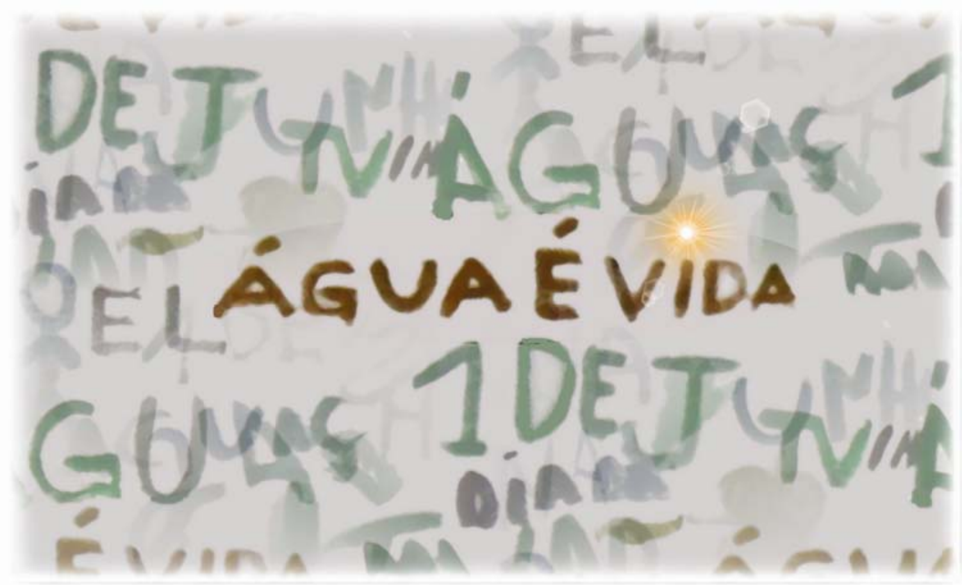
Assessment of drinking water treatment using Moringa Oleifera natural coagulant

A Minor Field Study in Maputo, Mozambique



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Front page photo: "Àgua é vida (Water is life)" - Inscriptions on a wall at the Maputo Waterworks (Aguas de Moçambique). Photo taken by E. Arnoldsson and edited by M. Bergman

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Resumo

O acesso à água potável é um dos principais desafios da Humanidade nos dias que correm. O recurso à fontes de origem superficial é prática comum em várias partes do globo principalmente naquelas situações onde a disponibilidade de fontes subterrâneas é limitada. O uso de águas de origem superficial exige no entanto tratamento cujo objectivo principal é a remoção de turvação e partículas suspensas da água bruta. A coagulação é um dos principais processos usados sendo prática comum, o uso de coagulantes produzidos na base de sais metálicos como sejam o sulfato de alumínio e o cloreto de ferro. O uso de sulfato de alumínio é também prática comum em Moçambique

Estudos realizados por vários investigadores têm mostrado que o uso de coagulantes naturais (e.g. Moringa Oleifera) pode ser alternativa viável aos sais metálicos na realização da coagulação da água. A Moringa Oleifera (MO) é uma planta silvestre que ocorre em várias regiões tropicais/subtropicais do Mundo cuja semente é tida como tendo propriedades coagulantes com potencial para uso na coagulação da água. Estudos realizados por vários investigadores mostraram já que a MO é bastante efectiva na remoção de turvação e partículas suspensas da água, tendo ainda a vantagem adicional de não alterar a qualidade química da água designadamente o pH e a alkalinidade da água. Tem no entanto como desvantagem principal a alteração do conteúdo em matéria orgânica da água tratada.

O presente relatório apresenta os resultados de uma pesquisa conduzida ao nível do Departamento de engenharia civil da Faculdade de engenharia da UEM sobre o uso da MO como coagulante natural no tratamento de água potável. A preparação das soluções de Moringa compreendeu três processos distintos designadamente a preparação com água destilada, a preparação com extracção de óleo e a preparação com água da rede.

No presente trabalho, faz-se uma comparação através de ensaios Jar Test, da eficiência de remoção de turvação com base no uso de sulfato de alumínio e Moringa. Os testes foram realizados para diferentes níveis de turvação da água bruta. Os testes compreenderam a determinação da dosagem óptima de coagulante tendo como base a Moringa Oleifera e o sulfato de alumínio. Para além da dosagem óptima, os resultados dos ensaios são usados para inferir sobre a influência da dosagem do coagulante na qualidade final da água em termos de pH, alkalinidade, matéria orgânica (COD) e contaminação bacteriológica. A pesquisa compreendeu ainda o uso da filtração por arrastamento.

Em termos de resultados, a pesquisa mostram que o uso dos sulfato de alumínio conduz à eficiência de tratamento aceitáveis para todos os níveis de turvação da água bruta mas conduz também a alterações significativas no pH e na alkalinidade da água.

A MO por sua vez não altera a qualidade da água em termos de pH e alkalinidade mas é pouco eficiente na remoção de baixos níveis de turvação. O uso de soluções de MO preparadas a partir da água canalizada conduziu à melhor eficiência de tratamento. O recurso à sedimentação prolongada das soluções coaguladas com MO permitiu melhorar a eficiência de remoção da turvação o mesmo acontecendo com o uso da filtração por arrastamento. O uso de MO combinada à filtração por arrastamento conduz portanto à melhores eficiências de tratamento quando comparado com o uso de sulfato de alumínio.

Embora atractivo em termos de sustentabilidade e custo, o uso da MO é ainda limitado como alternativa ao sulfato de alumínio principalmente quando os caudais a tratar são elevados. A MO pode no entanto constituir solução viável para pequenos sistemas de abastecimento de água principalmente quando estes fazem recurso à filtração por arrastamento para o pre-tratamento da água, antes da filtração.

Palavras chave: Moringa Oleifera, tratamento da água, coagulação, sulfato de alumínio.

Summary

The access to safe and clean drinking water is a major concern throughout the world. Surface water has become the most common source for raw water, when large quantities of groundwater often are inaccessible, and as surface water requires more treatment, simple, cheap and efficient process methods are necessary. Turbidity removal is essential for treatment of surface water and is often carried out with coagulation using metal salts as aluminium sulphate. This is used at Àguas de Mocambique (AdM), which provides the city of Maputo with water, but studies suggest that the metal salt can be replaced with a natural coagulant from the Moringa Oleifera tree.

The Moringa Oleifera (MO) tree grows in tropical and subtropical regions around the world and its seeds have been used in drinking water treatment in small scale in Sudan and India for generations. The coagulant in the seeds is believed to be one or several proteins that act as a cationic polyelectrolyte. The soluble particles in the water attaches to the active agent, that binds them together creating large flocs in the water. Previous studies indicate that MO is an efficient coagulant and does not have an effect on most of the properties of the water, but an increase in COD has been noticed. Different ways of extracting the active agents are used and this will have an effect of the treatment efficiency.

A comparison between MO and aluminium sulphate was conducted using jar test. The optimum dosage of the coagulant was investigated for different levels of turbidity, and monitoring of the properties of the water was performed. Use of MO together with roughing filter, and the possibilities to use MO at AdM was also investigated.

Most efficient treatment was found when using aluminium sulphate for all levels of turbidity but the coagulant had an effect on pH and alkalinity. MO had no effect on measured parameters and was found to be most efficient at high raw water turbidity. MO extracted with tap water gave a better treatment than the MO extracted with distilled water or oil, but neither had an impact on the characteristics of the water. A prolonged sedimentation time together with MO improved the treatment and the experiment with roughing filters was successful. Treatment with MO and roughing filter led to a more efficient treatment compared to aluminium sulphate and roughing filter.

Moringa is found to be a sustainable, cheap solution for coagulation in drinking water treatment. It is not considered possible to replace aluminium sulphate at AdM with MO at present time, but might be in the future. No current plantations of MO are located in the Maputo area and a stable and secure access to seeds is necessary. For best results MO is to be used together with roughing filters, which, will require reconstruction and investments at AdM. The possibilities of using MO at small scale treatment plants together with roughing filters are good, and provides a realistic alternative to conventional methods, presuming that an adequate amount of plantations are established.

Keywords: Moringa Oleifera, drinking water treatment, aluminium sulphate

Sammanfattning

Tillgången på rent och säkert drickvatten är ett stort problem runt om i världen. Ytvatten har blivit den vanligaste formen av råvatten, på grund av att stora mängder grundvatten oftast inte finns tillgängliga, och eftersom ytvatten kräver mer rening är enkla, billiga och effektiva metoder en nödvändighet. Att minska turbiditeten är en viktig del i reningen av ytvatten, och sker oftast med koagulering och flockning, där metallsalter som aluminiumsulfat används. Just aluminiumsulfat används på Àguas de Moçambique (AdM), som förser staden Maputo med vatten, men studier antyder att metallsalterna kan ersättas av ett naturligt koaguleringsmedel från trädet Moringa Oleifera.

Trädet Moringa Oleifera (MO) växer i tropiska och subtropiska områden runt världen och dess frön har använts i småskalig dricksvattenrening i Indien och Sudan i flera generationer. Koaguleringsmedlet är troligtvis ett eller flera protein som agerar likt katjoniska polyelektrolyter. De lösta partiklarna i vattnet binds till det aktiva ämnet och skapar stora flockar i vattnet. Tidigare studier påvisar att MO är ett effektivt koaguleringsmedel som inte har några effekter angående de flesta av vattnets fysikaliska egenskaper, men en ökning i COD har noterats. Olika sätt att extrahera det aktiva ämnet används och detta påverkar reningens effektivitet.

En jämförelse mellan MO och aluminiumsulfat genomfördes med så kallade jar tests. Den optimala dosen av koaguleringsmedlet undersöktes för olika turbiditetsnivåer, och vattnets fysikaliska egenskaper kontrollerades. Användning av MO tillsammans med direktfiltrering, samt möjligheterna att använda MO i stor skala vid AdM undersöktes också.

Den mest effektiva reningen, för alla turbiditetsnivåer, återfanns vid användning av aluminiumsulfat, med då påverkades både pH och alkalinitet. MO påverkade inte de fysikaliska egenskaperna och var mest effektiv för högre grumlighetsnivåer i råvattnet. MO som extraherats med kranvatten resulterade i bättre rening än MO extraherat med destillerat vatten och med oljeextraktion, men ingen av dem påverkade vattnets 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.

Moringa anses vara en hållbar och billig lösning att använda som koaguleringsmedel vid dricksvattenrening. För tillfället anses det inte vara möjligt att ersätta aluminiumsulfat på AdM med MO, men kan bli i framtiden. Det finns för tillfället inga plantager med MO i området kring Maputo, och en stabil och säker producent av frön är nödvändigt. För bästa resultat bör MO användas tillsammans med direktfiltrering och detta skulle kräva ombyggnad och investeringar på AdM. Möjligheterna att använda MO och direktfiltrering på reningsverk i mindre skala är däremot goda, och är ett realistiskt alternativ till konventionella metoder, förutsatt att plantager etableras i tillräcklig skala.

Nyckelord: Moringa Oleifera, dricksvattenrening, aluminiumsulfat

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The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work in a developing country resulting in a graduation thesis work, a Master's dissertation or a similar in-depth study. These studies are primarily conducted within subject areas that are important from an international development perspective and in a country supported by Swedish international development assistance.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of developing countries and their problems. An MFS should provide the student with initial experience of conditions in such a country. A further purpose is to widen the human resource base for recruitment into international co-operation. Further information can be reached at the following internet address: http://www.tg.lth.se , click at "MFS-stipendier".

The responsibility for the accuracy of the information presented in this MFS report rests entirely with the authors and their supervisors.

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Appendices

1 Introduction

1.1 Background

Drinking water is a vital resource for all human beings, and the access to safe and clean drinking water is a major concern throughout the world[1]. Producing potable water from surface water or ground water usually involves one or several treatment steps for removing unwanted substances. When surface water is used as raw water, turbidity removal is often an essential part of the treatment process. In order to make clean water an available resource for as many people as possible, cheap, simple, robust and efficient process methods are necessary.

At the waterworks of Aguas de Moçambique (figure 1), which provides Maputo with drinking water, aluminium sulphate, ($Al_2(SO_4)_3 \cdot 18H_2O$) is currently used as a coagulant for turbidity removal. However, a number of studies indicate that a natural coagulant from the Moringa Oleifera tree may be used as a substitute for metal salts[2]. Using Moringa instead of aluminium sulphate might give many advantages, such as smaller costs and less sludge production[3] and no need for importing the chemical (it is currently purchased from South Africa[4]). But there are also some disadvantages often connected with the use of Moringa, i.e. increased concentration of nutrients and COD[5].

Figure 1: *One of two treatment plants at Àguas de Moçambique. © AdM*

In this Minor field study, we will evaluate the possibility of using Moringa as an alternative to aluminium sulphate for the drinking water treatment in Maputo, and attempt to establish a procedure manual for the preparation, use and dosage of Moringa in order to use it for drinking water treatment.

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[1] WHO, 2007
[2] Ndabigengesere and Narasiah, 1998
[3] Ndabigengesere and Narasiah, 1998
[4] Matsinhe, 2007
[5] Bengtsson, 2003

1.2 Objectives

The overall aim of this field study is to assess the possibility of using Moringa as an alternative to the currently used coagulant, aluminium sulphate, and to establish a procedure manual for the usage of Moringa as a coagulant. An important part of the study is also to contribute to further understanding of the main factors affecting coagulation and flocculation mechanisms using Moringa.

The more specific objectives for this study include to:

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

2 Drinking water treatment and water quality

Water, H_2O, wherever present in nature, is always contaminated with various types of pollutants. Some of them are harmless, and sometimes even desired in the water whereas others need to be removed before the water can be used for drinking purposes. The following chapter describes the main aspects of drinking water treatment.

2.1 Parameters for drinking water quality

When evaluating the quality of drinking water, numerous parameters must be taken into account. The most important ones are presented and described below.

2.1.1 Bacteriological quality

The bacteriological quality has a large effect on the taste and smell of the water and can sometimes be a large problem in river waters. Eutrophication of the waters due to disposal of phosphorous from agriculture and wastewater, among others, favours algae and bacteria growth and can cause health risks.

Bacteria in waters can cause illnesses as typhoid (Salmonella typhi), cholera (Vibrio cholerae) and diarrhea (Giardia lamblia)[6].

Fecal coliforms and streptococci indicate that wastes from humans or animals contaminate the water[7]. Fecal streptococci are the most resistant group of bacteria, and are often analysed together with total coliforms as an indication of a total bacteriological status. Coliform bacteria can be removed from the water by chlorination[8].

2.1.2 Turbidity

The cloudiness of waters is referred to as turbidity and has its origin from particles suspended in the water[9]. These are natural contaminants and most often mineral particles such as clay and silt or organic flocs. Turbidity is a major problem in drinking water treatment when the water source is surface water but can often be neglected in treatment of groundwater[10].

Turbidity is usually measured in Nephelometric Turbidity Units (NTU), and is an optical measurement, where a light beam is transmitted through the water sample, and the amount of scattered and absorbed light is detected[11].

The World Health organisation allows drinking water with turbidity below 5 but recommends a turbidity level below 1 NTU.[12]

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[6] Hammer and Hammer Jr, 2004
[7] Environmental Protection Agency, 2007
[8] Degrémont, 1979
[9] Cech, 2005
[10] Knutsson and Morfeldt, 1995
[11] Hammer and Hammer Jr., 2005

2.1.3 Organic content – Chemical oxygen demand (COD)

The taste and smell of the water is affected by the amount of organic compounds in the water[13]. The organic content comes from both natural and anthropogenic sources and is often expressed as chemical oxygen demand (COD). COD is a measurement of the amount of oxygen it takes to degrade the oxidizable, mainly organic content of the water, and is expressed in mg O_2/l[14].

2.1.4 Hardness

The amount of calcium (Ca) and magnesium (Mg) decides the hardness of the water. Strontium (Sr) and barium (Ba) also contribute to the hardness but since the presence of these ions is so low they are often neglected[15].

Water with a high total hardness will cause problems with deposits and corrosion. This situation occurs when calcium carbonate and carbon dioxide in the water is not in equilibrium[16].

$$Ca^{2+} + 2HCO_3^- \leftrightarrow CaCO_3 + H_2O + CO_2$$

The calcium carbonate will in the case of a low amount of free carbon dioxide lead to deposits and corrosion. The equilibrium depends on temperature and affects the lime precipitation[17].

The hardness of a water can be described in several units such as the German hardness scale, °dH, or equivalents of $CaCO_3$.

2.1.5 pH and alkalinity

The pH and alkalinity of the water will have an impact on the water quality and are closely linked to corrosion[18].

pH is defined as the negative 10-logarithm of the hydrogen ion activity in the water, and thus indicates the amount of hydrogen ions in the water[19]. Alkalinity is the water's ability to neutralise added hydrogen ions, or buffering capacity. The main buffering species include carbonates (CO_3^{2-}), hydroxides (OH^-) and hydrogen carbonates (HCO_3^-) in the water[20]. Since corrosion is caused by calcium carbonate (as described above), the corrosion process is dependent on the pH and alkalinity of the water.

