THE EFFECTS OF THE SEED POWDER OF *MORINGA OLEIFERA* LAM ON THE QUALITY OF WASTEWATER USED FOR VEGETABLE FARMING IN THE KUMASI METROPOLIS

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CERTIFICATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of this or another university, except where due acknowledgement has been made in the text.

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DEDICATION

I wholeheartedly dedicate this thesis to my parents Mr. Henry Osei Appiah and Mrs. Grace Osei Appiah for their unflinching support, prayer and encouragement which has brought me this far. They are wonderful people who believe in my dream. May the Good Lord richly bless them.

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Abstract

Moringa oleifera Lam (MO) is a pan tropical, multipurpose tree whose seeds contains high quality edible oil (up to 40% by weight) and water soluble proteins that act as effective coagulants for water and wastewater treatment. Laboratory jar test procedures have been used for coagulation studies on experimental runs using actual wastewater from urban vegetable farms in Kumasi. Water extracts of *Moringa oleifera* seeds were applied to a wastewater treatment sequence comprising coagulation–flocculation–sedimentation.

The results indicate a significant ($p<0.05$) reduction in turbidity. It revealed that 20mL of 4% (w/v) and 5 % (w/v) MO seed coagulant were very effective in removing turbidity of 250-350NTU to 10 NTU for 1L of raw water. In addition turbidities of 250-300 NTU were lowered to 10-50NTU at 80-100ml of 1.5, 2 and 3 % (w/v). MO also achieved an overall percentage turbidity reduction of 70% for low turbid water (<50NTU), 80% for medium turbid water (50-150NTU) and 95% high turbid water (>150NTU) at 3%w/v and 100mL of MO using 1L of raw water.

It was also observed that pH, conductivity, and TDS of the wastewater were not affected by the MO seed powder. Nitrate, chlorine and sulphate were not influenced by the MO except phosphate which recorded a slight increase. Natural alkalinity and total hardness of the raw water remained unchanged after treatment with the MO seed powder.

From the results, MO concentrations of 1.5 - 5% (w/v) also reduced faecal coliform levels of the wastewater by 97.88%-99.96% (log 1.71-3.82) within one hour.

These studies have shown that the MO seeds are highly effective in the treatment of wastewater from shallow wells and ponds from urban vegetable farms.

LIST OF ABBREVIATIONS

MO.....Moringa oleifera

MOC.....Moringa oleifera coagulant

WHO.....World Health Organisation

FAO.....Food and Agriculture Organisation

APHW.....American Public Health Association

AWWA..... American Water Works Association

BOD..... Biochemical Oxygen Demand

COD .....Chemical Oxygen Demand

TSS.....Total Suspended Solids

TDS.....Total Dissolved Solids

FC.....Faecal Coliform

W/V.....Weight per Volume

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CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

Agriculture is the single largest user of freshwater in the world, accounting for nearly 70 percent (>90 percent in some countries) of all freshwater extractions worldwide (Gleick, 2000). As freshwater becomes increasingly scarce due to population growth, urbanization and climate change, the use of wastewater in agriculture will increase even more. At least one tenth of the world's population is thought to consume foods produced by irrigation with wastewater (Smit and Nasr, 1992).

Pollution of water bodies is a major health issue in many fast growing cities where population growth far exceeds the rate of development of wastewater collection and treatment infrastructure (Meybeck, 1989). Estimates show that more than 90% of wastewater in developing countries undergoes no treatment (Homsi, 2000). Ghana has few small capacity wastewater treatment facilities. Most of these are in poor operating conditions, leaving large volumes of untreated wastewater flowing through urban streams and drains. This has adversely affected the quality of surface water bodies in and around the main cities (Obiri-Danso *et al.*, 2005).

In Ghana, most wastewater is generated mainly from domestic sources, as Ghana's industrial development is concentrated along the coastal line where wastewater is disposed off into the ocean. However, in some inland cities like Kumasi, there are some limited industrial activities such as food processing (breweries, soft-drink

bottling factories) and light vehicle industries. Wastewater generated is disposed off into urban drains and gutters, which eventually ends up in urban streams. Some activities like farming, fishing, and domestic water use which rely on these sources of water have badly been affected.

Risk assessments done in Kumasi, Tamale and Accra showed high contamination levels in irrigation water (Amoah *et al.*, 2005, 2007; Obiri-Danso *et al.*, 2005). A legislation about the use of wastewater from street drains that states that, "No crops shall be watered or irrigated by the effluent from a drain from any premises or any surface water from a drain which is fed by water from a street drainage" (Local Government Bulletin 2, 1995:190; in Obuobie *et al.*, 2006). This is, however, not enforced due to a variety of reasons including capacity needs (Obuobie *et al.*, 2006).

In order to accommodate plant growth requirements the physicochemical quality of treated wastewaters for crop irrigation should comply with the guidelines set by the Food and Agriculture Organization (Ayers and Westcot, 1989; Tanji and Kielen, 2002). These recommended levels can easily be achieved by effective wastewater treatment using high-technology tertiary treatment systems (WHO, 2006). However, processes involved are difficult and costly to operate as they have high energy, infrastructure and maintenance requirements and highly skilled labour, hence making them less attractive for low-income countries (Carr and Strauss, 2001).

The cost involved in achieving the desired level of treatment depends, among other things, on the cost and availability of chemicals. Chemicals commonly used for the various treatment units are synthetic organic and inorganic substances. In many places

these are expensive and they have to be imported in hard currency. Many of the chemicals are also associated with human health and environmental problems (Kaggwa, 2001). In general *Moringa oleifera* seed (MO) is increasingly being recognized as a cheap substitute for wastewater treatment and is safe for human health (Hsu *et al.*, 2006).

In Ghana research on MO for water treatment is very limited, however the plant is being promoted locally for medicinal purposes. A study conducted on the use of Alum and *Moringa oleifera* in surface water treatment recorded 68.8-98.9% and 90-99% reduction in turbidity and faecal coliform respectively (Boateng, 2001). The present study seeks to investigate optimum conditions for effective wastewater treatment by the use of MO seeds as coagulant.

1.2 STATEMENT OF PROBLEM

Untreated wastewater is commonly used in urban irrigated vegetable farming in Ghana (Obuobie *et al.*, 2006). The wastewater is obtained from urban streams, shallow ponds and drains which are sources of irrigation for farmers. Most urban centres have no means of treating wastewater and only 4.5% of households in Ghana are connected to sewer networks (Ghana Statistical Services, 2002). This leaves most untreated wastewater (grey water), mainly from domestic sources, ending up in urban drains and water bodies in and downstream of the cities. The use of wastewater in vegetable farming leads to the transmission of pollution-related diseases affecting human health. Transmission of diseases, mainly bacterial and intestinal nematode infections, occurs through eating of produce from wastewater irrigated fields and

through direct contact by farmers and other field workers (Shuval *et al.,* 1986; WHO 1986).

High levels of turbidity in irrigation water restricts the use of better irrigation methods like drip irrigation and filtration techniques such as slow sand filters that can greatly reduce contamination as they become easily clogged. Measures to improve water quality should be simple and low-cost for easy adoption by urban vegetable farmers as they cannot afford high-cost wastewater treatment.

