formed suspensions

In large scale operations, the removal of particles from suspensions formed during coagulation-flocculation is

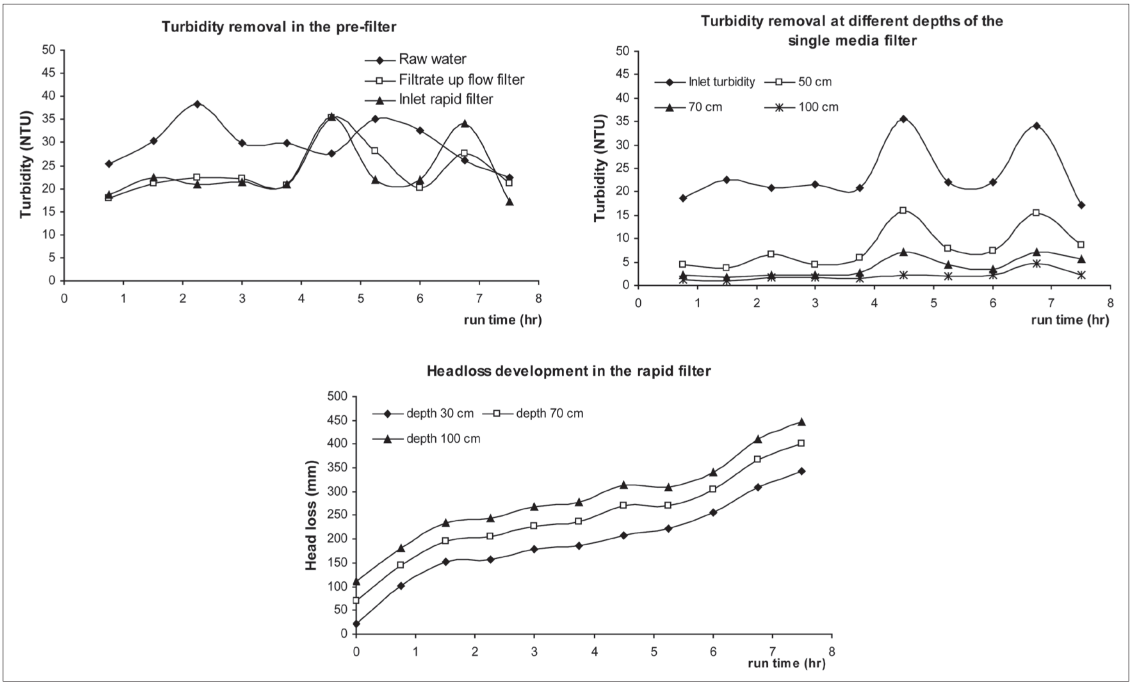

Figure 10. *Time-dependent turbidity residuals in the up-flow filter and single media gravity rapid sand filter and head loss development in the single media filter.*

accomplished by sedimentation followed by filtration in case of conventional treatment or by direct filtration when the sedimentation step is skipped. In order to assess the filterability of suspensions formed during coagulation with *Moringa Oleifera*, filtration experiments were conducted in a pilot plant consisting of an up-flow roughing filter used for hydraulic flocculation and a single media sand filter used for final treatmen. The results are resumed in Figure 10.

Raw water with an average initial turbidity of 30 NTU previously treated with MO extracts was used. Turbidity removal and head loss development were the variables used to evaluate the pilot plant's performance. The results obtained for the pre-filter (Figure 10-top left), indicates that turbidity removal was generally low and in average did not exceed 20 %. The effluent turbidity remained steady during the first 4.0 to 4.5 hours of filtration run but soon after that it started deteriorate and to experience variations. Two major factors might have contributed to this; first the relatively thin aggregates formed when coagulation was performed with MO as noted previously in this study and secondly the fact that the up-flow filter as was filled with a relatively coarse filtering material through which the relatively thin aggregates could flow without being retained.

The performance of the sand filter was much better. Average turbidity removals were in general above 92 % and the filtrate quality remained below 2.0 NTU throughout the entire test. As can be seen from Figure 10 (top-right) most of the particles were retained within the top 50–60 cm of the filter bed. This indicates that particles present in the suspensions transferred from the pre-filter were generally thin and could easily penetrate through the relatively fine filtering material used in the rapid sand filter. This also supports the observation made previously that flocs formed during coagulation with MO are generally thin and light which means they are poorly retained in coarse medium filters (e.g. roughing filters) or sedimentation tanks but are effectively removed in rapid sand filters.