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[12] Degrémont, 1979
[13] Kemira Kemwater, 2003
[14] Kemira Kemwater, 2003
[15] Kemira Kemwater, 2003
[16] Kemira Kemwater, 2003
[17] Kemira Kemwater, 2003
[18] Kemira Kemwater, 2003
[19] Cech, 2005
[20] Warfvinge, 1997

2.1.6 Ions, conductivity and total dissolved solids (TDS)

Examples of commons ions in the water are iron (Fe^{2+}), manganese (Mn^{2+}), nitrate (NO_3^-) and nitrite (NO_2^-). There are several others as well, but the above mentioned are some of the most important regarding drinking water quality aspects. Iron and manganese also has an impact on the taste, colour and odour of the water and can cause deposits in pipes[21]. Fluoride (F^-) is another common ion in waters, which can in too large amounts cause discoloration of the teeth in drinking water[22].

Conductivity is a measurement of the waters ability to lead electricity and depends on the amount of ions in the water. Conductivity increases with the content of dissolved salts in the water, and is also dependent on the temperature. It is measured in Siemens/m.

TDS represents the total amount of dissolved solids in water. Since water is a highly polar solvent, most of the dissolved matter will be in the form of ions. The TDS value is therefore often closely linked to the conductivity[23]. TDS is measured in ppm or mg/l.

2.1.7 Heavy metals and toxic substances

The concentration of heavy metals in drinking water should be carefully monitored as well as toxic substances. The recommended values from WHO varies from 10 μg/l (lead, Pb) down to 3.0 μg /l (cadmium, Cd)[24].

Pesticides from agriculture have become a problem in the last fifty years. Their toxic character and their reluctance to biodegradation make them a problem in water quality[25].

2.1.8 Recommended values for drinking water

Values for different parameters are presented in table 1 below.

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21 Kemira Kemwater, 2003
22 Kemira Kemwater, 2003
23 NALMS, 2007
24 WHO, 2006
25 Kemira Kemwater, 2003

***Table 1.** Recommended values in drinking water.*[26]

SUBSTANCE OR PROPERTY	MAXIMUM DESIRABLE CONCENTRATION	MAXIMUM PERMISSIBLE CONCENTRATION
Total solids	500 mg/l	1500 mg/l
Turbidity	5 NTU	25 NTU
Iron (Fe)	0.1 mg/l	1.0 mg/l
Manganese (Mn)	0.05 mg/l	0.5 mg/l
Copper (Cu)	0.05 mg/l	1.5 mg/l
Zinc (Zn)	5 mg/l	15 mg/l
Calcium (Ca)	75 mg/l	200 mg/l
Sulphates (SO_4)	200 mg/l	400 mg/l
Chlorides (Cl)	200 mg/l	600 mg/l
pH	7 to 8.5	6.5 to 9.2
Total hardness	100 mg $CaCO_3$ / l	100 mg $CaCO_3$ / l

2.2 Treatment process for production of potable water

This chapter describes the treatments steps for producing drinking water from surface water in more general terms. The design of the treatment process varies between different treatment plants, and also depends on the raw water source and quality, and the requirements regarding quality of the final product, the drinking water.

Groundwater is generally the best source for drinking water, since it has a naturally low content of contaminants[27]. Sometimes it can even be used directly as drinking water without prior treatment. When treatment is needed, common steps involve removal of hardness (calcium and magnesium) and disinfection. However, groundwater is not always present in sufficient amounts for drinking water production[28].

Surface water generally requires more treatment than ground water, since it is more easily contaminated with various substances.

Treatment of drinking water can be either mechanical or chemical, and in some cases even biological. Mechanical treatment removes solids and material physically. By chemical treatment contaminants and substrates are removed by adding chemicals, whereas biological treatment is done with help of microorganisms and mainly used in slow sand filtration. The most common steps in drinking water treatment are presented below.

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[26] Degrémont, 1979
[27] Knutsson and Morfeldt, 1995
[28] Kemira Kemwater, 2003

2.2.1 Screening

Screening is usually the very first step in treatment of surface water. It consists of one or several screens, designed to remove coarse contaminants from the water[29].

2.2.2 Pre-alkalinisation and pre-chlorination

The quality and characteristics of the raw water, such as its pH, alkalinity or organic content, affects the efficiency of the chemical and biological treatment steps[30]. It may therefore sometimes be necessary to adjust one or several of these parameters in a pre-treatment step.

Pre-alkalinisation is done in order to adjust pH and/or alkalinity before the coagulation. Coagulation and flocculation is more or less pH-dependent, depending on the coagulant used (see chapter 2.2.3) and many coagulants also affect the pH themselves. The latter can partly be prevented by adding carbonate or bicarbonate (hydrogen carbonate), which raises the alkalinity of the water and makes it more resistant to changes in pH.[31]

Pre-chlorination has an oxidizing effect on various substances in the water, such as iron, manganese, organic matter and microorganisms[32]. It improves the water quality and prevents clogging and bacterial growth in the following treatment steps[33]. It is however a controversial method, since chlorine can react with organic matter to form toxic and/or carcinogenic compounds, such as trihalomethane (THM)[34].

2.2.3 Coagulation and flocculation

Smaller particles, which are not removed by the grit, can sometimes be separated by means of sedimentation or filtration. Many particles in surface water are however so small that they settle extremely slowly, or not at all. In the coagulation and flocculation process, these small particles are aggregated into larger units, which can easily be removed in the following sedimentation and filtration steps[35].

Suspended and/or dissolved particles in water, such as clay, organic matter etc., usually have a net negative charge on the surface. They thus tend to repel each other rather than to aggregate. During coagulation, positively charged ions (usually aluminium or iron ions) are adsorbed on the surface of the particles, reducing their net charge and facilitating the forming of flocs. The forming of flocs is referred to as flocculation[36].

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[29] Kemira Kemwater, 2003
[30] Kemira Kemwater, 2003
[31] Kemira Kemwater, 2003
[32] Degrémont, 1979
[33] Degrémont, 1979
[34] Matshine, 2007
[35] Kemira Kemwater, 2003
[36] Kemira Kemwater, 2003

Common coagulants used for drinking water production are e.g. aluminium sulphate, ferric chloride, polyaluminium chlorides and synthetic polymers. All of these have in common the ability of producing positively charged ions when dissolved in water, which can contribute to charge neutralization[37].

Aluminium sulphate and ferric chloride will also react with water to form aluminium or iron hydroxides, thus lowering the pH of the water. The formed hydroxides tend to form polymers, which through a bridging action between contaminants contribute to the flocculation process. The phenomenon where polymers are adsorbed on the surface of two particles and thus joining them together is also known as patch coagulation[38].

Sweep coagulation is another process, which will occur when a coagulant is added to the water, and is usually the main coagulation process in waters of low turbidity. When a positively charged ion is adsorbed on the surface of a particle, layers of hydroxides may start to grow on the surface of the particle, gradually making the particle bigger. As the particle starts to sink it will bring along other contaminants, which will be enmeshed in or adsorbed to the hydroxides[39].

The dosage of coagulant depends on several parameters such as type and concentration of contaminants, pH, temperature etc[40]. It also depends on the way the coagulant is added. Rapid stirring ensures adequate mixing, and so does dosing below the surface. The optimal dosage for a specific water is defined as the dosage which gives the lowest turbidity in the treated water (see figure 2). Dosage beyond the optimum point will, apart from obvious disadvantages such as increased aluminium/iron content in the water, also lead to an increase in turbidity[41].

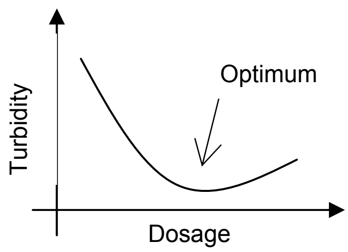

***Figure 2.** Optimum dosage for a specific turbidity level.*

[37] Kemira Kemwater, 2003
[38] Kemira Kemwater, 2003
[39] Kemira Kemwater, 2003
[40] Kemira Kemwater, 2003
[41] Mpagi Kalibbala, 2007

2.2.4 Separation

The flocs formed during the coagulation-flocculation process can be separated by several means, and the separation is ususally done in two steps; sedimentation or flotation followed by filtration[42].

Sedimentation is based on the principle that gravitational forces will make flocs and particles sink to the bottom of a tank or container, where they can be removed through an outlet[43].

In a flotation process, pressurized air is introduced at the bottom of the tank. The air will form small bubbles in the water, onto which the flocs will attach and float up to the surface. The foam formed at the surface is then removed mechanically[44].

2.2.5 Filtration

The filtration step can be used both in connection with separation of flocculated particles, and as an individual treatment. In both cases the main goal is removal of suspended solids with a small particle size, in large amounts. All filters will be exposed to gradual clogging when particles are trapped, and need to be cleaned regularly. In rapid sand filters this is done by backwashing the filters with clean water, whereas in slow filtration the microbial degradation is enough to prevent clogging.

Rapid sand filters most often occur directly after the sedimentation/flotation step and separates the last remaining flocs that failed to disappear during sedimentation. The filtration rate for a rapid filter is 5-10 m/h and the material is often coarse sand. Rapid sand filters have no biological degradation[45].

Slow sand filters are built on biologically active layers where algae and microorganisms break down or coagulate the suspended solids. Slow filters are sometimes used for treatment of surface waters without any prior coagulation or sedimentation. The filtration rate is less than 0.3 m/h and the filter reduces colour, taste, odour and the amount of COD in the water. It has also been found that the removal of micropollutants such as pesticides and phenols are not satisfactory good enough in slow sandfilters[46].

If the sedimentation step is omitted, and the flocculated water is led directly to filtration, the process is called direct filtration. This can be used to treat waters with low natural turbidity and color[47].

As an alternative to sedimentation, filters with coarse media of various size, also known as roughing filters, can be used. The size of the filter media is gradually decreasing throughout the filter, with the largest units close to the inlet and the smallest at the outlet. The water produced by

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[42] Kemira Kemwater, 2003
[43] Kemira Kemwater, 2003
[44] Hammer and Hammer Jr, 2004
[45] Kemira Kemwater, 2003
[46] Degrémont, 1979
[47] Hammer and Hammer Jr, 2004

coagulation/flocculation followed by filtration in roughing filters can produce water with a quality equal to that of a standard coagulation-flocculation-sedimentation process, but with smaller costs for both investment and operation[48].

2.2.6 Post-alkalinisation and post-chlorination

Alkalinisation is sometimes needed for compensating for the pH drop due to the aluminium sulphate added in the coagulation step. Recommendations for the EU are that the water leaving the treatment plant should have a pH between 6.5-9 (in Sweden 7.5-9). Lime ($CaCO_3$) is a common chemical used for this purpose[49].

As a last step before the water leaves the water treatment plant chlorination is often performed, in order to kill microorganisms in the water.

2.3 The drinking water treatment in Maputo

The area of Maputo city is home to 1.7 million people and not half of these have access to tap water[50]. Earlier this year, investigations showed that there were a big number of illegal connections to the water distribution system leading to higher cost for those who have a legal connection[51].

2.3.1 The Umbeluzi river

The raw water used for drinking water production in Maputo is taken from the Umbeluzi river, which originates from the northwest of Swaziland close to the South African border, and ends south of Maputo in the Indian Ocean. The turbidity varies greatly over the year, due to the heavy rains and larger flows in the rainy season (October-April). Figure 3 presents the monthly average, maximum and minimum values for different characteristics in Umbeluzi river. All values are from 2006 except temperature, microbial count and conductivity, which are from 2003. Unfortunately, no more recent data could be found for these three parameters. The data was obtained from Àguas de Moçambique, 2007.

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[48] Matsinhe, 2007
[49] Kemira Kemwater, 2003
[50] European Investment Bank, 2006
[51] Afrikagrupperna, 2007

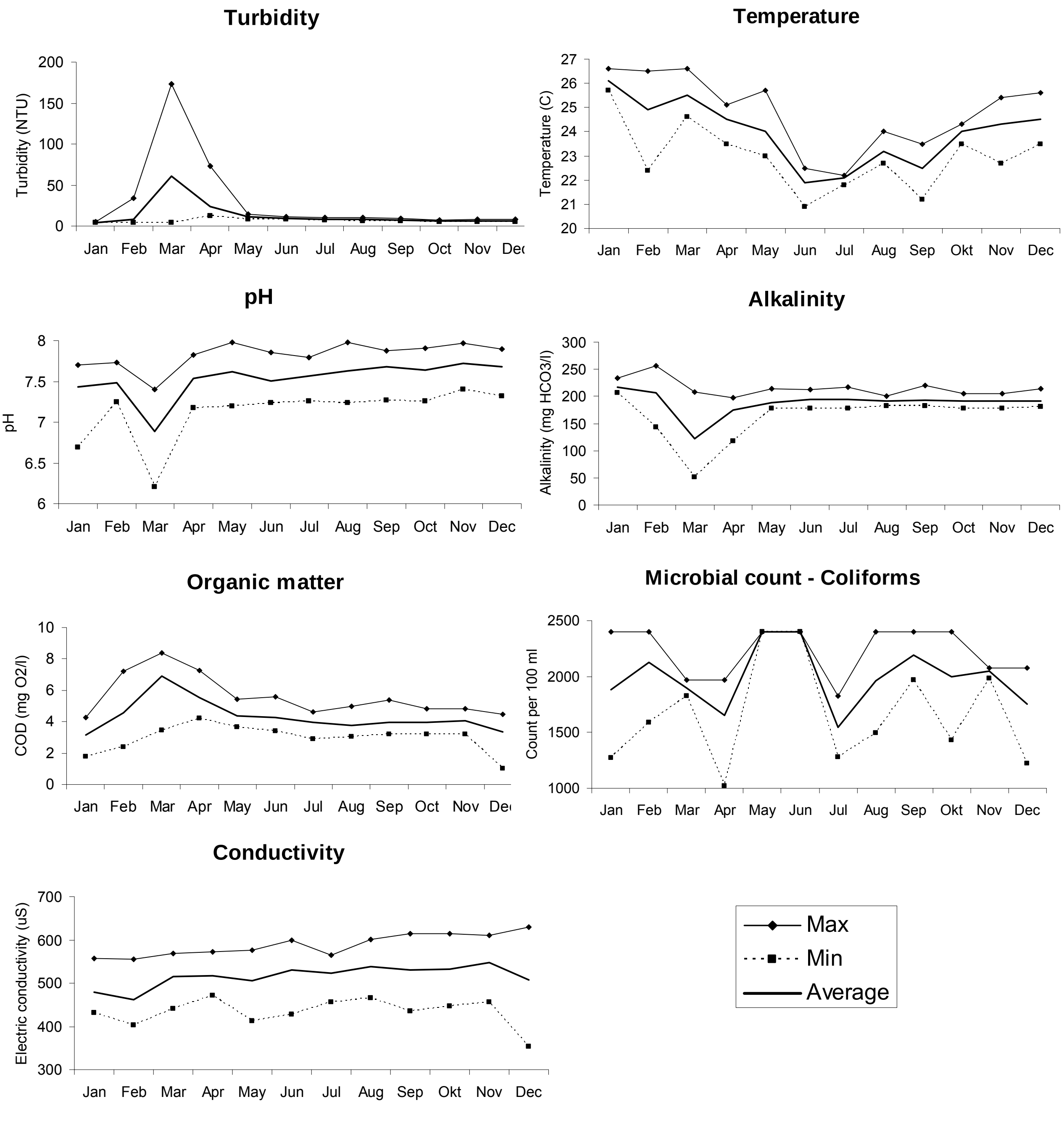

Figure 3. *Minimum, maximum and average for different characteristics in the Umbeluzi river. Values for pH, turbidity, alkalinity and organic matter are from 2006 and conductivity, temperature and microbial count are from 2003.*

2.3.2 Àguas de Moçambique and the Maputo waterworks

The drinking water treatment plant that supplies Maputo with potable water is situated by the Umbeluzi river in the Boane region, about 30 km from Maputo. Water treatment has been carried out on this location since the beginning of the 20th century. Originally, the capacity was a mere 2500 m^3 of potable water produced per day. Since then, the waterworks has been reconstructed and rebuilt several times, and has now two separate stations producing water (but with identical treatment steps) and a production maximum of approximately 7500 m^3 potable water per hour. The treatment plant is owned by the government, but leased and run by a private company; Águas de Moçambique (AdM)[52].