1.3 JUSTIFICATION

The most widely applied water treatment technology, a combination of some or all of coagulation, flocculation and sedimentation, plus filtration, has been used routinely for water treatment since the early part of the twentieth century. Coagulation is a simple and inexpensive way to improve the quality of water and reduces levels of organic compounds, dissolved phosphorus, colour, iron, and suspended particles. Up to 70% of Chemical Oxygen Demand (COD) in municipal wastewater is attributable to particulate matter larger than 0.45μm (Nieuwenhuijzen *et al.,* 2001). Several pollutants are also incorporated into, or adsorbed onto, the particulate material. Thus, it is of interest to explore the development of a treatment strategy for the enhanced removal of suspended and colloidal solids from wastewater.

The two most commonly used primary coagulants are aluminium and iron (III) salts (Okuda *et al.,* 1999). The use of alum and iron salts is not economically viable in some developing countries because of the high cost and low availability of chemical

coagulants (Schultz and Okun, 1983). To ease the problems associated with chemical coagulants, several studies have pointed out the introduction of natural coagulants produced or extracted from microorganisms, animals, or plants (Kawamura, 1991; Lee *et al.,* 1995; Ganjidoust *et al.,* 1997). *Moringa oleifera* contains a natural organic polymer, which is non-toxic and usually presumed safe for human consumption (Grabow *et al.,* 1985). In terms of water treatment applications, the MO seed in diverse extracted and purified forms has proved to be effective at removing suspended material (Ndabigengesere *et al.,* 1998; Raghuwanshi *et al.,* 2002), softening hard waters (Muyibi and Evison, 1995b) and acting as an effective adsorber of cadmium (Sharma *et al.,* 2006). The seeds have shown a high coagulation activity for high-turbid water (Muyibi *et al.,* 2001; Muyibi *et al.,* 2002).

Current studies reported that MO seed is effective sorbents for removal of heavy metals and volatile organic compounds in the aqueous system (Akhtar *et al.,* 2006, Sharma *et al.,* 2006). Many studies have also been done on the performance of MO seeds as a primary coagulant. The seed as a coagulant could be used for wastewater treatment (Foidl *et al.,* 2001). Although many studies have been carried out on *Moringa oleifera's* efficiency as a coagulant (Muyibi and Okufu, 1995; Muyibi and Evison, 1995, 1996), studies on the effects of its coagulation performance on wastewater for vegetable irrigated farms have not been established.

Risk assessments done in Kumasi, Tamale and Accra show high faecal contamination levels in irrigation water, 3-8 log units of faecal coliforms in 100 mL, in irrigated urban vegetable farms (Amoah *et al.,* 2005, 2007; Obiri-Danso *et al.,* 2005). High

turbidity levels of up to 791 NTU have also been recorded in irrigation water (Keraita *et al.,* 2008).

Many studies have been done on the performance of *Moringa oleifera* seeds as a primary coagulant in water treatment (Ghebremichael, 2004; Muyibi and Alfugara, 2003). Though most studies have focused on treatment of drinking water which has low turbidity, the seeds have also shown high coagulation for high-turbid water. *Moringa oleifera* can reduce turbidity in low-turbid water of 21.5-49.3 NTU to 2.7 NTU, water of medium turbidity of 51.8-114 NTU to 2.9 NTU and that of high turbidity of 163-494 NTU to 1.4 NTU (Muyibi and Alfugara, 2003). *Moringa oleifera* has antibacterial properties and studies show that an average of 1.1–4.0 log reductions of several microorganisms including E. Coli can be achieved (Ghebremichael, 2004). Microorganism removal was attributed to the extracts' flocculation and bactericidal action. Recently, there is an increasing trend to evaluate some indigenous cheaper materials for wastewater treatment as conventional wastewater treatment has many disadvantages such as high cost and energy requirements (Hsu *et al.,* 2006, Foidl *et al.,* 2001). Biological materials such as MO have been recognized as cheap substitutes for wastewater treatment and are safe for human health (Hsu *et al.,* 2006). Current studies report that MO seeds are effective sorbents for removal of heavy metals and volatile organic compounds in the aqueous system and can also coagulate algae as well (Akhtar *et al.,* 2006, Sharma *et al.,* 2006). Therefore *Moringa oleifera* will be a good alternative in treating waste water.

1.4.0 OBJECTIVES

1.4.1 General Objective

The focus of this study is the treatment of wastewater for use in irrigated urban vegetable farming by using *Moringa oleifera* seed powder.

1.4.2 Specific Objectives

(i) To test the efficacy of treatment of wastewater with *Moringa oleifera* as a natural coagulant.

(ii) To determine the conditions for the optimum performance of *Moringa oleifera* in treating polluted water (conductivity, pH, turbidity, removal of faecal coliforms etc).

(iii) To assess the effectiveness of *Moringa oleifera* in reducing pollution levels in surface water in actual field conditions.

1.4.3 Output

Effective conditions for wastewater treatment using *Moringa oleifera* seed will be established.

These objectives will be realized through:

i. testing of water quality parameters of raw and treated water

ii. determination of optimum dosage of *Moringa oleifera* for different levels of turbidity, and its removal efficiency.

iii. investigating the possibilities of using *Moringa oleifera* in reducing pollution in surface water in actual farm conditions.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 PHYSICOCHEMICAL QUALITY OF TREATED WASTEWATERS

With the increasing scarcity of freshwater resources available to agriculture, the use of urban wastewater in agriculture will increase, especially in arid and semi-arid countries. The major challenge is to optimize the benefits of wastewater as a resource for both the water and the nutrients it contains, and to minimise the negative impacts on human health. From the environmental point of view there are potentially positive and negative impacts that should be considered. International guidelines for use and quality standards of wastewater in agriculture exist (Mara and Cairncross, 1989). These standards can only be achieved if the wastewater is appropriately treated. Because of high treatment costs, most cities in low-income developing countries may not have wastewater treatment facilities in the foreseeable future. However, while the use of untreated wastewater has become a routine for urban irrigation, it is very important to look for economically viable interventions that could be adopted for wastewater treatment.

A number of studies indicate that a natural coagulant from the *Moringa oleifera* seed (MO) may be an alternative for metal salts (Ndabigengesere and Narasiah, 1998). Using *Moringa* instead of aluminium sulphate might give many advantages, such as smaller costs and less sludge production (Ndabigengesere and Narasiah, 1998). However, there are also some disadvantages often connected with the use of *Moringa*, i.e. increased concentration of nutrients and COD (Bengtsson, 2003).

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

2.1.1 Bacteriological quality

Bacteriological quality has a large effect on the taste and smell of the water and can sometimes be a large problem in both surface and 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 such as typhoid (Salmonella *typhi*), cholera (Vibrio *cholerae*) and diarrhea (Giardia *lamblia*) (Hammer and Hammer Jr, 2004). Faecal coliforms and streptococci indicate that wastes from humans or animals contaminate the water (U.S. Environmental Protection Agency, 2007). Faecal 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 (Degrémont, 1979).

2.1.2 Turbidity

The cloudiness of water is referred to as turbidity and has its origin from particles suspended in the water (Cech, 2005). These are natural contaminants and most often consist of mineral particles such as clay and silt or organic flocs. Turbidity is a major problem in water treatment when the water source is surface water but can often be neglected in treatment of groundwater (Knutsson and Morfeldt, 1995).