The increase in head loss over filters indicates generally the extent of clogging due to particles being retained in the filter media. As shown in Figure 10, the head loss developed more or less linearly in the rapid sand filter. This indicates a time-dependent reduction of the filter bed porosity as a result of accumulation of particles, and also that a uniform penetration of particles through the depth of the filter bed was observed. It is also seen from Figure 10 that the head losses developed very rapidly during the initial stage of filtration, a fact that was attributed to rapid accumulation of particles in the upper layers of the filter bed.

The pressure drop in the pre-filter was in all cases of a few centimetres and in general negligible. This resulted from the fact that the pre-filter did not contribute for the retention of aggregates formed during coagulation-flocculation.

Similar tests performed with aluminium sulphate as the main coagulant and with raw water turbidity in the range 4.0 to 22NTU produced better results. Overall, filtrate turbidities ranging from 0.4–0.8NTU could be attained at the end of the treatment train. The increase of head loss pressure in both units was significant and generally higher than that observed when using MO. The results also indicated that aggregates formed during coagulation were effectively retained at the pre-filter and rapid sand filter. This is an expected pattern since coagulation with aluminium sulphate generally results in large and dense aggregates which are easily retained even within coarse filter media such as that used in the pre-filter.

4.6. Applicability at large scale operation

The optimum dosage of MO, using tap water, was found between 17 mg/l and 67 mg/l for both low (15 NTU) and medium (50 NTU) initial turbidities. Assuming daily water production of about 5 000 m^3/d which is enough for an average of 50 000 people at an average of 100l/person/day, an average dosage of about 40 g MO seeds/m^3, an average daily supply of about 0.2 tons of MO seeds is required if alum sulphate is replaced with MO. This corresponds to a plantation of about 60 ha if an average of 3kg seed kernels/tree is assumed with a tree spacing of about 3 m (WELL, 1999).

The area required for production of MO seeds is not entirely unrealistic particularly for small to medium size water supplies located in rural areas. Moreover, a hypothetical change from aluminium sulphate to MO may bring about significant reductions in transportation costs of imported chemicals. Yet, additional investments will be required concerning facilities for storage, grinding and mixing of the seeds.

The preparation of the extract should be carried out on-site to minimize transport costs and also because the extract must not be stored for too long before use. Since the extracts can be stored for one day without losing coagulation properties, batch processes designed for the demand of one full production day are probably more suitable than continuous process.

5. Conclusions

1 MO shows good coagulating properties, and has many advantages compared to aluminium sulphate; it does not affect the pH, alkalinity or conductivity of the water and it can be produced locally at low cost. The optimum dosage of MO, using tap water preparation method, was found to be between 17 mg/l and 67 mg/l for both low (15 NTU) and medium (50 NTU) turbidity levels.

2 The extraction of MO should be performed using tap water as this is the cheapest, most practical and most efficient method. MO does not show the same efficiency in turbidity removal as aluminium sulphate, particularly for low turbid waters. In this case, turbidity removal can be increased by increased sedimentation time at the expenses however of large investment and operational costs.

3 MO combined to direct filtration is less effective for turbidity removal than aluminium sulphate with direct filtration. Yet, the treated water turbidity when MO was used was within acceptable limits for drinking water production (less than 2 NTU) and the increase in head losses over the filters was not higher for MO than for aluminium sulphate. This suggests that MO could be a very good substitute for aluminium sulphate when using this technique.

4 MO is a method that can be considered as a good, sustainable and cheap solution for smaller waterworks, if the supply of MO seeds can be guaranteed. Tap water extracted MO and treatment with flocculation followed by direct filtration processes should be considered in the event of expansion or construction of small scale waterworks. Complementary tests should however be carried out in order to determine the impact of raw water pH on treatment efficiency.

5 Overall, the amount of seeds required for production of MO extract is quite large. On the other hand, the knowledge about actual production of MO seeds in Mozambique is limited which means the potential for large scale use of MO in drinking water production still needs further research. Aspects concerning pH dependence, COD increase and optimum direct filtration treatment design should also be further examined before the method is implemented at large scale basis. However, once plantations are established and the supply of seeds secured, MO provides a good, cheap and sustainable alternative to aluminium sulphate which should be considered as a coagulant in smaller waterworks.

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