The treatment process involves most of the above described steps, according to the following list:

1. Screening
2. Pre-chlorination by gaseous chlorine
3. Addition of aluminium sulphate (main coagulant) and, in case of high turbidity, a polyelectrolyte to improve the flocculation process. The average daily use of aluminium sulphate is 3.5 tonnes
4. Flocculation in circular tanks
5. Sedimentation and sludge removal. The sludge, which contains a lot of aluminium, is released downstream in the river.
6. Rapid sand filtration
7. Post-alkalinisation with lime. The average daily use of lime is 50 kgs.
8. Post-chlorination with gaseous chlorine

After the treatment the water is distributed to 5 water towers around Maputo. Table 2 shows the consumption of aluminium sulphate and related costs for the first 3 months in 2006. As can be seen, the cost for aluminium sulphate can exceed 1 billion Mt., or almost 40 000 USD, in one single month.

Table 2. *Consumption of aluminium sulphate and related costs for January-March 2006 at the Maputo waterworks*[53]

	USE (KGS)	COST (MT.)	COST ($)
January	60 478	288 421 490	11 000
February	73 392	350 006 448	13 500
March	213 708	1 019 172 021	39 000
Total	347 578	1 657 599 959	63 500

The associated cost is one of the main drawbacks with the use of aluminium sulphate as a coagulant. However, the current dosage equipment is not optimal, and the amounts of aluminium sulphate used could probably be reduced if the dosage procedure was optimised[54].

Another problem is the sludge, which is released back in the Umbeluzi river downstream from the raw water intake, without any prior treatment. The sludge contains large amounts of aluminium, which at low pH can be toxic to aquatic organisms such as fish.[55]

[52] Gildo, 2007
[53] Gildo, 2007
[54] Persson, 2007
[55] Mannion and Bowlby, 1992

3 The Moringa Oleifera tree

3.1 General description

Moringa Oleifera (see figure 4) is a perennial plant that grows very fast, with flowers and fruits appearing within 12 months of planting. They grow up to a height of 5-12 meters and pods 30-120 cm long[56] and are harvested up to two times a year in India[57]. The tree prefers lowlands in hot semiarid conditions with sandy or loamy soils[58] but is known to adapt to new conditions quickly. It tolerates light frost, a soil pH of 9 and can live in areas with annual rainfall off up to 3000 mm. Today it can be found on elevations up to 2000 m in Zimbabwe[59].

With its origin in India and Pakistan M. Oleifera was brought to the Africa continent and Sudan in particularly for ornamental purposes during the colonial era. The women of Sudan soon discovered the abilities of the tree and have used the seeds for water treatment since the beginning of the 20th century[60]. The natural coagulant found in Moringa Oleifera is present in 6 of the 14 species of Moringa growing in Africa, Madagascar, India and Arabia. Moringa Oleifera is the only one of the species in the botanic family that is present in tropical and subtropical regions around the world, and is therefore the most famous[61].

The different purposes of the tree are many as all parts of the tree are used. Oil extracted from the seeds is used for working machinery, cosmetics, cooking and soap. The press cakes, what is left after the oil extraction, is used as soil fertilizer. Pods and leaves are used for eating both by humans and animals, as they contain a lot of vitamins. Using the tree as a vegetable is the main reason that it has been cultivated in large scale in India, but this is yet the only commercialized part of the tree[62]. Different parts of the tree are used in traditional medicine for treating diarrhoea and epilepsy among others[63], and some even claim to be treating tumors[64]. The wood pulp can be used for papermaking and the tree itself can be used as a fence, natural windbreaks or fuel[65].

***Figure 4**: Moringa Oleifera tree. © M. Bergman*

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56 Lilliehöök, 2005
57 WELL, 1999
58 Schwarz, 2000
59 Lilliehöök, 2005
60 Schwartz, 2000
61 Schwartz, 2000
62 Sutherland et al, 2001
63 Trees for life, 2006
64 Lilliehöök, 2005
65 Trees for life, 2006

3.2 Treating drinking water with Moringa Oleifera seeds

The knowledge that seeds from the Moringa Oleifera tree can purify water is not new; the seeds have been used for generations in countries like India and Sudan[66]. Women of Sudan has used the technique of swirling seeds in cloth bags with water for a few minutes and let it settle for an hour. This procedure is today recommended by different agencies (PACE and ECHO etc.) for people with limited access to clean water.

The required area for cultivation of Moringa when used for drinking water treatment is dependent on the raw water and dosage. With a production of 3 kg seed kernels per tree and year and a dosage of 100mg/l, 30 000 litres of water can be treated from on tree. By assuming tree spacing of 3 m, an area of 1 ha can treat 30 000m^3 annually[67].

Figure 5 shows a photo of shelled Moringa Oleifera seeds from this study.

Figure 5. *Dried and shelled Moringa Oleifera seeds. © M. Bergman*

3.2.1 Characteristics of the active agents

The coagulant in the seeds was first confirmed by the German scientist Samia Al azharia Jahn[68]. The active agent is believed to be a protein, but the exact form of the protein is not yet known. Recent research have identified proteins of sizes ranging from 3 to 60 kDa, all possessing coagulating ability, which means that the Moringa seeds probably contain several different proteins that may act as coagulants. The protein(s) act as a cationic polyelectrolyte[69], which attaches to the soluble particles and creates bindings between them, leading to large flocs in the water[70] (see chapter 2.2.3). Stirring and mixing accelerates the electrostatic flocculation, and the flocs condense the contaminants[71].

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[66] Lilliehöök, 2005
[67] WELL, 1999
[68] Schwartz, 2000
[69] Sutherland et al 1994
[70] Lilliehöök, 2005
[71] Göttsch, 1992

3.2.2 Extraction of the active agents

Extraction of the coagulants can be done in several ways. Most of them, including recommendations for domestic use, follow the pattern: dried seeds are ground, with or without shells, using either a kitchen blender or a mortar. The powder is mixed with a small amount of water and the solution is stirred and filtrated[72]. The filtered solution is called a “crude extract” or “stock solution” and could be used for treating water without further preparation.

Several studies show that salt water and/or tap water are more efficient as solvent for the active agent, compared to distilled water. The study from Okuda et al. 1999, showed that the coagulation capacity was up to 7.4 times higher with moringa extracted with NaCl than with destilled water. The reason for this is assumed to be that the coagulating protein is more soluble in waters with high concentration of ions[73]. 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[74]. A more low-tech way of reducing the organic content is to extract the oil from the seeds with an organic solvent[75].

3.2.3 Coagulation efficiency and influence on water quality

The coagulation and flocculation ability of the seeds has been investigated in several different projects around the world[76]. These previous studies have shown that neither pH nor alkalinity or conductivity were affected during the treatment, but an increase in COD, nitrate and orthophosphate has been observed[77]. Some studies indicate that treatment with Moringa are dependent on the pH of the raw water were optimum is above neutral[78], whereas others say it is independent of raw water pH[79]. The treatment efficiency is dependent on the turbidity of the raw water, as revealed in previous studies from Katayon et al. It was shown that Moringa is more efficient if the water has high inital turbidity[80].

Moringa 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 it is disposed of[81].

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[72] Ndabigengesere and Narasiah, 1998, Muyibi and Alfugara, 2003, Ghebremichael et al., 2005
[73] Okuda et al, 2001 (a)
[74] Ghebremichael, 2005, Ndabigengesere and Narasiah, 1998
[75] Ghebremichael, 2005
[76] Ndabigengesere and Narasiah 1998, Bengtsson 2003, Muyibi and Alfugara 2003, etc
[77] Bengtsson, 2003, Ndabigengesere and Narasiah 1998
[78] Okuda et al 2001 (b.)
[79] Schwartz, 2000
[80] Katayon et al, 2004
[81] Ndabigengesere et al., 1994

The Moringa coagulant can also be used in combination with other flocculation salts, such as aluminum sulphate[82]. The use of Moringa Oleifera on a large scale has been tested in a drinking water treatment plant in Malawi with good results[83].

3.2.4 Storage of seeds and extract

Previous studies indicated that storage of the crude extract is not possible in order to remain good coagulation. Storage of the crude extract will lead to a decrease of treatment efficiency with an increase in duration of storage[84]. The study does not discuss the reason for this but it could be assumed that it is due to microbial degradation of the proteins. Differences in temperature and container did not have any affect on the properties. Duration of storage should not be above 24 hours as degradation of active agents is though to occur within this time. A study from Katayon et al 2004, shows that stock solution stored for three days has between 73.6 % and 92.3% lower turbidity removal depending on the turbidity of the raw water. The study also states that the highest removal efficiency were performed by solutions stored maximum one day[85].

Storage of seeds and its influence on coagulation properties has been investigated by Katayon et al 2006. Seeds were dried, crushed and stored in different containers at different temperatures. The study concluded what the temperature and 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 the seeds stored for three and five months.

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[82] Ndabigengesere and Narasiah 1998
[83] Sutherland et al 1994
[84] Katayon et al, 2006
[85] Katayon et al, 2004

4 Methodology

4.1 Preparation of coagulant and raw water

Dried and shelled Moringa Oleifera seeds were obtained from IIAM (Agronomic research institute of Mocambique) via the Department of Chemical Engineering at Faculty of Engineering. The shells were ground to a fine powder using a mortar. The powder was weighed and dissolved in distilled water to make a 50 g/l solution. The solution was then 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 also tested, 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 then first dissolved in hexane, stirred for 30 minutes and filtrated through a filter as the one mentioned above. The remaining solids in the filter ("press cake") were then dissolved in water, stirred and filtrated in the same way as previously described. The tap water preparation process was identical to the standard method mentioned above, but with tap water as a solvent instead of distilled water.

The raw water used throughout the study was obtained from the Umbeluzi river, on a location just next to the raw water intake at Aguas de Mozambique. New water was collected approximately every second to third day, and stored in a plastic tank in the lab. The water in the Umbeluzi river has a low natural turbidity during the months when this study was carried out (September and October), and for most test series the water had to be spiked with artificial turbidity. This was done 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 turbidity.

4.2 Jar tests

Jar test is the most commonly used way of determining the efficiency of a coagulant, since it is easy to perform[86]. The equipment used in this study was a Janke & Kunkel jar test apparatus with 5 beakers (see figure 6). Each jar was filled with 1.5 l of raw water with identical turbidity level, and the initial stirring rate was set to 120 rpm. Different volumes of the selected coagulant was then added to 4 of the jars (number 1-4, see figure 6). After 3 minutes the stirring rate was lowered to 40 rpm and this rate was kept for 17 minutes. Then the propellers were stopped completely and the jars were left for 30 minutes sedimentation. After the sedimentation phase the parameters described below were measured on the supernatant in each jar.

For each coagulant and turbidity level, three identical jar tests were carried out in order to obtain statistically reliable results. However, some of the parameters were only measured during one of these three jar tests and/or in the jar with the optimal dosage, due to restricted time and economic means. If

[86] Ndabigengesere and Narasiah 1998

the optimal dosage was not found in the jar test, a new jar test with new dosage was carried out until the optimum was found.

Figure 6. *Jar test equipment in action.*

4.2.1 Measured parameters

Turbidity was measured with a 2100P turbidimeter from Hach. The initial turbidity was measured 3 times on the raw water while stirring, and the average value from the three measurements was used as a starting value. After the sedimentation phase, samples for turbidity measurement were collected from the supernatant using a standard pipette. The sample beaker was washed once with distilled water and twice with the supernatant before recording the turbidity. Each measurement took 1-2 minutes, washing included, thus the last jar to be measured upon had in fact been sedimentating for up to 40 minutes. In order to eliminate any differences in turbidity due to different sedimentation times, two samples were taken and measured from jars 1-4 in the following order: 1-2-3-4-4-3-2-1, and the average value was recorded.

Temperature was measured with a regular thermometer held for 1 minute in the water, and the observed temperature was rounded to the nearest integer.

pH and conductivity were measured with automatic waterproof meters from Wagtech International Ltd, and TDS was measured with a waterproof TDScan Low (0-1990 ppm) from Eutech Instruments. These were held for 1 minute (or until a stable value had been reached) in the water.

Alkalinity was measured by means of titration. Phenolphtalein and mixed indicator solution of methyl red and bromcresol green were added to a 50 ml sample, 3 to 4 drops of each indicator. The phenolphtalein is used for indicating high alkalinity values, and the mixed indicator is used for the lower alkalinity range. A solution of hydrochloric acid was then added to the sample, using a 725 Dosimat automatic titration equipment from Metrohm. The added volume of acid was noted at the colour changes (from pink to transparent for phenolphtalein and from blue to yellow for the mixed indicator). The alkalinity was then calculated using the following equations:

$$meq/l = \frac{a \cdot N \cdot 1000}{c} \quad (P)$$

$$meq/l = \frac{b \cdot N \cdot 1000}{c} \quad (T)$$

$where:$

$a = ml\ titration\ fluid\ used\ when\ fenoftaleina\ was\ used$

$N = Molarity\ of\ HCl\ (calibrated)$

$c = ml\ of\ sample$

$b = ml\ titration\ fluid\ used\ when\ mixed\ indicator\ was\ used$

$$when\ P \leq 1/2\, T$$

$$HCO_3^- = T - 2P \left(meq/l \right) = (T - 2P) \cdot 61 \left(mg/l \right)$$

Calibration of the molarity of HCl was done once a week and done by using 25 ml of Na_2CO_3, 0.02M. Mixed indicator solution was added, 3-4 drops, and titration took place until a colour change took place, from blue to green. When this happened the bottle was heated and let to boil for 2-5 minutes and then cooled down under a lid to prevent dissolution of CO_2 from the air. When the solution had obtained room temperature the titration continued until the solution reached the colour of yellow-black. The amount of HCl was noticed and the molarity of the HCl was calculated by:

$$N = \frac{V1 \cdot N1}{V}$$

$where:$

$V1 = Volume\ of\ Na_2CO_3$

$N1 = Molarity\ of\ Na_2CO_3$

$V = Volume\ of\ HCl$

COD and bacteriological analyses were conducted by the laboratory at the Ministry of Health in Maputo. For the bacteriological analysis, sterilized bottles were received from the laboratory in which the samples to be analysed were collected. The bottles were filled completely to minimise the dissolution of air oxygen, and thereby aerobic degradation, in the samples. This was done for only two turbidity levels per coagulant and/or extraction method, 15 and 50 NTU, since the procedure was quite time consuming. The bacteria types that were analysed were total coliforms, fecal coliforms and fecal streptococci.

Suspended solids was measured by drying glass microfibre filters in an oven at 150 ºC for 1h, then letting them cool down for 15 minutes in a desiccator and weighing them on scales with 0.1 mg precision. The drying and weighing procedure was repeated until all humidity had been removed from the filters, i.e. until the filter weights did not change between measurements. Next, 200 ml samples with different turbidity were passed through the filter using a compression unit, and the filters were dried again, now at 105 ºC, for one hour, cooled down in a desiccator and weighed. Once more, the procidure of drying and weighing was repeated until a stable value had been reached. The difference in weight before and after filtration was noted, and divided by the sample volume in order to obtain the suspended solids concentration.

The concentration of suspended solids was measured for 6 different levels of turbidity and a calibration curve was created, 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 can easily be converted into approximate values of suspended solids.

4.3 Filtration test with roughing filter

The pilot scale plant with roughing filters at the laboratory of hydraulics was being run for one day with tap water extracted Moringa coagulant. The initial turbidity of the raw water used was 8.7 NTU, and the dosage of Moringa extract 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 rapid sand filter, and the turbidity and piezometric pressure was measured every 30 minutes at several points along the filters.

4.4 Investigation of applicability in large scale at AdM

The possiblity of using Moringa in a large scale in Maputo was evaluated mainly by personal communication with staff at the Faculty of Engineering and by literature study. In addition, results and conculsions drawn from the jar tests and filtration tests were discussed in the aspect of potential use in industrial scale at Àguas de Moçambique.

4.5 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 rise from the lack of calibration for the equipment used in measuring turbidity, pH, conductivity and TDS. The dosage for the flocculation was not done at the exact same time in each jar, leading to time differences for the mixing of the water. The time of mixing was at a few times too long, and the sedimentation time was quite frequently too long since there was only one turbidimeter available at the lab, and it was often used by others.

However, the main factors affecting the jar test results are believed to be differences in preparation of raw water and Moringa extract. As for the raw water preparation, the size of the clay particles may have varied a lot, due to the manual grinding procedure. The difference after sedimentation between the water samples not treated (beaker 0) could give an indication of the correct results. Differences up to 50% are obtained and the results of the treated water should be looked at with the same level of uncertainty. The results for the water treated with Moringa might be higher considered the source of error concerning grinding of the seeds and the quality of the seeds, since this has not been investigated in this study and the size of the error is therefore unknown.

COD and bacteriological analyses were done at the Health ministry, and the lack of control over these analyses makes it one source of error. For example, the time passing between filling the bottles with samples and the actual analysis can be important 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. Regarding the analyses of the bacteriological quality of the water, all the obtained results were given as either "<1" or ">100" per 100 ml, which only gives a very rough estimation of the real number.