Turbidity is usually measured in Nephelometric Turbidity Units (NTU). This is an optical measurement, where a light beam is transmitted through the water sample, and

the amount of scattered and absorbed light is detected (Hammer and Hammer Jr., 2005). The World Health Organisation allows agricultural water with turbidity below 5 (WHO, 2007).

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 (Kemira, 2003). 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 mgO_2/l (Kemira, 2003).

2.1.4 Hardness

The amount of calcium (Ca) and magnesium (Mg) determine 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 (Kemira, 2003). 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 (Kemira, 2003).

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

In the case of a low amount of free carbon dioxide the calcium carbonate will lead to deposits and corrosion. The equilibrium depends on temperature and affects the lime precipitation (Kemira, 2003). The hardness of a water can be described in several units such as the German hardness scale, °dH, or equivalents of $CaCO_3$.

2.1.4 pH and Alkalinity

The pH and alkalinity of the water have an impact on the water quality and are closely linked to corrosion (Kemira, 2003).

pH is defined as the negative logarithm to base 10 of the concentration of hydrogen ions in a solution, and thus indicates the amount of hydrogen ions in the water (Cech, 2005). A pH of 7 is neutral. Values less than 7 are acidic, and values greater than 7 are basic. 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 (Warfvinge, 1997). Since corrosion is caused by calcium carbonate (as described earlier), the corrosion process is dependent on the pH and alkalinity of the water.

2.1.5 Ions, Conductivity and Total dissolved solids (TDS)

Examples of common ions in 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 agricultural water quality aspects. Iron and manganese also have an impact on the taste, colour and odour of the water and can cause deposits in pipes (Kemira, 2003). Fluoride (F^-) is another common ion in waters, which in large amounts of drinking water can cause discoloration of the teeth (Kemira, 2003).

Conductivity is a measurement of the water's ability to transport electricity and it 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 (NALMS, 2007). TDS is measured in ppm or mg/L.

2.1.6 Heavy metals and toxic substances

The concentration of heavy metals as well as toxic substances in water should be carefully monitored. The recommended allowable values from WHO varies from 10 µg/L (lead, Pb) down to 3.0 µg /l (cadmium, Cd) (WHO, 2006).

Pesticides from agriculture have become a problem in the last fifty years. Their toxic character and their inability to biodegrade make them a problem in water quality (Kemira, 2003)

2.1.7 Correlation between microorganisms, toxic or trace element and plant macro-nutrients

Levels of biodegradable organic matter and suspended solids are often used for classification of treated wastewater intended for irrigation because there are fairly effective and efficient methods for measurement of BOD/COD/TSS (TSS is Total suspended solids), and, because they give an overall assessment of the treatment performance. Removal of biodegradable organic matter and suspended solids may coincide with the removal of clogging agents, part of the pathogenic microorganisms,

toxic and trace elements and plant macro-nutrients. The extent of this correlation, however, depends on the type of treatment system applied. Levels of BOD/COD/TSS can be monitored indirectly in conjunction with turbidity measurements. Turbidity (NTU), which can be monitored on-line, is thus often used as a parameter for water quality monitoring (Crook, 1998; Feigin *et al.*, 1991). Low levels of turbidity or TSS, however, do not indicate that reclaimed water is, for example, devoid of microorganisms. As such, NTU and TSS are not used as indicators of microbial quality, but rather as quality criteria for wastewater prior to disinfection (Crook, 1998). The effluent must be low in NTU and TSS prior to disinfection to reduce shielding of pathogens and also reduce chlorine demand (Metcalf and Eddy, 1995)

2.1.8 Phosphorus and nitrogen: overdose and nutrient imbalance

The rate of phosphorus (P) uptake by plants is not high and usually surpassed by immobilization processes in the soil. Thus the main source of P for plant development is from effluent applications. The amount of P added to the soil through sewage effluent is usually not excessive to crop requirements. However excessive levels of available P, if they occur, may result in nutrient imbalances such as Cu, Fe and Zn deficiencies, necessitating soil or foliar application of micronutrients (Feigin *et al.*, 1991). The movement of phosphorus through the soil is very restricted and most P remains contained in the top-soil, and even transport of small quantities of P from agricultural soils into surface waters can induce eutrophication.

Nitrogen overdose in the form of excessive nitrates and water-soluble ammonium may seriously affect the quality of crop production. Problems associated with nitrogen overdose are crop specific and attributable to a number of processes such as: plant

physiological disorders, reduced carbohydrate metabolism, enhanced vegetative growth, increased tissue succulence and delays and non-uniformity in ripening of fruits (Feigin *et al.*, 1991)

2.2 WATER QUALITY

Often, the limits on concentrations of many chemicals in wastewater will be determined by crop requirements and not by health concerns (Table 2.1). The nutrients in wastewater (i.e., nitrogen, potassium, phosphorus, zinc, boron and sulphur) should be present in the right concentrations or they can damage the crops and/or the environment. For example, wastewater often contains high concentrations of nitrogen. Although plants require nitrogen for growth, excessive nitrogen can cause over-stimulation of growth, delayed maturity or poor quality produce. Plants require different amounts of nitrogen based on the stage of growth. In the first stages of growth plants may require high quantities of nitrogen (in the earliest stages of growth plants require lots of nitrogen but may be too small to usefully assimilate all that is applied), but in the later flowering and fruiting stages they may require less. In some cases nitrogen levels will need to be adjusted by blending water supplies (FAO, 1985). This is also an important consideration to reduce leaching of nitrate into groundwater supplies and posing a potential health risk to consumers of the drinking water.

Sodium chloride, boron and selenium should be monitored carefully. Many plants are sensitive to these substances. Boron is frequently present in wastewater because it is used in household detergents. Many types of trees (e.g., citrus and stone fruits) will

have impaired growth even when low boron concentrations are present in the water (FAO, 1985).

Table 2.1 Threshold values for plant toxicity for selected trace elements

Parameter	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity Ec_w[1]	dS/m	< 0.7	0.7 - 3.0	> 3.0
Total dissolved solids (TDS)	mg/L	< 450	450 – 2000	> 2000
Total suspended solids (TSS)	mg/ L	< 50	50 – 100	> 100
Sodium (Na^+) (surface irrigation)	meq/ L	< 3	3 – 9	> 9
Chloride (Cl^-) (surface irrigation)	meq/L	< 4	4 – 10	> 10
Chlorine (Cl_2) (Total residual)	mg/L	< 1	1 – 5	> 5
Bicarbonate (HCO_3^-)	mg/ L	< 90	90 – 500	> 500
Boron (B)	mg/L	< 0.7	0.7 - 3.0	> 3.0
Hydrogen sulphide (H_2S)	mg/ L	< 0.5	0.5 - 2.0	> 2.0
Total nitrogen (N)	mg/ L	< 5	5 – 30	> 30
pH			Normal range 6.5-8	

[1] EC_w means electrical conductivity in deciSiemens per metre at 25°C. Source: (WHO, 2006)

Selenium can be toxic to plants in very low concentrations and can accumulate in plant tissue to toxic concentrations, for example in alfalfa grown for forage (FAO, 2002). Concentrations of these elements in the irrigation water may be improved by blending water supplies if other water sources are available (FAO, 2002)

Water quality is also a factor in selecting the type of irrigation method. For example, sprinkler irrigation with water that contains relatively high concentrations of sodium or chloride ions can cause leaf damage to sensitive crops especially when climatic conditions favour evaporation (i.e., high temperatures and low humidity) (FAO, 1985). Similar damage to crops occurs when wastewater with high levels of residual chlorine (>5 mg/L) is sprayed directly onto leaves (Asano and Levine, 1998).