The r^2-value for the calibration curve used for suspended solids shows that the certainty of the measured values could be better.

5 Results and discussion

5.1 Raw water characteristics

The characteristics of the raw water were measured at the laboratory, except for COD and bacteriological analyses, which were made at the Ministry of Health. These samples were taken straight from the river, unlike the other parameters that were measured just before the jar tests. Previously to each jar tests temperature, pH, turbidity, conductivity were tested. Alkalinity was measured once for each turbidity level and COD and bacteriological quality for turbidity levels 15 and 50. These values were fairly stable throughout the experiment period, and are presented in table 3 below.

Table 3. *Raw water characteristics*

Temperature	23 °C	± 2
pH	8.4	± 0.2
Conductivity	720 µS/cm	± 10
TDS	490 ppm	± 10
Alkalinity	212 mg/l	± 8
COD	*	*
Bacteria	*	*

**The results are not presented since the measurements are too few and too diverse to be reliable. Individual results can be found in Appendix B*

Due to the small natural variations in pH and temperature around the year, these parameters were not changed and focus was put on variations in turbidity. Most coagulants perform less effective in low temperatures, but this will not affect the study as the temperature of Umbeluzi river is stable throughout the year, and only varies with a few degrees as shown previously in figure 3 in chapter 2.3.1.

Measured values of pH, conductivity and alkalinity were all higher than given values from previous measurements from Umbeluzi (see figure 3 in 2.3.1). The average monthly pH-value at the raw water intake ranged from 6.9-7.7, which are 1-1.5 units lower than the pH of the water used in this study. The conductivity and TDS values were also higher in the raw water used in this study, between 30-50% higher than the monthly average values at the intake. Since samples in this study were collected from a location just downstream the waterworks, the increase in pH and alkalinity could be explained by the disposal of sludge containing $Al(OH)_3$ from the plant The sludge also contains a large amount of ions, which can explain the increase in conductivity and TDS.

The difference in pH is important to note, since, as reported in chapter 2.2.3, the efficiency of most coagulants is dependent on the raw water pH. This must be taken into consideration when discussing and evaluating the possibility of using a new coagulant in the drinking water treatment process.

The calibration curve for converting turbidity measurements into approximate levels of suspended solids is shown in figure 7. As can be seen, the results indicate a more or less linear relationship, except for the low turbidities (below

10). The reason for the bad correlation at low turbidity values is probably that the total mass of suspended solids in a 200 ml sample with low turbidity is very small, around 1 mg, which is difficult to measure with high precision. A larger sample volume would increase the precision, but the measurements were already very time demanding and unfortunately there was not enough time to filter larger volumes.

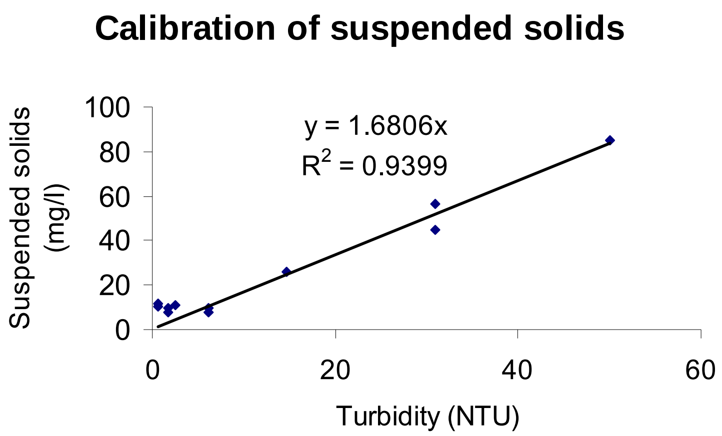

Figure 7. *Estimated relationship between turbidity and suspended solids*

5.2 Aluminium sulphate

5.2.1 Optimum dosage and turbidity removal efficiency

The graphs in figure 8 below show the turbidity removal for various levels of turbidity and dosage of $Al_2(SO_4)_3$.

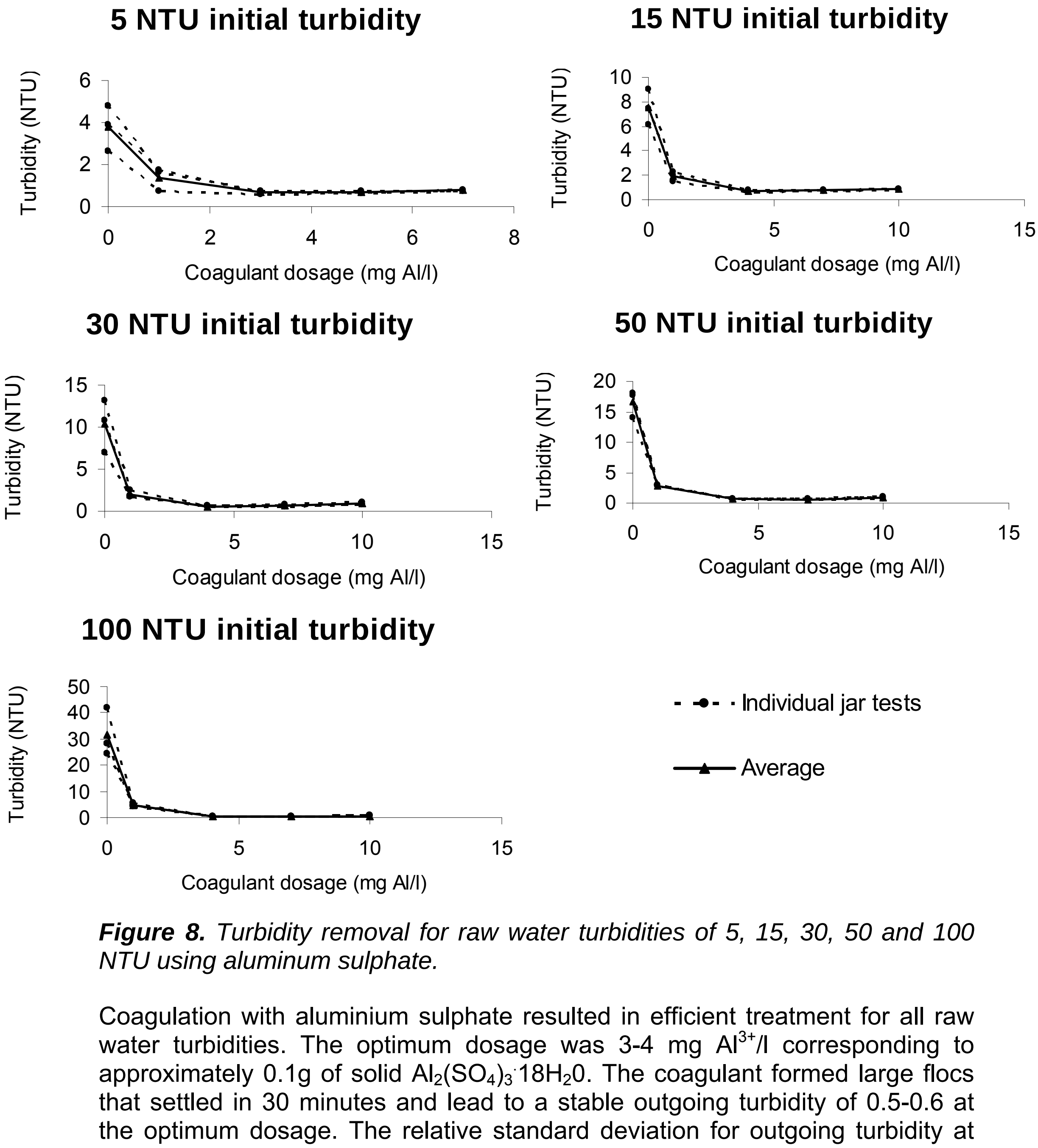

Figure 8. *Turbidity removal for raw water turbidities of 5, 15, 30, 50 and 100 NTU using aluminum sulphate.*

Coagulation with aluminium sulphate resulted in efficient treatment for all raw water turbidities. The optimum dosage was 3-4 mg Al^{3+}/l corresponding to approximately 0.1g 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.

5.2.2 Influence on water quality and characteristics

Figure 9 below shows how the conductivity, alkalinity and pH of the water are affected by dosage of aluminium sulphate.

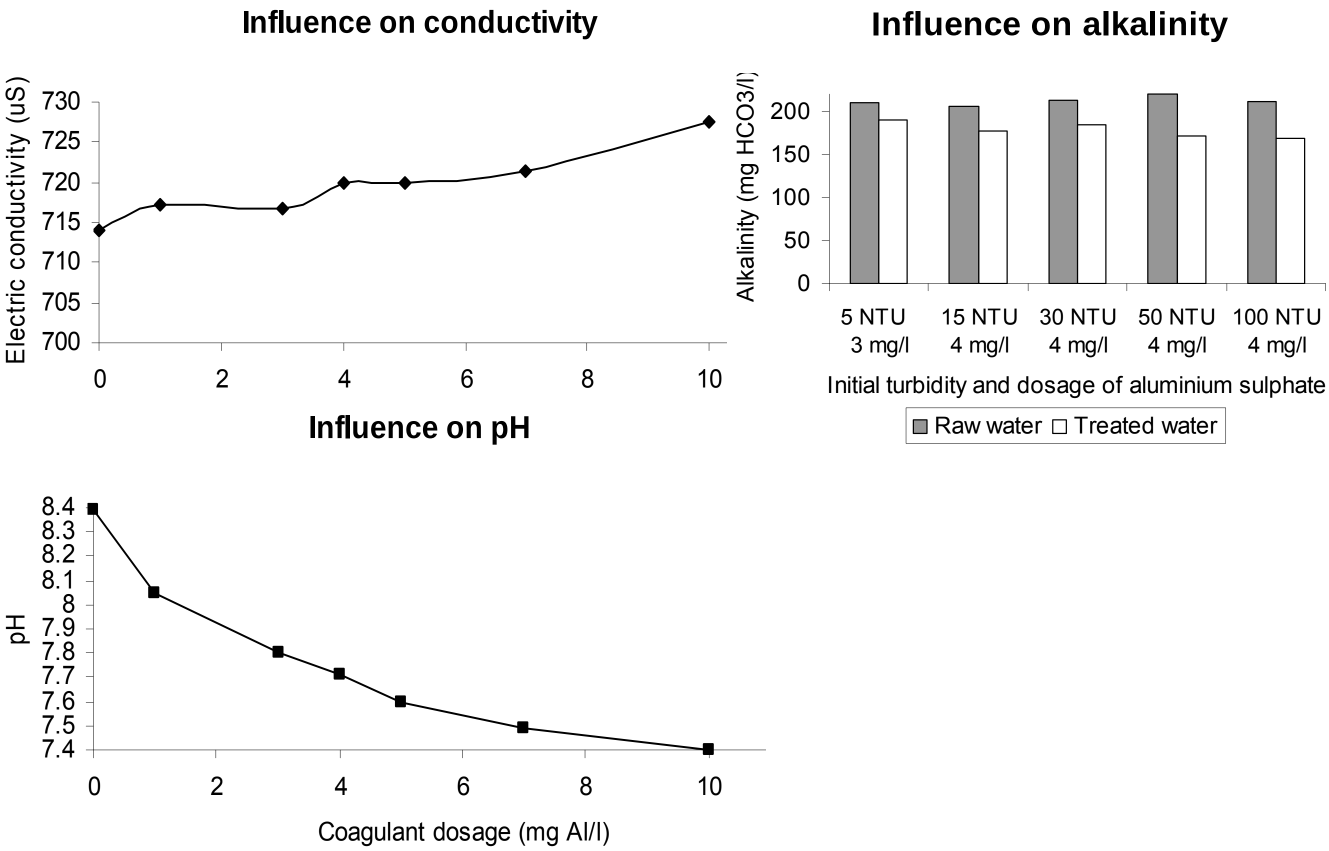

Figure 9. *Influence on conductivity, pH and alkalinity using aluminium sulphate.*

It is seen that coagulation and flocculation using aluminium sulphate led to a decrease in pH and alkalinity, and an increase in conductivity. All these trends were confirmed statistically with a 0.05 level of significance. These effects are also well known from previous studies and use of aluminium sulphate throughout the world, as reported in chapter 2.2.3.

At an initial turbidity level of 15 NTU, the results from the COD analyses indicated an increase in COD from 1.6 to 2.4 mg O_2/l. The number of total coliforms per 100 ml were reduced from >100 to 24, and the fecal coliforms increased from <1 to 18 counts per 100 ml. Fecal 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 mg O_2/l, and the microbial count reduced from >100 to 8 and 3 for total coliorms and Fecal coliforms. The fecal streptococci reduced from 98 to <1 after treatment. 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 bacteriological quality.

5.3 Moringa Oleifera, standard preparation method

Moringa Oleifera, prepared with distilled water, was chosen as the standard preparation method because of earlier studies done with distilled water, and to reduce the number of unknown parameters in the tests.

5.3.1 Optimum dosage and turbidity removal efficiency

Figure 10 below shows the turbidity removal for various levels of turbidity and dosage. The coagulant dosage indicates the mass of seeds that were used initially per litres of raw water, not the actual concentration of Moringa extract in the water. The difference is important, since a lot of the seed mass was separated during the filtration step when preparing the extract. The exact concentration of Moringa in the crude extract is therefore not known.

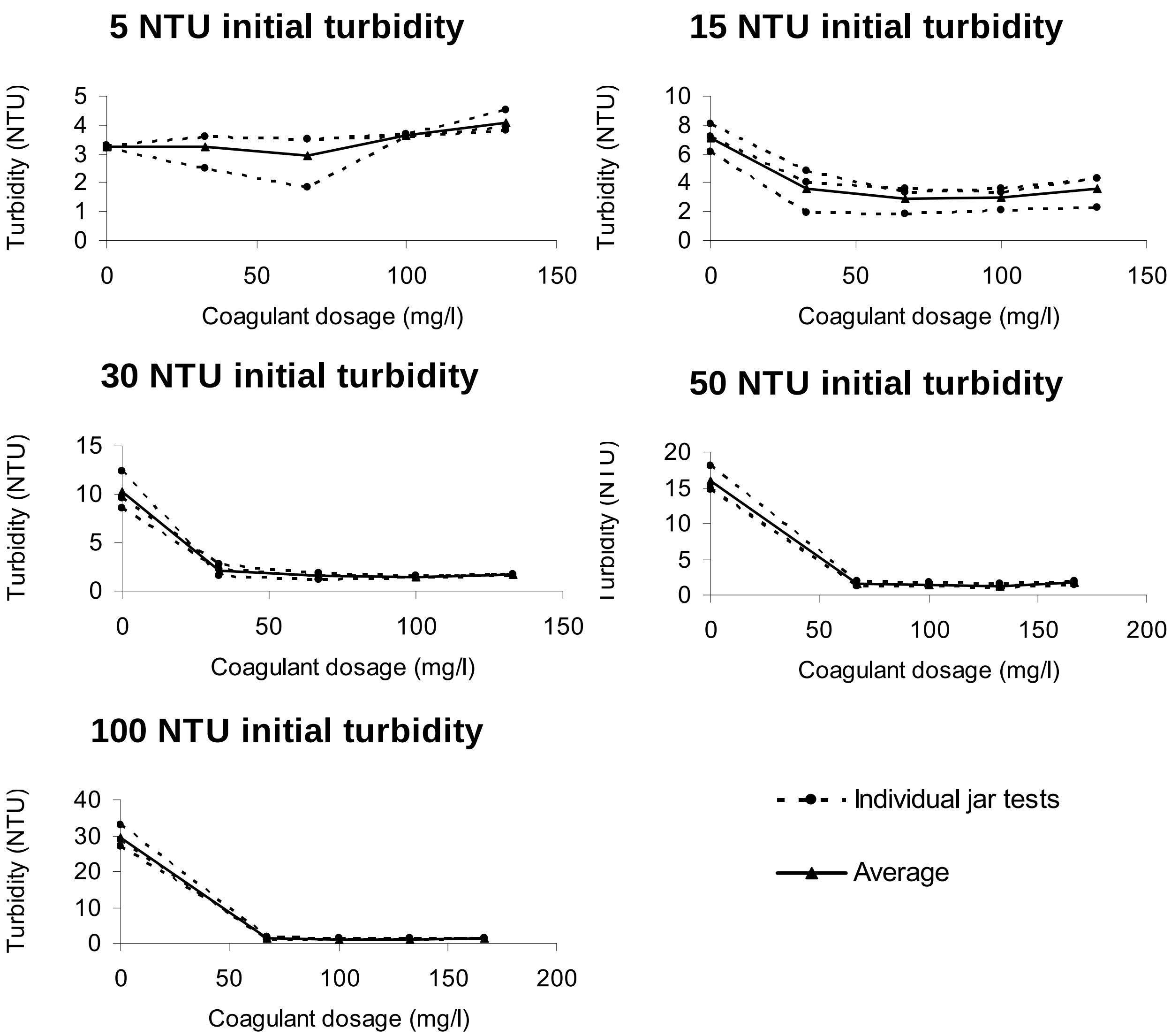

Figure 10. *Optimum dosage and turbidity removal at different levels of turbidity using Moringa Oleifera standard preparation as coagulant.*

For medium and high turbidity levels (30-100 NTU), the outgoing turbidity at the optimum dosage ranged between 1-1.5 NTU. For low levels of turbidity (5-15 NTU) the lowest outgoing turbidity remained around 3 NTU.