Municipal wastewater may contain a range of other toxic substances, including heavy metals, as a result of industrial effluents entering the municipal wastewater stream (FAO, 1992). Some of these substances may be removed during wastewater treatment processes when available, but others may remain in quantities great enough to cause toxicity to the crops. In cases where industrial wastes are released into the general wastewater stream or where crops exhibit signs of trace element toxicity, it may be necessary to test the water and soil for these elements. Heavy metals are usually fixed by the soil matrix and tend to be mobile only in the topmost soil layers. When water containing toxic trace elements is applied to crops, these elements may be concentrated in the soil as the water is lost into the atmosphere. (FAO, 2002)

Table 2.2 Log unit reduction or inactivation of excreted pathogens achieved by selected wastewater treatment processes

Treatment process	Log unit pathogen removals[a]			
	Viruses	Bacteria	Protozoan (oo)cysts	Helminth eggs
Low-rate biological processes				
Waste stabilization ponds	1−4	1−6	1−4	1−3[b]
Wastewater storage and treatment reservoirs	1−4	1−6	1−4	1−3[b]
Constructed wetlands	1−2	0.5−3	0.5−2	1−3[b]
High-rate processes				
Primary treatment				
Primary sedimentation	0−1	0−1	0−1	0−<1[b]
Chemically enhanced primary treatment	1−2	1−2	1−2	1−3[b]
Anaerobic upflow sludge blanket reactors	0−1	0.5-1.5	0−1	0.5−1[b]
Secondary treatment				
Activated sludge secondary sedimentation	+ 0−2	1−2	0−1	1−<2[b]

Treatment process	Log unit pathogen removals[a]			
	Viruses	Bacteria	Protozoan (oo)cysts	Helminth eggs
Trickling filters secondary sedimentation	+ 0−2	1−2	0−1	1−2[c]
Aerated lagoon + settling pond	1−2	1−2	0−1	1−3[c]
Tertiary treatment				
Coagulation/flocculation	1−3	0−1	1−3	2[b]
High-rate granular or slow-rate sand filtration	1−3	0−3	0−3	1−3[b]
Dual-media filtration	1−3	0−1	1−3	2−3[b,d]
Membranes	2.5−>6	3.5−>6	>6	>3[b,d]
Disinfection				
Chlorination (free chlorine)	1−3	2−6	0−1.5	0−<1[b]
Ozonation	3−6	2−6	1−2	0−2[e]
Ultraviolet radiation	1−>3	2−>4	>3	0[e]

Source: (WHO, 2006)

[a] The log unit reductions are $\log_{10}$ unit reductions defined as $\log_{10}$ (initial pathogen concentration/final pathogen concentration). Thus, a 1-log unit reduction = 90%

reduction; a 2-log unit reduction = 99% reduction; a 3-log unit reduction = 99.9% reduction; and so on.

[b] Data from full-scale plants.

[c] Theoretical efficiency based on removal mechanisms.

[d] Data from tests with up to 2 log units initial content; removal may be greater than that reported.

[e] Data from laboratory tests.

Values of pathogens are transformed from figures to logarithms in order to obtain normal distribution curves. Besides it is convenient to work with log rather than big exponential figures. Therefore large exponential figures in this work will be transformed into natural logarithms of base ten (10).

2.2.1 Primary treatment

Primary treatment is achieved in sedimentation tanks with a retention time of approximately 2−6 hours. Pathogen reduction is minimal, generally <1 log unit. However, where wastewaters have high helminth egg numbers, primary treatment can remove substantial numbers of eggs even though the reduction is <1 log unit.

Chemically enhanced primary treatment

The pathogen reduction efficiency of primary treatment can be increased by incorporating coagulation/flocculation upstream, and/or by using filtration downstream of, gravity sedimentation (Metcalf & Eddy, Inc., 2003). Chemically enhanced primary treatment (CEPT), also called advanced primary treatment (APT), uses specific chemicals (e.g., lime or ferric chloride often with a high-molecular-weight anionic polymer) to facilitate particle coagulation and flocculation. Improving

these processes increases the removal of suspended solids, including helminth eggs (Gambrill, 1990; Morrissey and Harleman, 1992; Jimenez and Chavez 2002; Harleman and Murcott, 2001). Studies in Mexico City showed that APT was capable of producing effluents with 2−5 eggs/litre. When APT effluents were filtered through polishing sand filters, effluents with <1 egg/litre were produced at one third of the cost of a secondary treatment system (activated sludge), including sludge treatment and disposal 30 km away (Landa *et al*., 1997; Harleman and Murcott, 2001). Additionally many virus particles are associated with particulate matter (suspended solids) and CEPT increases suspended solids removal from approximately 30 percent to 70−80 percent (Jiménez, 2003). Another advantage is that nitrogen, organic matter and phosphorus are only partially removed (Jimenez and Chavez, 2002)

2. 2.2 Secondary treatment

Secondary treatment systems, which follow primary treatment, are biological treatment processes coupled with solid/liquid separation. The biological processes are engineered to provide effective bio-oxidation of organic substrates dissolved or suspended in the wastewater. Secondary treatment processes comprise an aerobic microbial reactor followed by secondary sedimentation tanks to remove and concentrate the biomass produced from the conversion of wastewater organic constituents. The aerobic reactors use either suspended-growth processes (e.g., activated sludge, aerated lagoons, oxidation ditches) or fixed-film processes (trickling filters, rotating biological contactors). Although secondary treatment systems are designed primarily for the removal of BOD, suspended solids and often nutrients (nitrogen and phosphorus), they can, with optimized performance, reduce bacterial and viral pathogens by approximately 2 log units, protozoan (oo) cysts by 0−1 log

unit and helminth eggs by approximately 2 log units, depending on the suspended solids concentration.

2.2.3 Tertiary treatment

Tertiary treatment refers to treatment processes downstream of secondary treatment such as (a) additional solids removal by flocculation, coagulation and sedimentation, and/or granular medium filtration; and (b) disinfection. When tertiary treatment processes are used, the overall sequence of wastewater treatment processes is generally described as 'advanced wastewater treatment'.

2.2.3.1 Coagulation, flocculation and sedimentation

These unit processes further reduce pathogens. Chemicals (e.g., $FeCl_3$, $FeCl_2$, $Al_2(SO_4)_3$, CaO) are added to secondary effluents which cause very small particles to combine or aggregate. Larger aggregated particles then settle out of the liquid. Because viruses and bacteria are often associated with particulate matter, increasing removal of particulates also increases the removal of these microorganism − for example, viruses can be reduced by 2−3 log units under optimal conditions (Jiménez, 2003); reductions for other pathogens are given in Table 2.2

2.2.3.2 Filtration

Filtration is also an effective additional step for removing pathogens. It can be used after primary treatment to improve helminth removal (e.g., after a coagulation/flocculation step in CEPT) or more commonly after secondary treatment. In filtration pathogens and other particulate matter are removed by passing the effluents through sand or other porous media. There are several types of filtration including high rate granular filtration, slow sand filtration, and dual media filtration.

Dual media filtration uses two types of media with different properties to maximize the removal of particles with different properties. The effectiveness of filtration techniques for removing pathogens depends upon the operating conditions. For example, fast rate and dual media filtration are usually preceded by coagulation. By optimizing the coagulation process with dual media filtration, bacteria reduction can increase from <1 log unit to 2−3 log units (WHO, 2004). Efficient slow sand filtration requires optimum ripening, cleaning, and refilling without short-circuiting (WHO, 2004). Pathogen reductions achieved by filtration processes are given in Table 2.2

2.2.3.3 Disinfection

The effectiveness of disinfection depends upon several factors, including the type of disinfectant, contact time, temperature, pH, effluent quality and type of pathogen (WEF, 1996). Chlorine (free chlorine), ozone, and ultraviolet irradiation are the principal disinfectants used to treat wastewater; chloramines may be used for CEPT/APT effluents. Disinfection should be optimized for each type of disinfectant. In general, bacteria are the most susceptible to all three disinfectants. Helminth eggs and protozoan cysts/oocysts are the most resistant to chlorine and ozone; and certain viruses (e.g., adenoviruses) are the most resistant to UV (Rojas *et al*., 2004); although there are no data for helminth eggs, they are also expected to be resistant to UV. Pathogen reductions achieved by these disinfection processes are given in Table 2.2

2.2.4 The coagulation process

Coagulation is accomplished by the addition of ions having the opposite charge to that of the colloidal particles. Since the colloidal particles are almost always negatively charged, the ions which are added should be cations or positively charged. The

coagulating power of an ion is dependent on its valency or the magnitude of the charge. A bivalent ion (+2 charge) is 30 to 60 times more effective than a monovalent ion (+1 charge). A trivalent ion (+3 charge) is 700 to 1000 times more effective than a monovalent ion.

Typically, two major types of coagulants are added to water. These are aluminum salts and iron salts. The most common aluminum salt is aluminum sulphate, or alum. When aluminum sulphate is added to water, the aluminum ions enter into a series of complicated reactions. The aluminum ions become hydrated, meaning that water molecules attach themselves to the aluminum ions. In addition, anions present in the water, such as hydroxide and sulphate ions can be attached to the aluminum ions. These reactions result in large, positively charged species having aluminum ions at their center. These particles may have charges as high as +4. Following these reactions, a second type of reaction occurs, called olation. This reaction involves the bridging of two or more of these large species to form even larger, positively charged ions. A typical species can contain eight aluminum ions, twenty hydroxide ions, and will have a +4 charge. Iron salts behave in a similar manner when added to water.

Once these large polymeric aluminum or iron compounds are formed, the magnitude of their high positive charge allows these species to rapidly move toward the colloid, where they are adsorbed onto the negatively charged surface of the turbidity particle. The coagulant compounds can penetrate the bound water layer because of their high positive charge. This rapid adsorption results in the compression of the electrical double layer, and results in the colloid becoming coated with the coagulant compounds. The net result of this process is that the electrical charges on the particle are reduced. The suspension is now considered to be destabilized, and the particles

can be brought together through, among other forces, Brownian movement, and will be held together by the van der Waals forces.

An additional process occurs which assists this process. As the coagulant continues to undergo the hydrolyzation and olation reactions, progressively larger masses of flocculent material are formed. These compounds can become large enough to settle on their own, and tend to trap turbidity particles as they settle. This is commonly referred to as sweep floc.

As the coagulation reactions and destabilization are occurring, the zeta potential at the surface of the colloid is also found to be reducing. Typically, the zeta potential for naturally occurring water may be in the range of 10 to 25 millivolts. As the reactions occur, this zeta potential will be reduced to approximately 5 millivolts. These figures are only examples of what might be considered typical waters. Since all waters exhibit a specific set of characteristics, these numbers will vary. It is interesting to note that the zeta potential does not have to be reduced to zero in order for coagulation to occur, because the forces of attraction can become predominant before complete destabilization occurs.

Hydrophilic colloids participate in the coagulation process in a slightly different way. These colloids tend to attract water molecules to their surfaces. This is also a hydration process, and the water molecules act as a barrier to contact between particles. Also attached to the surfaces are hydroxyl, carboxyl, and phosphate groups, all to which are negatively charged. Coagulant products react chemically with the negatively charged groups attached to the hydrophilic colloids, forming an insoluble product which is electrically neutral and destabilized.

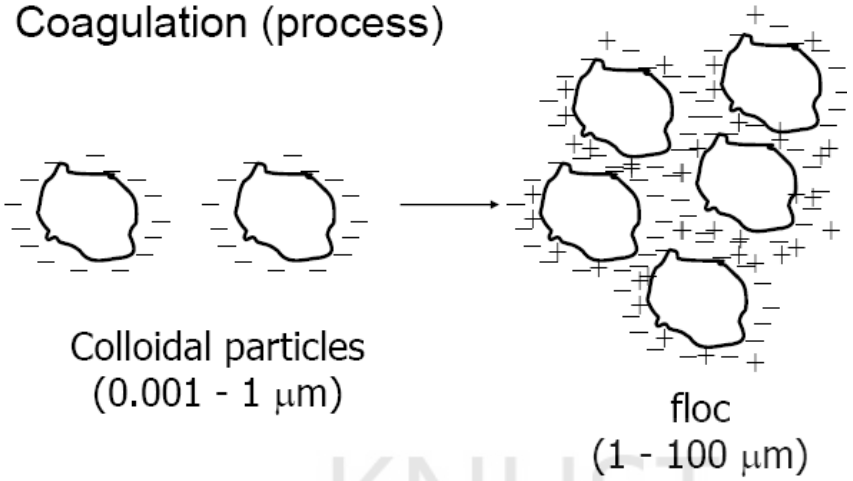

Figure 2.1 Schematic diagram of coagulation and floc formation processes

2.2.4.1 Purpose of coagulation

Untreated surface waters contain clay, minerals, bacteria, inert solids, microbiological organisms, oxidized metals, organic color producing particles, and other suspended materials. Some of the microbiological organisms can include Giardia cysts, pathogenic bacteria, and viruses. Oxidized metals include iron and manganese. All of these materials can inhibit disinfection, cause problems in the distribution system, and leave the water cloudy rather than clear. The purpose of coagulation is to remove these particles.

The ability of particles to remain suspended in water is a function of both the particle size and specific gravity.

Turbidity particles can range in size from molecular to 50 microns. Particles which are greater than one micron in diameter are considered silt, and settle out due to their relatively large size and density without the need to coagulate in a matter of seconds

or minutes. Colloidal material ranges in size from 0.001 to one micron in diameter. These materials require days to months for complete settling. Since retention times in the water treatment process are generally less than twelve hours, the rate of settling of these colloidal particles must be increased in the water treatment process. This is accomplished in the coagulation process when tiny particles agglomerate into larger, denser particles which will settle more quickly.

These tiny colloidal particles have a very large surface area to mass ratio, and this factor is important in keeping the particles suspended for long periods of time. In fact, the surface area to mass ratio is so high that electric charges and ionic groups become important in keeping the particles suspended. Two types of colloids exist. These are hydrophobic or water hating colloids, and hydrophilic or water loving colloids. Hydrophilic colloids form suspensions easily, and can be difficult to remove. These colloids can, however, react chemically with the coagulants commonly added to water under proper conditions. Examples of hydrophilic colloids would be organic color forming compounds. Hydrophobic colloids do not easily form suspensions. The reactions between hydrophobic colloids and the coagulants commonly added to water are largely physical rather than chemical. Examples of hydrophobic colloids would be clays and metal oxides.