As can be seen above, Moringa extracted with distilled water (standard preparation method) showed poor removal efficiency for lower levels of turbidity (5 and 15 NTU). The treated water displayed a high amount of flocs still suspended in the supernatant after 30 minutes of sedimentation, indicating that these flocs were either too small or not dense enough to settle in 30 minutes. Complementary test with a longer sedimentation time confirmed this theory and resulted in significantly better treatment efficiency. This is seen in figure 11 below.

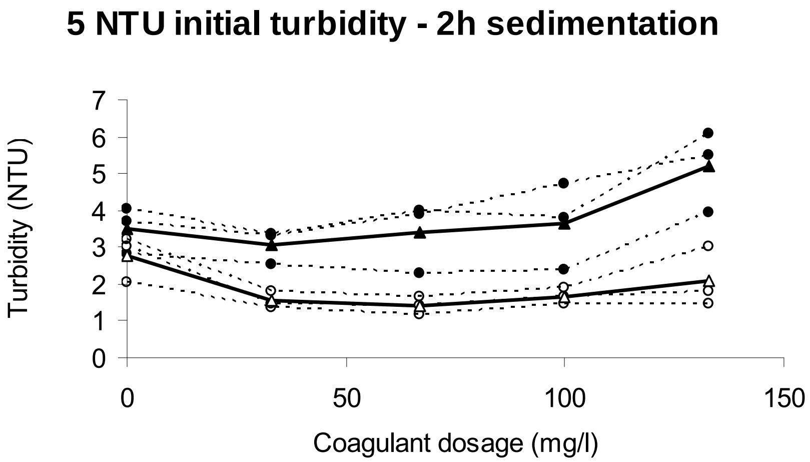

Figure 11. *The turbidity level after 30 minutes of sedimentation (filled dots) and 2 h of sedimentation (empty dots) respectively, using an initial turbidity of approximately 5 NTU. Dotted lines show individual jar test results and solid lines the average values.*

The prolonged sedimentation time resulted in an average outgoing turbidity of 1.4 NTU, a significant improvement. The extra sedimentation time indicates that coagulation using Moringa can result in efficient removal for low as well as high turbidity. However, if used in an industrial scale, increased sedimentation time will lead to lower production of potable water or a need of investment in largers sedimentation basins, which is not always possible nor feasible.

Flocs that do not settle during sedimentation will be removed during the following filtration. If a large fraction of the flocs pass through the sedimentation step without settling, it will lead to a high load on the filters, and increase the clogging. The filters will thus need to be backwashed more often, which also will have a negative impact on the drinking water production rate.

The graph in figure 12 below summarizes the treatment efficiency and optimum dosage for coagulation with Moringa standard preparation.

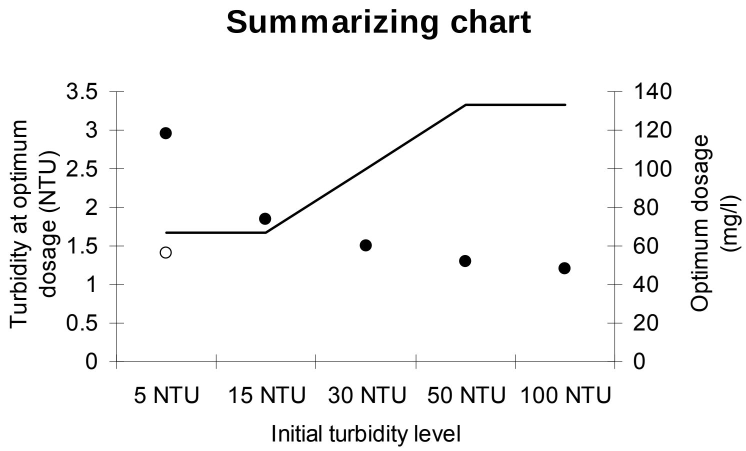

Figure 12. *Summary of the jar test results for Moringa with standard preparation method. The dots indicate turbidity level (empty dot is after 2 h sedimentation time) and the line the optimum dosage.*

It is seen that the optimum dosage for Moringa, standard preparation method, lies between 67 and 133 mg/l depending on the turbidity of the raw water. For waters with low turbidity the treatment was not effective but could be improved by prolonging the sedimentation time. The treatment became more efficient for high turbidities, as earlier studies also have concluded, but removal efficiency for low turbidities can be increased by prolonging the sedimentation time.

5.3.2 Influence on water quality and characteristics

The results, presented in figure 13 and 14 below, show that Moringa has no effect on the pH, alkalinity or conductivity of the treated water, which is in agreement with all results from previous research (see chapter 3.2). The results were confirmed statistically, by performing linear regression on dosage versus pH/alkalinity/conductivity, and making a 95% confidence interval for the inclination of the slope. None of the above parameters showed a significant trend, and were thus not affected by the dosage of Moringa. The TDS concentration remained steadily within 67-68% of the conductivity and has therefore not been illustrated below.

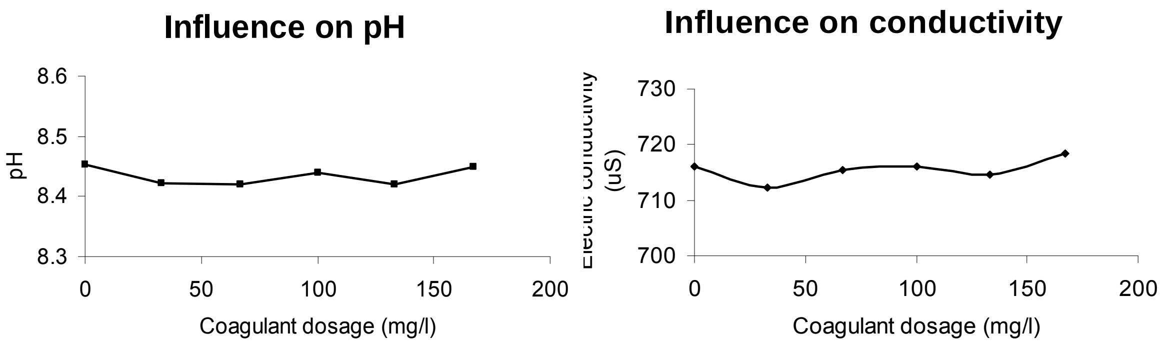

Figure 13. *Average values of pH and conductivity related to dosage of Moringa, standard preparation method.*

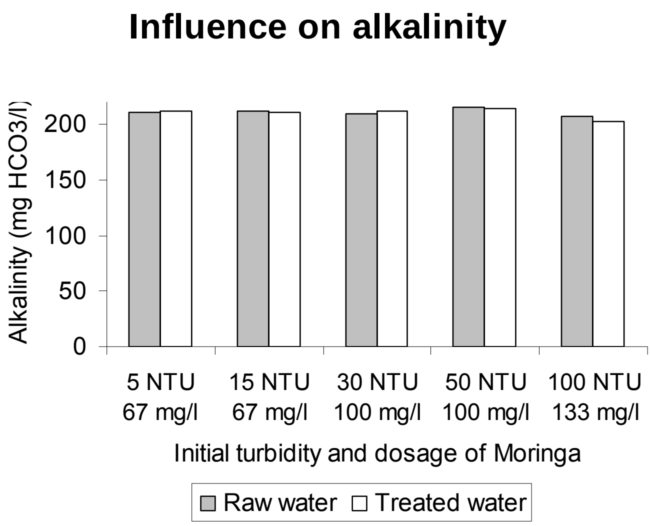

Figure 14. *The alkalinity of raw water and water treated with Moringa, standard preparation method, for different levels of raw water turbidity*

The COD level and bacterological quality were evaluated for initial turbidity levels of 15 and 50 NTU respectively. At 15 NTU, the COD results indicated an increase from 2 mg O_2/l to 2.4 mg O_2/l after sedimentation at optimum dosage, whereas at 50 NTU the result was a decrease from 40 mg O_2/l to 7 mg O_2/l. Considering the yearly variations of COD in the Umbeluzi river in 2006, where no value exceeded 9 mg O_2/l and the values in september-october ranged between 2-6 mg O_2/l, this leads to the conclusion that the results from 50 NTU turbidity level are incorrect.

The COD results from the 15 NTU turbidity level may indicate what has been previously reported, that Moringa leads to an increase in COD, but this can not be confirmed since the results in general are so few and unreliable.

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 fecal streptococci were reduced to 3 after treatment at 15 NTU turbidity level, and the fecal coliforms were increased to 7 after treatment at 50 NTU turbidity level. Again, the large variations in the results makes it impossible to draw any conclusions, apart from the assumption that there is a major flaw somewhere in the sampling or analysis procedure (especially since the number of fecal coliforms in one analysis were found to be higher than the number of total coliforms, which is of course unrealistic).

5.4 Moringa Oleifera, alternative preparation methods

Different preparation methods have been investigated in previous studies. For comparison with the standard preparation, two different methods were tested. The methods were chosen based on previous studies and for practical purposes. Due to restricted time, these tests were only carried out for two different levels of turbidity; 15 NTU and 50 NTU.

5.4.1 Preparation with oil extraction

Preparation with oil extraction from the seeds was conducted as previous studies indicate that oil extraction prevents the increase in COD in the treated water (see chapter 3.2). The results are presented in figure 15.

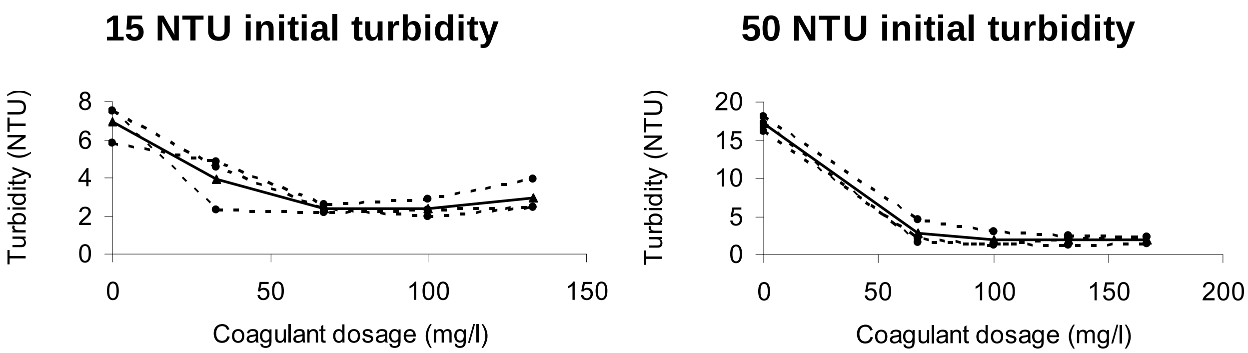

Figure 15. *Removal efficiency with Moringa Oleifera prepared with oil extraction for an initial turbidity of 15 and 50 NTU.*

The average outgoing turbidity at optimum dosage was 2.4 NTU (67 mg/l) for 15 NTU initial turbidity, and 1.9 NTU (100 mg/l) for 50 NTU initial turbidity. 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 (October 9^{th}). The same extract was used in one of the jar tests at 15 NTU, and gave higher outgoing turbidities in that test as well, however not as extremely high as the in the 50 NTU jar test. Another possibility is that the extraction process with cyklohexane removed some of the coagulating agents as well, thus lowering the coagulating ability of the crude extract.

Measurements of pH, conductivity, TDS and alkalinity were carried out and tested for a trend at a significance level of 0.05. None of these parameters were affected by the dosage of oil extracted Moringa.

The main reason for extracting oil from the seeds before preparing the crude extract was to determine whether the outgoing COD concentration could be reduced. The COD for 15 NTU went from 5.04 O_2 mg/l to 2.72 O_2 mg/l. For 50 NTU the COD for the raw water is 0.64 O_2 mg/l but the COD values after treatment is missing in the given values from the Health ministry. The bacteriological has for the study on 15 NTU did not show any reduce in the total coliforms. The fecal coliforms increased from 78 to >100 but the fecal streptococci reduced from 24 to 8. In the water with a initial turbidity of 50 NTU the number of total coliforms stayed at >100 but an increase in fecal coliforms from 98 to >100 was observed. The fecal streptococci stayed at <1 during treatment.

5.4.2 Preparation with tap water

Preparation with tap water was tested, as extraction using tap water is more convenient in a large scale at a water treatment plant than distilled water. The results are presented in figure 16.

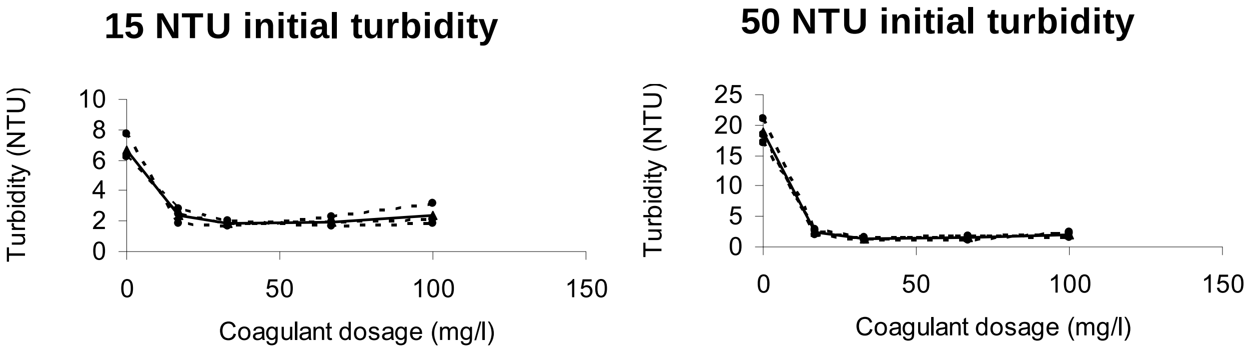

Figure 16. *Removal efficiency with Moringa Oleifera prepared with tap water for an initial turbidity of 50 NTU.*

Flocculation with tap water extracted Moringa led to an outgoing turbidity of 1.85 and 1.3 NTU for low and medium turbidity respectively. Optimum was located around 33 mg/l for water with both low turbidity (15 NTU) and medium turbidity (50 NTU). The standard deviation at optimum was 10-15%.

As in previous experiments, measurements of pH, conductivity and TDS were carried out and tested for a trend at a significance level of 0.05. No trend could be seen, and it can therefore be concluded that tap water extracted Moringa does not affect the above parameters.

COD, alkalinity and bacteria were not measured for the jar tests with tap water due to lack of time.

5.5 Comparison between coagulants and preparation methods

This section discusses the differences between the various coagulants and preparation methods used in this study.

5.5.1 Optimum dosage and turbidity removal efficiency

Figure 17 below shows a summary of outgoing turbidity with the different coagulants and extraction methods, for all tested initial turbidity levels.

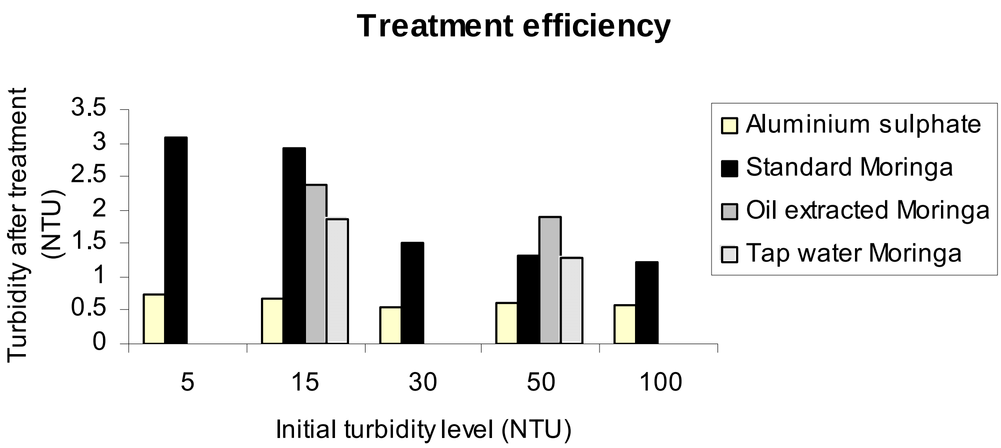

Figure 17. *Comparison of treatment efficiency between the four different coagulants.*

As can be seen, the efficiency of Moringa 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 Moringa never produced water with a turbidity below 1 NTU. The aluminium sulphate also produced more stable results, the relative standard deviation was never more than 20%, corresponding to 0.1 NTU. As for Moringa, the relative standard deviation reached as high values as 50%. The relative standard deviation at optimum for high initial turbidity levels, was as a matter of fact lower for Moringa than for aluminium sulphate, but this was mainly due to the fact that the outgoing turbidities for the water flocculated with aluminium sulphate were much lower than the corresponding values for Moringa.