Coagulation, generally followed by filtration, is by far the most widely used process to remove the substances producing turbidity in water. These substances which normally produce turbidity consist largely of clay minerals and microscopic organisms and occur in widely varying sizes, ranging from those large enough to settle readily to those small enough to remain suspended for very long times.

Coarser components, such as sand and silt, can be removed from water by simple sedimentation. Finer particles, however, will not settle in any reasonable time and must be flocculated to produce the large particles that are settleable. The long-term ability to remain suspended in water is basically illustrated in Table 2.3, which shows the relative settling times of spheres of different sizes. It can be seen that the settling rates of the colloidal and finely divided (approximately 0.001 to 1 micron) suspended matter are so slow that removing them from water by plain sedimentation in tanks having ordinary dimensions is impossible. The enormous increase of surface area for a given weight of solids as the particles become smaller and more numerous is an important property of colloids. Substances producing colour, as distinct from turbidity, consist either of colloidal metallic hydroxides, iron for example, or of organic compounds having a much smaller particle size. These substances, too, can be removed by coagulation, which serves to agglomerate the very small particles into sizes, which are settleable or can be removed by filters.

Table 2.3: Effect of decreasing size of spheres on time of settling

Diameter of particle, mm	Order of size	Total surface area	Time required to settle
10	Gravel	3.14 cm^2	0.3sec
1	Coarse sand	31.4 cm^2	3 sec
0.1	Fine sand	314.1 cm^2	38 sec
0.01	Silt	21.8cm^2	33 min
0.001	Bacteria	218.0 cm^2	55 hr
0.0001	Colloidal Particles	24.5 cm^2	230 days
0.00001	Colloidal Particles	28329 m^2	6.3 yr
0.000001	Colloidal Particles	283290 m^2	63 yr minimum

Notes: Area for particles of indicated size produced from a particle 10 mm in diameter with a specific gravity of 2.65. Calculation based on sphere with a specific gravity of 2.65 to settle 30.5 cm.

Source: (Powell S. T., 1954)

The process of coagulation may also find use, although not always, in the softening of hard water with lime or lime and soda ash. Softening is more properly a precipitation

process, and coagulation is used to obtain a more rapid and complete settling of the precipitated hardness components.

The dosage of coagulant depends on several parameters such as type and concentration of contaminants, pH, temperature etc (Kemira, 2003). 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 specific water is defined as the dosage which gives the lowest turbidity in the treated water (Figure 2.2). 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 (Mpagi, 2007).

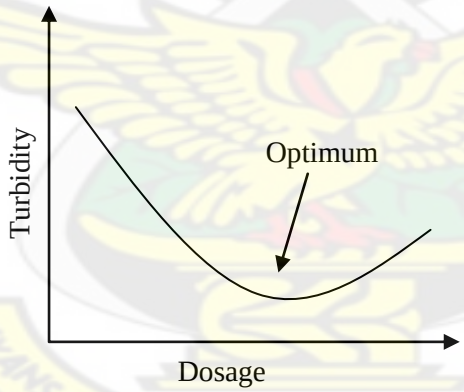

Figure 2.2 Optimum dosages for a specific turbidity level.

2.3 IRRIGATION WATER QUALITY IN GYINYASI

Some physicochemical and bacteriological parameters of the two farming sites that is Gyinyase farm (GYN) and Karikari farm (KAK) where the study took place are in Tables 2.4 and 2.5 respectively

Table 2.4 Ranges in levels of physicochemical parameters in irrigation water from 20 ponds (Keraita *et al.*, 2008).

Farming site	pH	Conductivity (ds/m)	Turbidity (NTU)	NO_3-N (mg/l)	NH_3-N (mg/l)	P(mg/l)	K(mg/l)
GYN	7.0-7.8 (7.2)*	0.10-0.47 (0.20)	35-791 (325) †	0.12-5.32 (2.30)	0.14-1.30 (34.96)	30.09-41.59 (34.96)	5.75-6.84 (6.36)
KAK	7.4-7.8 (7.2)*	0.14-0.59 (0.36)	18-88 (47)	0.90-2.99 (1.98)	1.08-1.54 (1.35)	18.55-58.70 (38.34)	6.41-21.99 (14.15)

*Figures in parenthesis are arithmetic means

†Four ponds had more than 500 NTU. Without them maximum and mean levels were 77 and 59 NTU respectively.

Table 2.5 Indicator organisms in ponds under different pond status (N=36) (Keraita *et al.*, 2008)

Farming site	***Thermotolerant coliforms*** ***(log of MPN 100 ml $^{-1}$)***	***Helminths*** ***(No. of eggs Litre $^{-1}$)***
GYN	6.61 ± 1.18	4.3 ± 0.9
KAK	9.26 ± 0.53	4.9 ± 0.9

2.4 THE MORINGA OLEIFERA TREE

2.4.1 GENERAL DESCRIPTION

Moringa oleifera Lam (Figures 2.3 and 2.4) 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 (Lilliehöök, 2005) and are harvested up to two times a year in India (WELL, 1999). The tree prefers lowlands in hot semiarid conditions with sandy or loamy soils (Schwarz, 2000) 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 of up to 3000 mm. Today it can be found on elevations up to 2000 m in Zimbabwe (Lilliehöök, 2005).

Figure 2.3: Open fruit with seeds of *M. oleifera*

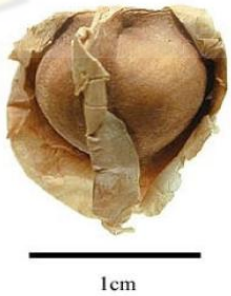

Figure 2.4: Seed of *M. oleifera*

With its origin in India and Pakistan *M. oleifera* was brought to the Africa continent and Sudan in particular 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 (Schwartz, 2000). 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 (Schwartz, 2000).

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 (Sutherland et al, 2001). Different parts of the tree are used in traditional medicine for treating diarrhoea and epilepsy among others (Trees for life, 2006), and some even claim to be treating tumors (Lilliehöök, 2005). The wood pulp can be used for papermaking and the tree itself can be used as a fence, natural windbreaks or fuel (Trees for life, 2006).

2.4.2 NATURAL COAGULANTS

A number of effective coagulants have been identified of plant origin. Some of the common ones include nirmali (Tripathi *et al*., 1976), *M. oleifera* (Olsen, 1987; Jahn, 1988), okra (Al-Samawi and Shokrala, 1996), *Cactus latifaira* and *Prosopis juliflora* (Diaz *et al*., 1999), tannin from valonia (Özacar and Sengil, 2000), apricot, peach

kernel and beans (Jahn, 2001), and maize (Raghuwanshi *et al*., 2002). Bhole (1995) compared 10 natural coagulants from plant seeds. The study indicated that maize and rice had good coagulation effects when used as primary coagulants or coagulant aid.