Figure 17 above and 18 below show that Moringa prepared with tap water was more efficient than the other two Moringa preparation methods. The outgoing turbidity was lower, especially at low initial turbidity level, and the dosage needed to reach optimum was significantly lower as well.

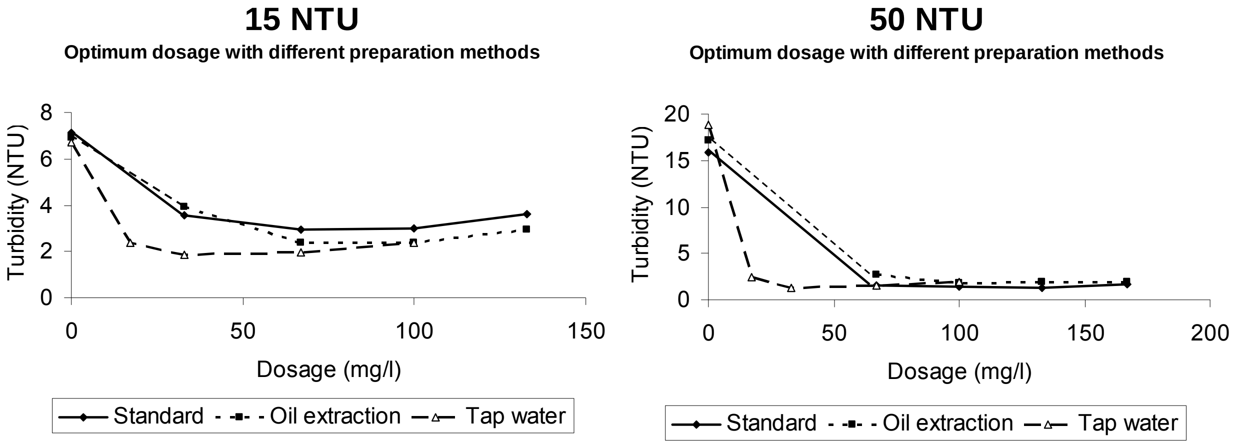

Figure 18. *Comparison of optimimum dosge for different coagulants.*

As mentioned above, coagulation with Moringa resulted in smaller flocs than coagulation with aluminium sulphate. Smaller flocs settle more slowly, and remaining flocs in the supernatant may have contributed to the higher outgoing turbidity for water treated with Moringa. The flocs that don't settle during sedimentation will continue to the filter, where they will add to the clogging of the filter. The need for backwash of the filters will in this case increase and the production capacity decrease.

5.5.2 Influence on water quality and characteristics

Regarding the effects on water quality, Moringa 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. This can be seen in figures 9, 13 and 14 above, and is also verified statistically and in accordance with previous research.

As has been stated before, no certain conclusions 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.

5.6 Filtration test

A comparison of Moringa and aluminium sulphate in the use of roughing fiters with Umbeluzi water was conducted. The pressure over the filters and the turbidity of the water at different points in the filter are displayed below in figures 19, 20 and 21.

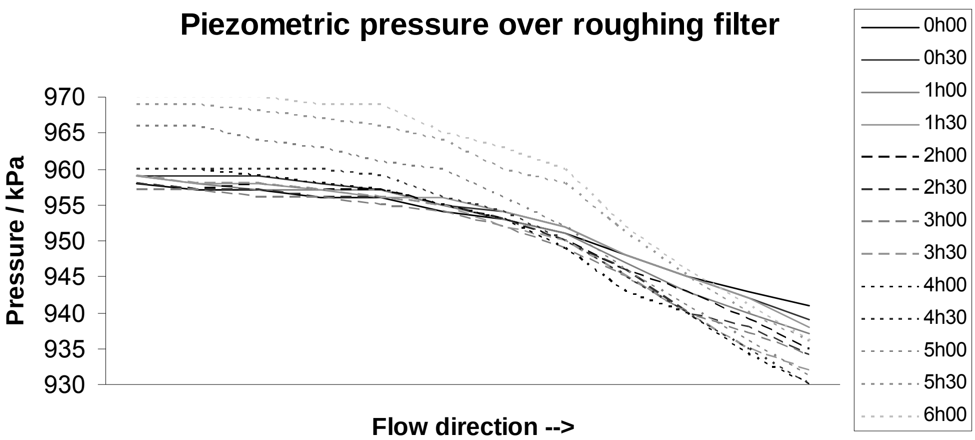

Figure 19. *Peizometric pressure for the roughing filter during filtration test with Moringa.*

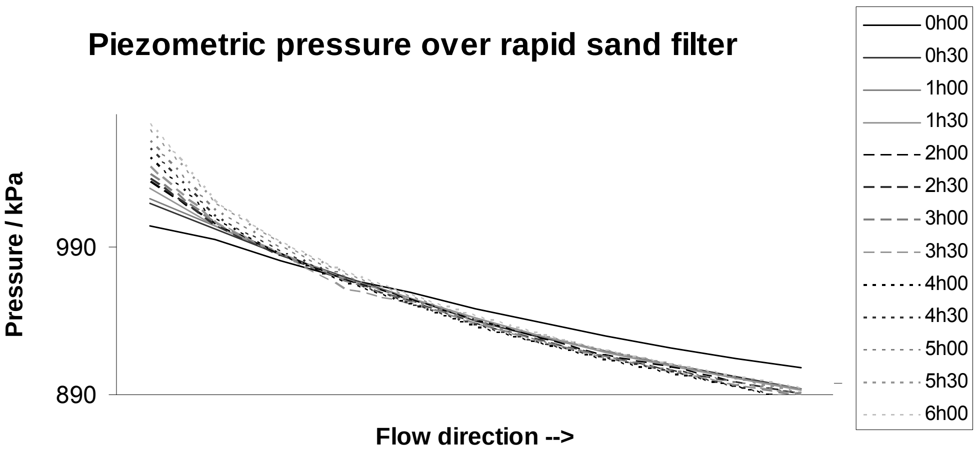

Figure 20. *Piezonmetric pressure for the rapid sand filter during filtration test with Moringa.*

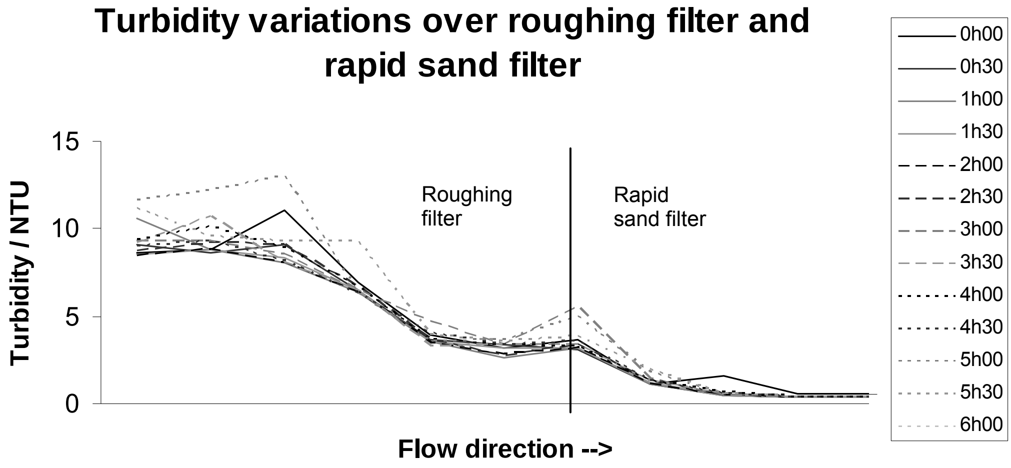

Figure 21. *Turbidity variations during filtration test with Moringa.*

The turbidity of the water leaving the sand filter remained steadily at 0.4 NTU through the test. The increase in pressure and head loss over the filter indicates the extent of the clogging. During the 6 hours that the process was run, the pressure increased with 12 kPa at the inlet of the roughing filter, and with 70 kPa at the inlet of the rapid sand filter. The increase in head loss was 17 kPa for the roughing filter and 84 kPa for the rapid sand filter.

Similar tests were done with aluminium sulphate during 9 days in April and May 2007, with a raw water turbidity of 4-8 NTU. This resulted in daily average outgoing turbidities ranging from 0.4-0.8 NTU. The increase in pressure at the filter inlets, and the increase in head loss, were comparable to or higher than the observed values during the Moringa test run.

The discussion following the jar test results suggested that the load on the rapid sand filter may increase when using Moringa instead of aluminium sulphate, due to small flocs with poor settling properties. When using direct filtration with roughing filter and rapid sand filter, the results seem to be the opposite; the load when using Moringa is smaller than (or possibly similar to) the performance when using aluminium sulphate. This may seem contradictory, but as stated in chapter 3.2.3, Moringa has been proven to produce much less sludge than aluminium sulphate. Therefore it might be that aluminium sulphate is more appropriate in a sedimentation-filtration process, where a large fraction of the sludge can be removed in the sedimentation step, whereas Moringa is preferred in a direct filtration step, since it produces less sludge and thus less clogging in the filters.

Unfortunately, the roughing filter process was only tested during one day, due to lack of time. However, the results so far indicate that Moringa may perform just as good as aluminium sulphate (or maybe even better) when using this technique.

5.7 Applicability of Moringa Oleifera in large scale at AdM

The following chapter presents a discussion regarding the possibility of applying Moringa Oleifera as a coagulant in large scale at the Àguas de Moçambique waterworks outside Maputo.

5.7.1 Availability and supply chain of seeds

The optimum dosage of Moringa, 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. Assuming a dosage of 40 mg Moringa seeds/litres of water to be treated, and a drinking water production of 7500 m^3 water/hour on average, a daily supply of 7.2 tons of Moringa seeds is required. Using the values given in chapter 3.2, this corresponds to what a plantation of 6-7 km^2 can produce.

At present time there is no current production of Moringa seeds that is secured regarding quality and quantity, and reliable in the Maputo area, and this is crucial for a replacement of aluminium sulphate. The area required for production of seeds is not entirely unrealistic, but in the foreseeable future it is very unlikely that such large plantations will be established.

Currently, the average daily use of aluminium sulphate is 3.5 tonnes, which means that the required supply of coagulant will increase to the double. On the other hand, the need of lime will probably decrease significantly since Moringa does not lower the pH. However, the lime consumption is only 1-2 % of the aluminium sulphate consumption (in kilos), and the decrease in chemical use due to lime can therefore be neglected.

A change to Moringa will lead to an increase in transportation to and from the plant and this might be a problem logistically. There is a need of 4-5 weekly loads of Moringa, assuming that an average truck can carry approximately 12 tonnes. The condition of the roads leading to the plant is fairly poor and thus maintenance and monitoring of the road is recommended if the numbers of transports are to be doubled. However it is belived that the increase is not unreasonable on the roads. The roads are at their worst during the rainy season and a change to Moringa will actually lead to fewer trucks during this time of the year.

5.7.2 Cost and on-site investments

It is recommended that the preparation of the extract be carried out on-site, both since delivery of the prepared extract would require much larger transport volumes, and since the extract must not be stored for too long before use. The treatment plant will thus need a space for storage, grinding and mixing of the seeds. A space for storage of the extract is also necessary. It is likely that the present area for storing and mixing of aluminium sulphate could be used for the latter purpose, but most probably complementary space is needed for the extraction steps. A schematic illustration of the preparation process and space is seen in figure 22 below.

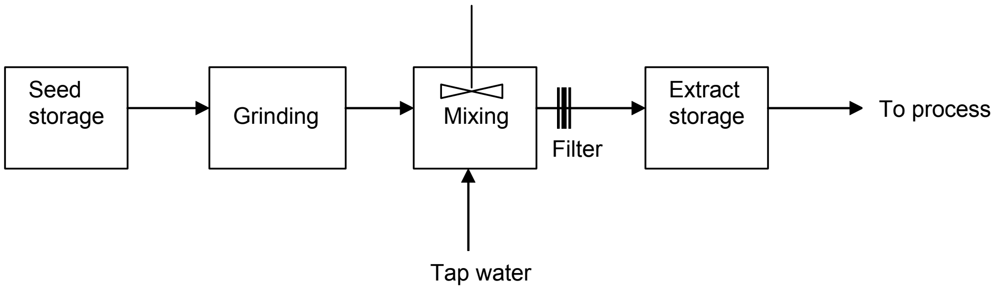

Figure 22. *Schematic illustration of the Moringa extract preparation steps.*

A batch process is probably more suitable than a continuous process, as stirring of ground seeds and water is to be done for 30 minutes before filtration and a constant flow will lead to uncertainties in the retention time. Even if the certainty of the retention time might not be crucial, it is a large source of error, which can be avoided in a batch process. It is assumed that the present tanks used for aluminium sulphate could be used and a complementary area for filtration. A tank for the filtration does not need to be as large as the rest of the containers, assuming it is built in connection with the storage tanks for the extract.

The cost for procuring coagulants will most certainly decrease considerably, but an exact cost estimation is not possible since, according to Matsinhe at the Faculty of Engineering, no current plantations of Moringa exist in the region of Maputo except for the one at IIAM (Agronomic research institute of Mozambique). This is most probably due to the lack of knowledge about Moringa and its purposes, as there is not market for Moringa. A project at the chemistry department, at Faculty of Engineering, about using Moringa for nutritional purposes are currently conducted and might raise the need and knowledge for Moringa, again according to Matsinhe.

5.7.3 Process adaptation

Using Moringa instead of aluminium sulphate may, as mentioned above, lead to a decrease in drinking water production rate since the settling properties of the Moringa flocs are not as good as for aluminium sulphate. This will lead to either a longer sedimentation time, or more frequent backwashing of the rapid sand filters. An alternative is to use a direct filtration process instead, since this seems to give better results, but since this requires a major reconstruction of the plant, it is not a realistic alternative unless in the event of expansion of the treatment plant.

If the use of Moringa is to be implemented in the drinking water treatment process at Àguas de Moçambique, it must also be remembered that the raw water used in this study has a higher pH, alkalinity and conductivity compared to the raw water at the intake to the waterworks. The results from this study must therefore be treated with caution. As reported in chapter 3.2.3, some studies indicate that the coagulation activity of Moringa is significantly lower below pH 7. The reason why other studies state that the efficiency of Moringa is independent of raw water pH may be that different extraction methods have been used, and thus that the active agents are not the same, depending on the extraction method. If some active agents are pH dependent and others not, it could explain the difference in conclusions from these studies.

One of the studies described in chapter 3.2.2, used tap water for extraction and obtained turbidity removal efficiency equal to that of aluminium sulphate with a raw water pH of 7.6. The average monthly pH of the Umbeluzi river at the raw water intake of Àguas de Moçambique was around 7.5 or higher for every month except March during 2006. This indicates that tap water extracted Moringa probably would be efficient for treating the Umbeluzi water even if the pH is lower than the pH of the water tested in this study. However, it is recommended that complementary tests are carried out to determine whether the turbidity removal is as efficient at a pH of 6.5-7.5.

The sludge that is today distributed back to the river containing a large amount of aluminium could possibly be used as fertilizer after a change to Moringa in the process. The pollution of Umbeluzi will decrease and the Moringa plantations possible need for fertilizers handled automatically. This makes Moringa a more sustainable option on a long-term basis.

5.7.4 Recommendations

The amount of seeds required is quite large, and at the moment the known production of Moringa seeds in Mozambique is very small, which means that drinking water treatment with Moringa in an industrial scale cannot be implemented. In addition, there is a need for extensive reconstruction and adaptation at the existing drinking water treatment plant in Maputo before Moringa can be used, which makes Moringa an unrealistic alternative in a large scale waterworks such as the Maputo waterworks.

However, the method with Moringa as a coagulant combined with direct filtration should definitely be considered if a new small scale drinking water treatment plant is to be constructed, since it then is more realistic that an adequate amount of seeds can be obtained and processed.

In any case, the question marks regarding pH dependence, COD increase and direct filtration method should be further examined before the method is implemented in an industrial scale. But once plantations are established and the supply of seeds secured, Moringa provides a good, cheap and sustainable alternative to aluminium sulphate, which should be considered as a coagulant in smaller waterworks.

6 Conclusions

Moringa Oleifera 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 extraction of Moringa should be performed by tap water as this is the cheapest, most practical and most efficient method. Since no proof could be obtained that oil extraction from the seeds prior to use improved the treatment, this can not be recommended at present.