Chitosan, a natural coagulant from animal origin is also an effective coagulant (Pan *et al*.,1999; Davikaran and Pillai, 2001; Guibal *et al*., 2006). It has unique properties among biopolymers, especially due to the presence of primary amino groups. It is a high molecular weight polyelectrolyte derived from deacetylated chitin and it has characteristics of both coagulants and flocculants: high cationic charge density, long polymer chains, bridging of aggregates, and precipitation (in neutral or alkaline pH conditions). It has also been used for the chelating of metal ions in near-neutral solution and the complexation of anions in acidic solution (cationic properties due to amine protonation). Its coagulation and flocculation properties can be used to treat particulate suspensions (organic or inorganic) and also to treat dissolved organic materials. It has also been reported that chitosan possesses antimicrobial properties (Liu *et al*., 2000; Chung *et al*., 2003).

By using natural coagulants, considerable savings in chemicals and sludge handling cost may be achieved. Al-Samawi and Shokrala (1996) reported that 50 – 90% of alum requirement could be saved when okra was used as a primary coagulant or coagulant aid.

Apart from being less expensive, natural coagulants produce readily biodegradable and less voluminous sludge. For example, sludge produced from *M. oleifera* coagulated turbid water is only 20 – 30% of that of alum treated water (Ndabigengesere *et al*., 1995; Narasiah *et al*., 2002). The coagulation process in water treatment is complimented by filtration. The successfulness of coagulation in most

cases determines the performance of the filtration system, which may be of a mono medium or dual media type.

2.4.3 MECHANISM OF WATER PURIFICATION USING *MORINGA OLEIFERA*

The mechanism of coagulation was suggested to be adsorption and neutralization of charges, or adsorption and bridging of destabilized particles, the two assumed to take place simultaneously. Jahn, 1981; Gassenschmidt *et al.*, (1994) and Ndabigengesere *et al.,* (1995) reported the isolation from *M. oleifera* of a flocculating protein of 60 residues with molecular mass of about 6.5 kDa, isoelectronic point above pH 10, high levels of glutamine, arginine and proline with the amino terminus blocked by pyroglutamate, and flocculant capacity comparable to a synthetic polyacrylamide cationic polymer. However, a non-protein coagulant has also been reported but not characterised (Okuda *et al.,* 2001a).

2.4.4. TREATING 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 (Lilliehöök, 2005).

Women of Sudan have used the technique of swirling seeds in cloth bags with water for a few minutes and letting 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 one tree. By assuming tree spacing of 3 m, an area of 1 ha can treat 30 000m^3 annually (Lilliehöök, 2005).

Figure 2.5 Shelled *Moringa oleifera* seeds

After oil extraction from *M. oleifera* seeds, the residue pressed cake contains water soluble proteins that act as effective coagulants for water purification. One to two seeds per liter are required for water purification. Seed powders are mixed with water, after hours, the water is filtered to get purified water. The charged protein molecules can serve as nontoxic natural polypeptide to settle mineral particles and organics in the purification of drinking water, vegetable oil, depositing juice (sugarcane) and beer (Foidl *et al.*, 2001).

In recent times, there has been an increasing trend to find some indigenous cheaper material for wastewater treatment. Since the conventional procedure of wastewater treatment has some disadvantages, such as incomplete metal removal, high cost and high energy requirements, biological materials have been recognized as cheap substitutes for wastewater treatment. Current studies report that *Moringa* seeds and pods are effective sorbents for removal of heavy metal and volatile organic

compounds in the aqueous system (Akhtar *et al.,* 2006, Sharma *et al.,* 2006). It can be added in oxidation lagoons of wastewater treatment units to coagulate algae as well. The algae are removed by sedimentation, dried and pulverized, and then used as protein supplement for livestock (Foidl *et al.,* 2001). The unique characteristic of *Moringa* seeds could be a possible solution for the developing countries which are suffering from lack of clean water for irrigation.

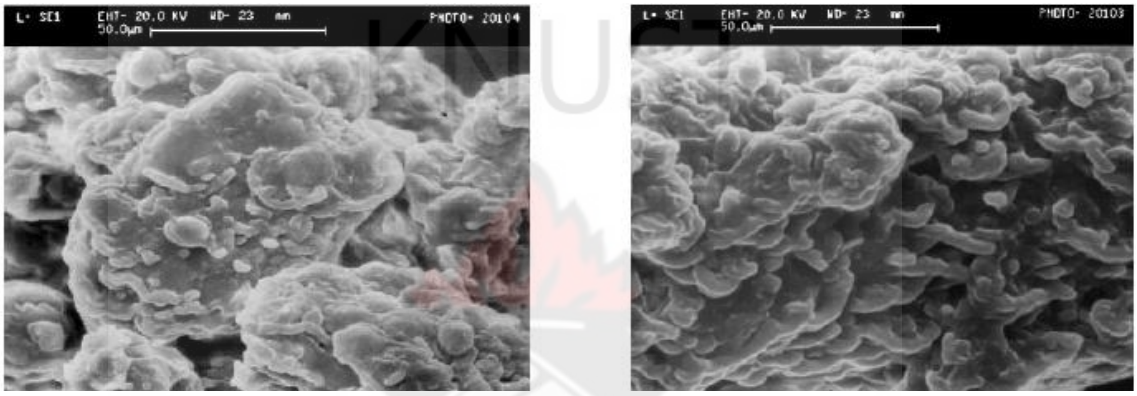

Figure 2.6 Left: Scanning electron micrograph (SEM) of untreated *Moringa* seeds showing large spherical clusters type morphology. Right: SEM of treated *Moringa* seeds showing dense agglomerated, etched dendrite type morphology (Kumari *et al.,* 2006).

2.4.5 CHARACTERISTICS OF THE ACTIVE AGENTS

The coagulant in the seeds was first confirmed by the German scientist Samia Alazharia Jahn (Schwartz, 2000). The active agent is believed to be a protein, but the exact form of the protein is not yet known. Recent researchers 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 cationic polyelectrolytes (Sutherland et al 1994),

which attach themselves to the soluble particles and create bindings between them, leading to large flocs in the water. Stirring and mixing accelerates the electrostatic flocculation, and the flocs condense (Göttsch, 1992).

2.4.6 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 filtered (Ndabigengesere and Narasiah, 1998, Muyibi and Alfugara, 2003, Ghebremichael et al., 2005). 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 is more efficient as solvent for the active agents as compared to distilled water. The study from Okuda *et al.,* (1999) showed that the coagulation capacity with NaCl was up to 7.4 times higher with *Moringa* extract than with distilled water. This is based on the assumption that the coagulating protein is more soluble in water with high concentration of ions (Okuda et al, 2001a). Other studies have focused on purifying the active agent as much as possible and producing a stable protein powder without excessive organic matter. Two separate studies show that the active agents could be purified from the extract using a cation exchanger, leading to reduced levels of COD in the treated water (Ghebremichael, 2005; Ndabigengesere and Narasiah, 1998). A more low-tech way of reducing the organic content is to extract the oil from the seeds with an organic solvent (Ghebremichael, 2005).

2.4.7 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 (Ndabigengesere and Narasiah 1998, Bengtsson 2003, Muyibi and Alfugara 2003). These previous studies have shown that neither pH nor alkalinity or conductivity was affected during the treatment, but an increase in COD, nitrate and orthophosphate has been observed (Bengtsson, 2003, Ndabigengesere and Narasiah 1998). Some studies indicate that treatment with *Moringa* is dependent on the pH of the raw water, optimum treatment is achieved above neutral pH (Okuda *et al.,* 2001a), whereas others showed that, it is independent of raw water pH (Schwartz, 2000). 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 initial turbidity (Katayon *et al,* 2004).