Regardless of extraction method, Moringa does not show the same efficiency in turbidity removal as $Al_2(SO_4)_3$ in performed jar tests. The water flocculated with Moringa has a somewhat higher turbidity than water flocculated with aluminium sulphate, especially if the raw water has a low initial turbidity. In chapter 5.3.1, it was seen that the turbidity could be decreased by increasing the sedimentation time. This will however lead to a lower flow and drinking water production rate. Another solution is to let the excessive flocs continue to the rapid sand filter, but this will also eventually decrease the production rate due to more clogging and more frequent backwashing.

When using Moringa as a coagulant in a direct filtration process with roughing filter and rapid sand filter, the turbidity of the outgoing water was on the other hand as low as the corresponding values for aluminium sulphate. The increase in pressure and head loss over the filters were not proven to be higher for Moringa than for aluminium sulphate, and it seems thus as if Moringa could be a very good substitute for aluminium sulphate when using this technique. However, this test was only performed for one day, and further studies need to be done to draw any definite conclusions on this topic.

Further studies need also be done regarding the impact of raw water pH on the efficiency of Moringa, since the water used in this study had a very narrow pH range and the efficiency of most coagulants is pH dependent.

Considering the large amount of seeds required, and the extensive on-site investments needed, is not considered possible for Águas de Mocambique to replace the aluminium sulphate with Moringa. It is however a method that certainly can be considered as a good, sustainable and cheap solution for smaller waterworks, if the supply Moringa seeds can be guaranteed.

In accordance with the above conclusions, it is suggested that tap water extracted Moringa and treatment with flocculation followed by direct filtration with roughing filters be considered in the event of expansion or construction of small scale industrial waterworks, and that complementary tests be carried out to determine the impact of raw water pH on treatment efficiency.

7 References

Personal communication:

Gildo Timóteo, Director of the water treatment plant, Águas de Mocambique, Boane, Moçambique, 29th of August 2007

Khan Maida, Chemical Engineer, Faculty of Engineering, Eduardo Mondlane University, Moçambique, 9th of November 2007

Matsinhe Nelson, Doctoral student, Faculty of Engineering, Eduardo Mondlane University, Moçambique, August-October 2007

Persson Kenneth M., Professor, Dept. of Water resources engineering, Faculty of Engineering, Lund University, 8th of November 2007

Books and articles:

Bengtsson Jessica, 2003, ***Förbehandling av kommunalt avloppsvatten före anaerob behandling***, Avdelningen för vattenförsörjnings- och avloppstenik, Lunds Tekniska Högskola

Cech Thomas V., 2005, ***Principles of Water Resources – History, development, management and pollution***, 2nd edition, John Wiley & Sons Inc. ISBN: 0-471-48475-X

Degrémont, 1979, ***Water Treatment handbook***, 5th edition, Halsted Press, John Wiley & Sons Inc.

Ghebremichael K., 2007, ***Overcoming the drawbacks of natural coagulants for drinking water treatment***, Water Malaysia IWA Conference Developing Countries 2007

Ghebremichael K. A., Gunaratna K. R., Henriksson, H., Brumer, H. and Dalhammar, G., 2005, ***A simple purification and activity assay of the coagulant protein from Moringa oleifera seed***, Water Research, Vol 39(11), June 2005, pp. 2338–2344

Hammer, Mark J. and Hammer Jr, Mark J., 2004, ***Water and Wastewater Technology, 5th ed.,*** Pearson Education International, ISBN 0-13-191140-6.

Katayon S., Megat Mohd Noor M.J., Asma M., Abdul Ghani L.A, Thamer A.M., Azni I., Ahmad J., Khor B.C, Suleyman A.M, 2006, ***Effects of storage conditions of Moringa Oleifera seeds on its performance in coagulation***, Bioresource Technology, Vol 97(13), September 2006, pp. 1455-60

Katayon S., Megat Mohd Noor M.J., Asma M., Thamer A.M., Liew Abdullah A.G., Idris A., Suleyman A.M,, Aminuddin M.B, Khor B.C., 2004, ***Effects of storage duration and temperature of Moringa Oleifera stock solution on its perfomance in coagulation***, International Journal of Engineering and Technology, Vol. 1(2), pp. 146-151, ISSN: 1823-1039

Kemira Kemwater, 2003, ***About water treatment***, ISBN: 91-631-4344-S

Knutsson G., Morfeldt C-O., 1995, ***Grundvatten teori och tillämpning***, Andra upplagan, AB Svensk byggtjänst, ISBN: 91-7332-740-9

Lilliehöök, Henrik, 2005, ***Use of Sand Filtration on River Water Flocculated with Moringa Oleifera***, Division of Sanitary Engineering, Department of Civil and Environmental Engineering, Luleå University of Technology, ISRN: LTU-EX- -05/177- - SE

Mannion, A. M. and Bowlby S. R., 1992, ***Environmental Issues in the 1990s,*** John Wiley & Sons Ltd, ISBN: 0-471-93326-0

Ministério de saúde, 1997, ***Métodos de análise de água***, Laboratório nacional de higiene dos alimentos e águas, Ministério de saúde – Direcção nacional de saúde, República de Moçambique

Mpagi Kalibbala, H., 2007, ***Application of indigenous materials in drinking water treatment***, Royal Institute of Technology, Sweden, ISBN: 978-91-7283-565-76.

Muyibi, Suleyman A. and Alfugara, Akif M. S., ***Treatment of surface water with Moringa Oleifera seeds and alum – a comparative study using a pilot scale water treatment plant***, International Journal of Environmental Studies, Vol. 60(6), December 2003, pp. 617–626(10)

Ndabigengesere, A., Narasiah, K.S., 1998, ***Quality of water treated by coagulation using Moringa oleifera seeds***. Water Research, 1998, Vol. 32 (3), March 1998, pp.781–791(11)

Ndabigengesere A, Narasiah K. S., Talbot B.G., 1995, ***Active agents and mechanism of coagulation of turbid waters usng Moringa Oleifera***, Water Research, Vol 29(2), February 1995, pp. 703-710

Okuda T., Baes A.U, Nitshijima W, Okada M, 1999, ***Improvement of extraction method of coagulation active components from Moringa Oleifera seed***, Water Research, Vol 33(15), October 1999, pp. 3373-3378

Okuda T., Baes A.U, Nitshijima W, Okada M, 2001, ***Coagulation Mechanism of Salt Solution-Extracted Active Component in Moringa oleifera Seeds***, Water Research, Vol 35(3), February 2001, pp. 830-834 (a.)

Okuda T., Baes A.U, Nitshijima W, Okada M, 2001, ***Isolation and charcterization of coagulant extracted from Moringa Oleifera seed by salt solution***, Water Research, Vol 35(2), February 2001, pp. 405-410 (b.)

Sutherland J.P., Folkard G.K., Mtawali M.A., Grant W.D, University of Leicester, UK***. Moringa Oleifera as a natural coagulant***, Affordable water supply and sanitation, 20th WEDC Conference Colombo, Sri Lanka 1994

Sutherland J.P., Folklard G.K., Poirier Y.L., 2001, ***Moringa Oleifera. The constraints to commercialization***, Development potential for Moringa products, October 29th –November 2nd 2001, Dar es Salaam, Tanzania

Warfvinge Per, 1997, ***Miljökemi – Miljövetenskap i biogeokemiskt perspektiv***, KFS AB, Lund, Sweden

World Health Organisation, 2006, ***Guidelines for drinking water quality***, Third edition, ISBN: 92 4 154696 4

Internet:

Afrikagrupperna, 2007, Sweden
http://www.afrikagrupperna.se/cgi-bin/afrika.cgi?d=s&n=10086
(Retrieved 6th of November 2007)

Doerr Beth, 2005, ***Moringa Water Treatment***,
AnECHO technical note, ECHO, USA,
http://www.echotech.org/mambo/images/DocMan/MorWaterTreat.pdf
(Retrieved 5th of November)

Göttsch E, 1992, ***Purification of turbid surface water by plants in Ethiopia***,
Walia 14 (1992): 23-28
http://www.deutsch-aethiopischer-verein.de/Walia-1992-Purification.pdf
(Retrieved on 13th of November)

European Investment Bank, 2006,
http://www.eib.org/projects/news/maputo-water-supply-project-mozambique.htm?
(Retrieved 6th of November 2007)

North American Lake Management Society, 2007,
Madison, Winsconsin, USA
http://www.nalms.org/Resources/Glossary.aspx?show=C
(Retrieved 20th November 2007)

Schwarz Discha, 2000, ***Water clarification using Moringa Olefiera***,
Gate information Service, Germany,
http://www.deutsch-aethiopischer-verein.de/Gate_Moringa.pdf
(Retrieved 13th of August 2007)

Swedish National Food Administration, 2001,
http://www.slv.se/upload/dokument/Lagstiftning/2000-2005/2001_30.pdf
(Retrieved 13th of November 2007)

Trees for life, 2006, St Louis, Kansas, USA,
http://www.treesforlife.org/project/moringa/default.en.asp
(Retrieved 12th of December 2006)

U.S Environmental Protection Agency, 2007
http://www.epa.gov/safewater/hfacts.html
(Retrieved 9th of Noember 2007)

WELL, 1999
Water, Engineering and Development Centre, Loughborough University, UK
http://www.lboro.ac.uk/well/resources/technical-briefs/60-water-clarification-using-moringa-oleifera-seeds.pdf
(Retrieved 13th of August 2007)

World Health Organization, 2007
http://www.who.int/topics/drinking_water/en/
(Retrieved 12th of November 2007)

Appendices

A Procedure manual for Moringa Oleifera coagulant preparation

Emelie Arnoldsson and Maria Bergman, 2007

Based on laboratory testings and literature study carried out in August-November 2007.

1. Remove husks and shells from the seeds if not already done
2. Grind the seeds to a fine powder, the smaller particle size the better
3. Weigh the powder
4. Mix the powder with tap water to a 5% solution (20 ml of water per g of powder). The solution should be stirred for 30 minutes to ensure satisfactory extraction of the active agent.
5. Filter the solution in order to remove particulater matter from the extract
6. Recommended dosage for low and medium turbidity levels (<100 NTU) is approximately 1 ml extract per litre of raw water.

- Do not store the extract more than one day.
- Seeds can be stored for at least 1 month.

B Jar test schedules

Coagulant: **Moringa with oil** Turbidity level: **5 NTU**

2007-09-10	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	5.2	3.3	3.6	3.5	3.6	3.8
Temperature (ºC)	23	22	22	22	22	22
pH	8.3	8.4	8.4	8.4	8.4	8.3
Conductivity (µS)	710	720	710	720	720	720
TDS (ppm)	480	-	-	480	-	-
HCO_3^- (mg/l)	211.1	-	-	212.1	-	-
Observations:	Very small flocs in suspension					

2007-09-10	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	5.2	3.3	3.6	3.5	3.7	4.5
Temperature (ºC)	23	22	22	22	22	22
pH	8.3	8.4	8.4	8.4	8.4	8.3
Conductivity (µS)	720	710	710	710	720	720
TDS (ppm)	490	-	-	490	-	-
Observations:	Very small flocs in suspension					

2007-10-10	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	6.1	3.2	2.5	1.85	3.6	3.95
Temperature (ºC)	23	22	22	22	22	22
pH	8.4	8.6	8.5	8.5	8.5	8.5
Conductivity (µS)	710	710	720	710	710	710
TDS (ppm)	480	-	-	480	-	-
Observations:						

Coagulant: **Moringa with oil** Turbidity level: **15 NTU**

2007-09-10	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	15.1	7.2	4.0	3.6	3.3	4.3
Temperature (ºC)	23	22	22	22	22	22
pH	8.3	8.4	8.4	8.3	8.4	8.4
Conductivity (µS)	720	710	710	720	720	710
TDS (ppm)	490	-	-	-	490	-
Observations:	Very small flocs in suspension					

2007-09-10	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	17.5	8.1	4.8	3.3	3.6	4.3
Temperature (ºC)	23	22	22	22	22	22
pH	8.3	8.4	8.4	8.4	8.4	8.3
Conductivity (µS)	710	720	710	710	710	710
TDS (ppm)	490	-	-	490	-	-
Observations:	Very small flocs in suspension					

2007-09-27	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	14.7	6.1	1.9	1.85	2.1	2.25
Temperature (ºC)	22	22	22	22	22	22
pH	8.5	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	720	710	710	710	710	710
TDS (ppm)	490	-	-	480	-	-
HCO_3^- (mg/l)	211.3	-	-	210.8	-	-
COD (mg O_2/l)	2			2.4		
Microbiology	>100 >100 >100			>100 >100 3		
Observations:						

Coagulant: **Moringa with oil** Turbidity level: **30 NTU**

2007-09-11	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	29.3	9.6	2.7	1.85	1.6	1.75
Temperature (ºC)	23	22	22	22	22	22
pH	8.3	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	720	720	720	720	720	720
TDS (ppm)	480	-	-	-	480	-
HCO_3^- (mg/l)	209.9	-	-	-	211.3	-
Observations:						

2007-09-11	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	29.9	8.6	2.2	1.57	1.4	1.6
Temperature (ºC)	23	23	23	23	23	23
pH	8.3	8.4	8.4	8.3	8.4	8.4
Conductivity (µS)	720	720	710	720	720	720
TDS (ppm)	480	-	-	-	480	-
Observations:	Measurements taken 20 minutes too late (total sedimentation time 50 minutes)					

2007-10-10	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	31.1	12.4	1.55	1.25	1.5	1.7
Temperature (ºC)	23	22	22	22	22	22
pH	8.4	8.5	8.5	8.5	8.6	8.5
Conductivity (µS)	710	710	710	700	710	710
TDS (ppm)	480	-	-	480	-	-
Observations:						

Coagulant: **Moringa with oil** Turbidity level: **50 NTU**

2007-09-11	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	2	3	4	5
Concentration (mg/l)	-	-	67	100	133	167
Turbidity (NTU)	50.4	18.1	2.0	1.7	1.65	1.9
Temperature (ºC)	23	22	22	22	22	22
pH	8.3	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	710	720	720	710	720	720
TDS (ppm)	490	-	-	-	-	-
HCO_3^- (mg/l)	215.2	-	-	214.5	-	-
Observations:						

2007-09-18	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	2	3	4	5
Concentration (mg/l)	-	-	67	100	133	167
Turbidity (NTU)	49.8	14.7	1.2	1.25	1.15	1.75
Temperature (ºC)	23	23	23	23	23	23
pH	8.4	8.5	8.4	8.4	8.4	8.5
Conductivity (µS)	720	720	720	720	720	720
TDS (ppm)	490	-	-	-	?	-
Observations:						

2007-09-21	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	2	3	4	5
Concentration (mg/l)	-	-	67	100	133	167
Turbidity (NTU)	49.8	15.0	1.3	1.25	1.1	1.45
Temperature (ºC)	23	23	23	23	23	23
pH	8.6	8.6	8.6	8.6	8.6	8.6
Conductivity (µS)	710	720	720	710	700	720
TDS (ppm)	480	-	-	-	-	-
COD (mg O_2/l)	40			7.2		
Microbiology	<1 <1 <1			<1 7 <1		
Observations:						

Coagulant: **Moringa with oil** Turbidity level: **100 NTU**

2007-09-11	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	2	3	4	5
Concentration (mg/l)	-	-	67	100	133	167
Turbidity (NTU)	103	27.1	1.75	1.35	1.25	1.45
Temperature (ºC)	23	23	23	23	23	23
pH	8.4	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	720	720	720	720	720	710
TDS (ppm)	480	-	-	-	480	-
HCO_3^- (mg/l)	207.6	-	-	-	202.6	-
Observations:						

2007-09-12	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	2	3	4	5
Concentration (mg/l)	-	-	67	100	133	167
Turbidity (NTU)	102	28.7	1.0	1.0	1.1	1.25
Temperature (ºC)	23	23	23	23	23	23
pH	8.5	8.5	8.4	8.4	8.5	8.4
Conductivity (µS)	720	720	720	720	720	720
TDS (ppm)	490	-	490	-	-	-
Observations:						

2007-09-28	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	2	3	4	5
Concentration (mg/l)	-	-	67	100	133	167
Turbidity (NTU)	101	33.1	1.75	1.3	1.25	1.4
Temperature (ºC)	23	23	23	23	23	23
pH	8.5	8.5	8.5	8.5	8.5	8.4
Conductivity (µS)	720	710	710	720	710	720
TDS (ppm)	490	-	-	-	490	-
Observations:						

Coagulant: **Moringa with oil** Turbidity level: **5 NTU**

Prolonged sedimentation time

2007-09-18	**Raw water**	**Treated water after 30 min**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	2	3	4
Concentration (mg/l)	**-**	-	33	67	100	133
Turbidity (NTU)	5.3	2.8	2.55	2.3	2.4	3.95
Temperature (ºC)	23	23	23	23	23	23
pH	8.4	8.5	8.4	8.4	8.4	8.4
Conductivity (µS)	710	710	710	710	710	720
TDS (ppm)	480	**-**	**-**	-	**-**	**-**
		Treated water after 2 h				
Turbidity (NTU)	-	2.05	1.35	1.15	1.45	1.45
Temperature (ºC)	-	23	23	23	23	23
pH	-	8.5	8.4	8.4	8.4	8.5
Conductivity (µS)	-	710	710	710	710	710
TDS (ppm)	-	**-**	**-**	-	**-**	**-**
Observations:						

2007-09-19	**Raw water**	**Treated water after 30 min**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	2	3	4
Concentration (mg/l)	**-**	-	33	67	100	133
Turbidity (NTU)	4.6	3.7	3.3	3.9	4.7	5.5
Temperature (ºC)	23	23	23	23	23	23
pH	8.4	8.4	8.4	8.4	8.4	8.5
Conductivity (µS)	720	710	710	710	710	720
TDS (ppm)	480	**-**	480	-	**-**	**-**
		Treated water after 2 h				
Turbidity (NTU)	-	3.0	1.45	1.4	1.65	1.8
Temperature (ºC)	-	23	23	23	23	23
pH	-	8.5	8.4	8.4	8.4	8.4
Conductivity (µS)	-	710	710	710	710	720
TDS (ppm)	-	**-**	**-**	480	**-**	**-**
Observations:						

2007-09-26	**Raw water**	**Treated water after 30 min**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	2	3	4
Concentration (mg/l)	**-**	-	33	67	100	133
Turbidity (NTU)	6.8	4.05	3.35	4.0	3.8	6.1
Temperature (ºC)	22	23	23	23	23	23
pH	8.4	8.5	8.5	8.5	8.4	8.4
Conductivity (µS)	700	720	710	710	710	710
TDS (ppm)	480	**-**	480	-	**-**	**-**

		Treated water after 2 h				
Turbidity (NTU)	-	3.2	1.8	1.65	1.9	3.0
Temperature (ºC)	-	23	23	23	23	23
pH	-	8.5	8.5	8.4	8.4	8.4
Conductivity (µS)	-	710	710	710	710	710
TDS (ppm)	-	-	-	480	-	-
Observations:						

Coagulant: **Moringa without oil** Turbidity level: **15 NTU**

2007-10-03	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	15.3	7.5	4.55	2.4	1.95	2.45
Temperature (ºC)	24	24	24	24	24	24
pH	8.3	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	710	710	710	710	710	710
TDS (ppm)	480	-	-	-	480	-
Observations:						

2007-10-03	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	15.1	7.5	2.3	2.15	2.3	2.45
Temperature (ºC)	24	25	25	25	25	25
pH	8.4	8.3	8.3	8.3	8.3	8.3
Conductivity (µS)	710	710	700	710	710	710
TDS (ppm)	480	-	-	480	-	-
Observations:						

2007-10-09	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	2	3	4
Concentration (mg/l)	-	-	33	67	100	133
Turbidity (NTU)	15.6	5.8	4.85	2.6	2.9	3.95
Temperature (ºC)	23	24	24	24	24	24
pH	8.4	8.5	8.5	8.5	8.4	8.4
Conductivity (µS)	710	710	710	710	710	700
TDS (ppm)	480	-	-	480	-	-
HCO_3^- (mg/l)	206.4			200.7		
COD / Al^{3+}	5.04			2.72		
Microbiology	>100 78 24			>100 >100 8		
Observations:						

Coagulant: **Moringa without oil** Turbidity level: **50 NTU**

2007-10-03	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	2	3	4	5
Concentration (mg/l)	**-**	-	67	100	133	167
Turbidity (NTU)	50.1	16.2	2.1	1.25	2.05	2.35
Temperature (ºC)	24	25	25	25	25	25
pH	8.2	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	710	710	710	710	710	710
TDS (ppm)	480	**-**	**-**	480	-	**-**
HCO_3^- (mg/l)	204.5			209.6		
Observations:						

2007-10-03	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	2	3	4	5
Concentration (mg/l)	**-**	-	67	100	133	167
Turbidity (NTU)	51.2	17.2	1.55	1.35	1.25	1.45
Temperature (ºC)	24	24	24	24	24	24
pH	8.3	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	710	700	710	700	710	700
TDS (ppm)	480	**-**	-	-	480	**-**
Observations:						

2007-10-09	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	2	3	4	5
Concentration (mg/l)	**-**	-	67	100	133	167
Turbidity (NTU)	49.3	18.0	4.55	3.0	2.4	2.2
Temperature (ºC)	23	24	24	24	24	24
pH	8.3	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	710	710	710	700	700	710
TDS (ppm)	480	-	-	-	-	480
COD / Al^{3+}	0.64			-		
Microbiology	>100 98 <1			>100 >100 <1		
Observations:						

Coagulant: **Moringa with tap water** Turbidity level: **15 NTU**

2007-10-16	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	0.5	1	2	3
Concentration (mg/l)	**-**	-	17	33	67	100
Turbidity (NTU)	16.3	6.2	2.45	1.8	1.9	2.1
Temperature (ºC)	25	25	25	25	25	25
pH	8.2	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	720	730	730	730	730	730
TDS (ppm)	500	**-**	**-**	500	-	**-**
Observations:						

2007-10-16	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	0.5	1	2	3
Concentration (mg/l)	**-**	-	17	33	67	100
Turbidity (NTU)	13.6	6.2	2.85	2.05	1.7	1.8
Temperature (ºC)	25	25	25	25	25	25
pH	8.2	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	730	730	730	730	730	730
TDS (ppm)	500	-	-	-	500	-
Observations:						

2007-10-16	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	0.5	1	2	3
Concentration (mg/l)	**-**	-	17	33	67	100
Turbidity (NTU)	16.1	7.7	1.8	1.7	2.25	3.2
Temperature (ºC)	25	25	25	25	25	25
pH	8.3	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	730	730	730	730	730	730
TDS (ppm)	500	-	-	500	-	-
Observations:						

Coagulant: **Moringa with tap water** Turbidity level: **50 NTU**

2007-10-16	Raw water	Treated water				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	0.5	1	2	3
Concentration (mg/l)	**-**	-	17	33	67	100
Turbidity (NTU)	48.8	21.0	2.6	1.25	1.7	1.5
Temperature (ºC)	25	25	25	25	25	25
pH	8.3	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	730	730	730	730	730	730
TDS (ppm)	500	-	-	500	-	-
Observations:						

2007-10-16	Raw water	Treated water				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	0.5	1	2	3
Concentration (mg/l)	**-**	-	17	33	67	100
Turbidity (NTU)	50.4	18.4	1.9	1.15	1.15	2.35
Temperature (ºC)	25	25	25	25	25	25
pH	8.3	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	730	730	720	730	730	730
TDS (ppm)	500	-	-	500	-	-
Observations:						

2007-10-17	Raw water	Treated water				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	0.5	1	2	3
Concentration (mg/l)	**-**	-	17	33	67	100
Turbidity (NTU)	48.9	17.0	2.8	1.55	1.75	2.1
Temperature (ºC)	25	25	25	25	25	25
pH	8.4	8.4	8.4	8.4	8.4	8.4
Conductivity (µS)	730	730	730	730	730	730
TDS (ppm)	500	-	-	500	-	-
Observations:						

Coagulant: $\mathbf{Al_2(SO_4)_3}$ Turbidity level: **5 NTU**

2007-09-13	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	3	5	7
Concentration (mg/l)	-	-	1	3	5	7
Turbidity (NTU)	6.4	4.8	1.65	0.75	0.75	0.75
Temperature (ºC)	24	23	23	23	23	23
pH	8.2	8.4	8.0	7.8	7.6	7.3
Conductivity (µS)	710	710	720	720	720	730
TDS (ppm)	-	-	-	-	-	-
$\mathbf{HCO_3^-}$ (mg/l)	209.6	-	-	189.7	-	-
Observations:						

2007-09-13	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	3	5	7
Concentration (mg/l)	-	-	1	3	5	7
Turbidity (NTU)	4.6	3.9	1.75	0.7	0.7	0.8
Temperature (ºC)	24	23	23	23	23	23
pH	8.2	8.3	8.0	7.8	7.6	7.5
Conductivity (µS)	710	710	710	720	720	720
TDS (ppm)	480	-	-	490	-	-
Observations:						

2007-10-10	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	3	5	7
Concentration (mg/l)	-	-	1	3	5	7
Turbidity (NTU)	5.5	2.65	0.75	0.6	0.65	0.75
Temperature (ºC)	23	22	22	22	22	22
pH	8.4	8.4	8.0	7.8	7.6	7.5
Conductivity (µS)	710	720	710	710	720	720
TDS (ppm)	480	-	-	480	-	-
Observations:						

Coagulant: **$Al_2(SO_4)_3$** Turbidity level: **15 NTU**

2007-09-13	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	4	7	10
Concentration (mg/l)	**-**	-	1	4	7	10
Turbidity (NTU)	16.7	9.0	2.25	0.75	0.8	0.85
Temperature (ºC)	24	23	23	23	23	23
pH	8.3	8.3	8.0	7.6	7.4	7.4
Conductivity (µS)	710	710	720	720	720	730
TDS (ppm)	-	**-**	**-**	-	-	**-**
HCO_3^- (mg/l)	205.7	**-**	**-**	176.9	-	**-**
Observations:						

2007-09-13	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	4	7	10
Concentration (mg/l)	**-**	-	1	4	7	10
Turbidity (NTU)	14.4	7.5	1.95	0.6	0.65	0.8
Temperature (ºC)	24	23	23	23	23	23
pH	8.3	8.3	8.0	7.6	7.5	7.4
Conductivity (µS)	710	720	720	720	720	730
TDS (ppm)	480	**-**	-	480	-	**-**
Observations:						

2007-09-27	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	4	7	10
Concentration (mg/l)	**-**	-	1	4	7	10
Turbidity (NTU)	15.2	6.1	1.5	0.6	0.75	0.85
Temperature (ºC)	21	21	21	21	21	21
pH	8.5	8.4	8.1	7.8	7.5	7.4
Conductivity (µS)	720	710	720	720	730	720
TDS (ppm)	490	**-**	**-**	490	**-**	**-**
COD (mg O_2/l)	1.6			2.4		
Microbiology	>100 <1 >100			24 18 >100		
Observations:						

Coagulant: $Al_2(SO_4)_3$ Turbidity level: **30 NTU**

2007-09-13	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	4	7	10
Concentration (mg/l)	-	-	1	4	7	10
Turbidity (NTU)	30.9	13.2	2.5	0.6	0.7	0.85
Temperature (ºC)	24	23	23	23	23	23
pH	8.3	8.4	8.1	7.7	7.5	7.4
Conductivity (µS)	710	710	710	720	720	720
TDS (ppm)	480	-	-	490	-	-
HCO_3^- (mg/l)	212.7	-	-	184.3	-	-
Observations:						

2007-09-17	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	4	7	10
Concentration (mg/l)	-	-	1	4	7	10
Turbidity (NTU)	30.7	10.8	1.85	0.5	0.55	0.75
Temperature (ºC)	23	22	22	22	22	22
pH	8.3	8.3	8.0	7.7	7.5	7.4
Conductivity (µS)	710	710	720	720	720	730
TDS (ppm)	480	-	-	490	-	-
Observations:						

2007-10-11	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	4	7	10
Concentration (mg/l)	-	-	1	4	7	10
Turbidity (NTU)	30.3	7.0	1.75	0.65	0.85	1.0
Temperature (ºC)	22	23	23	23	23	23
pH	8.6	8.6	8.2	7.8	7.5	7.4
Conductivity (µS)	710	710	720	720	720	730
TDS (ppm)	480	-	-	490	-	-
COD / Al^{3+}						
Microbiology						
Observations:						

Coagulant: $Al_2(SO_4)_3$ Turbidity level: **50 NTU**

2007-09-17	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	4	7	10
Concentration (mg/l)	-	-	1	4	7	10
Turbidity (NTU)	50.7	18.0	2.9	0.55	0.5	0.65
Temperature (ºC)	23	22	22	22	22	22
pH	8.4	8.4	8.0	7.7	7.5	7.4
Conductivity (µS)	710	720	720	720	720	730
TDS (ppm)	490	-	-	-	490	-
HCO_3^- (mg/l)	220.3	-	-	-	171.3	-
Observations:						

2007-09-17	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	4	7	10
Concentration (mg/l)	-	-	1	4	7	10
Turbidity (NTU)	48.1	17.8	2.9	0.7	0.65	1.0
Temperature (ºC)	23	22	22	22	22	22
pH	8.4	8.4	8.0	7.6	7.5	7.4
Conductivity (µS)	710	720	720	720	720	730
TDS (ppm)	490	-	-	490	-	-
Observations:						

2007-10-09	**Raw water**	**Treated water**				
Jar number	-	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	-	0	1	4	7	10
Concentration (mg/l)	-	-	1	4	7	10
Turbidity (NTU)	48.1	14.1	2.85	0.65	0.65	0.95
Temperature (ºC)	23	23	23	23	23	23
pH	8.5	8.4	8.1	7.8	7.6	7.4
Conductivity (µS)	710	720	710	720	720	720
TDS (ppm)	480	-	-	490	-	-
COD (mg O_2/l)	12.8			9.6		
Microbiology	>100 >100 98			8 3 <1		
Observations:						

Coagulant: **$Al_2(SO_4)_3$** Turbidity level: **100 NTU**

2007-09-17	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	4	7	10
Concentration (mg/l)	**-**	-	1	4	7	10
Turbidity (NTU)	99	28.3	4.35	0.56	0.5	0.5
Temperature (ºC)	23	23	23	23	23	23
pH	8.4	8.3	8.0	7.7	7.5	7.4
Conductivity (µS)	720	720	720	720	720	730
TDS (ppm)	480	**-**	**-**	-	500	**-**
HCO_3^- (mg/l)	211.7	**-**	**-**	-	168.9	**-**
Observations:						

2007-09-17	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	4	7	10
Concentration (mg/l)	**-**	-	1	4	7	10
Turbidity (NTU)	103	41.9	4.45	0.55	0.55	0.765
Temperature (ºC)	23	23	23	23	23	23
pH	8.4	8.4	8.0	7.7	7.5	7.4
Conductivity (µS)	710	710	720	720	720	730
TDS (ppm)	480	**-**	-	-	-	**-**
Observations:						

2007-09-28	**Raw water**	**Treated water**				
Jar number	**-**	**0**	**1**	**2**	**3**	**4**
Added volume (ml)	**-**	0	1	4	7	10
Concentration (mg/l)	**-**	-	1	4	7	10
Turbidity (NTU)	100	24.2	5.35	0.6	0.6	0.7
Temperature (ºC)	22	23	23	23	23	23
pH	8.6	8.6	8.2	7.8	7.5	7.4
Conductivity (µS)	720	710	720	720	720	730
TDS (ppm)	490	-	-	-	490	-
Observations:						

C Calcualtions for alkalinity

The calculations were done according to the standard practice described in "*Métodos de análise de água*" published by the Health department of Moçambique.

Calibration of equipment

$$N = \frac{V1 \cdot N1}{V} \qquad (1.)$$

where:

N = Molarity of HCl

V1 = Volume of NA_2CO_3

N1 = Molarity of NA_2CO_3

V = Volume of HCl

Alkalinity with use of phenolphtalein:

$$meq/l = \frac{a \cdot N \cdot 1000}{c} \quad (P)$$

$$mg/l\ CaCO_3 = \frac{a \cdot N \cdot 1000}{c} \cdot 50$$

Total alkalinity:

$$meq/l = \frac{b \cdot N \cdot 1000}{c} \quad (T)$$

$$mg/l\ CaCO_3 = \frac{b \cdot N \cdot 1000}{c} \cdot 50$$

where:

a = ml titration fluid used when using phenolphtalein.

b = ml titration fluid used using mixed indicator (methyl red and bromcresol green)

c = ml of sample

N = Molarity of HCl (calibrated once a week)

When P ≤ ½ T: (no presence of hydroxides):

$OH^{-} = 0$

$CO_3^{2-} = 2 \cdot P \quad (meq/l) = 2 \cdot P \cdot 30 \quad (mg/l)$

$HCO_3^{-} = T - 2P \quad (meq/l) = (T - 2P) \cdot 61 \quad (mg/l)$

When P ≥ ½ T (no presence of bicarbonates)

$HCO_3^{-} = 0$

$CO_3^{2-} = 2(T - P) \quad (meq/l) = 2(T - P) \cdot 30 \quad (mg/l)$

$OH^{-} = 2P - T \quad (meq/l) = (2P - T) \cdot 17 \quad (mg/l)$