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 (Ndabigengesere *et al.,* 1994)

The *Moringa* coagulant can also be used in combination with other flocculating salts, such as aluminum sulphate (Ndabigengesere and Narasiah 1998). The use of *Moringa oleifera* on a large scale has been tested in a drinking water treatment plant in Malawi with good results (Sutherland *et al.,* 1994).

2.4.8 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 (Katayon *et al.,* 2006). The study does not discuss the reason for this but it could be assumed that it is due to microbial degradation of the proteins. Differences in temperature and container did not have any effect on the properties. Duration of storage should not be above 24 hours as degradation of active agents is believed to occur beyond 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 observed that the highest removal efficiency was performed by solutions stored maximum one day (Katayon *et al.,* 2004).

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 that the temperature and container did not have any 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.

2.4.9 PREVIOUS STUDIES

For treatment applications, the seed pods are allowed to dry naturally on the tree prior to harvesting. The mature seeds are readily removed from the pods, easily shelled and then crushed and sieved using traditional techniques such as those employed for the production of maize flour. The crushed seed powder, when mixed with water, yields water soluble proteins that possess a net positive charge (molecular weight 13 kDa and isoelectric pH 10-11). Dosing solutions are generally prepared as 1-3% solutions and are filtered prior to application to the untreated water (Sutherland *et al.,* 1990). *M. oleifera* seeds in diverse extracted and purified forms have proved to be effective at removing suspended material (Ndabigengesere *and Narasiah* 1998; Raghuwanshi *et al.,* 2002). The seeds have shown a high coagulation activity for highly-turbid water (Muyibi *et al.,* 2001; Muyibi *et al.,* 2002a).

Bench scale testing at Leicester confirmed that the press cake (solids residue remaining after oil extraction) still contains the active, water-soluble proteins. Significantly, two potentially valuable products may be derived from the seed.

Moringa derived coagulants offer several advantages over conventional coagulants such as aluminium sulphate:

- Activity is maintained over a wide range of influent pH values – no pH correction is required.
- Natural alkalinity of the raw water is unchanged following coagulation – no addition of alkalinity is required.
- Sludge production is greatly reduced (by a factor of up to 5) and is essentially organic in nature with no aluminium residuals (Ndabigengesere and Narasiah 1998).

Experiment on purification of the coagulant protein from *Moringa oleifera* seed, showed both flocculating and antibacterial effects of 1.1 – 4 log reduction (Kebreab *et a.l.,* 2005).

Moringa oleifera acts as an effective adsorber of cadmium (Sharma *et al.,* 2006). Earlier studies have shown that *M. oleifera* seed powder is effective in heavy metal remediation of water (Sajidu *et al.,* 2005). Ongoing studies by Mataka, et al (2006) on low cost effective heavy metal remediation using *Moringa stenopetala* and *Moringa oleifera* seed powder techniques in developing countries has already demonstrated that *Moringa oleifera*, the well known source of natural water clarifiers, is effective in heavy metal detoxification of water. Recent studies by (Akhtar *et al.,* 2006, Sharma *et al.,* 2006) reported that *Moringa* seeds are effective sorbents for removal of heavy metal and volatile organic compounds in the aqueous system.

It is now regarded as axiomatic that both water and wastewater technology for developing countries must be no more complex than strictly necessary and be robust and inexpensive to install and maintained. A prototype treatment works was designed based on this philosophy. The pilot plant was constructed within the grounds of the Thyolo Water Treatment Works controlled by the Malawi Government. The pilot plant, with a design flow rate of 1 m^3h^{-1}, consisted of; a header tank, where *M. oleifera* seed solutions were introduced into the turbulent jet of incoming water and mixed hydraulically; an 18-minute flocculation period provided within gravel bed flocculators; plain horizontal sedimentation and rapid gravity filtration. All the units were locally fabricated in sheet steel.

The system was successfully commissioned during the rainy season with the source river exhibiting turbidity levels in excess of 400 NTU throughout the study period. In general solids removal within the plant was consistently above 90% following the gravel bed flocculation stage and plain horizontal flow sedimentation. Subsequent rapid gravity sand filtration gave final, treated water turbidity generally well below 5 NTU with *M. oleifera* seed dose ranging from 75-250 mgL^{-1} depending on the initial raw water turbidity (Folkard *et al.*, 1993).

During the following wet season the main Thyolo works was operated using *M. oleifera* solution as coagulant. The works comprised up flow contact clarifiers followed by rapid gravity filters and chlorination. The clarifiers were in a state of some disrepair with the impeller drives and chemical feed pumps inoperative. Under normal operation, alum solution is introduced into the incoming flow of $60m^3h^{-1}$ by simple gravity feed at a declining rate. Comparable treatment performance with alum was achieved. During a 7.5-hour test run with the main works flow at 60 m^3h^{-1}, the inlet turbidity of 325 NTU was reduced to below 2 NTU following filtration with a seed dose of 75 mgL^{-1}. This was the first time that *M. oleifera* had been successfully used as a primary coagulant at such a scale with the treated water entering supply (Sutherland *et al.*, 1994). *M. oleifera* seed for the full-scale trials was purchased from enthusiastic, local villagers. This was viewed as a temporary yet very welcome new source of cash income in what is a poor rural community of Southern Malawi. The tree is widely cultivated in this area, being highly prized as a source of fresh, green vegetable.

Ndabigengasere and Narasiah 1996 investigated the effects of ambient temperature on turbidity removal. The authors reported lower residual turbidity (from 21 to 8 NTU

residual turbidity for 105 NTU initial turbidity) at the optimum coagulant doses at temperature increased (from 2 to 25^{o}C) for set physical conditions.

A comprehensive study was also undertaken, to evaluate the potential of using *M. oleifera* coagulant within a contact flocculation-filtration (CFF) pilot plant rig. CFF is defined as the high rate filtration process for relatively low turbidity raw waters (< 50 NTU) wherein the coagulant is dosed immediately prior to entry to the sand bed. Flocculation and subsequent deposition occurs entirely within the filter bed. A wide range of operating conditions was evaluated in order to establish the useful 'working envelope' of operational parameters for this single stage process. Previous studies had shown that at the low turbidities of the River Nswadzi experienced in the dry season, the effectiveness of *M. oleifera* coagulant is reduced. Flocs that formed were small, compact and light giving reduced settling velocities. This is considered to be a result of the fundamental nature of the coagulation and flocculation involved. The relatively low molecular weight of the active proteins indicates that charge neutralisation and floc formation are brought about by the patch mechanism as opposed to the bridging mechanism (Gregory, 1991).

The field installation of the pilot CFF rig and full experimental details are given elsewhere (McConnachie *et al.*, 1999), however, for prevailing raw water turbidities of < 50 NTU the single stage treatment of CFF gives consistent filtrate turbidity < 1 NTU for filtration rates up to 10 mh^{-1}.

Moreover, the *M. oleifera* seed dose required to achieve this is relatively low (< 25 mgL^{-1}) and the filter run times are appropriate for effective plant operation.

As a coagulant within chemically enhanced primary sedimentation (CEPS) of a mixed domestic/industrial wastewater, *M. oleifera* dosed at 150 mg l^{-1} gave additional

removals (compared to a plain sedimentation control) of 40% for biochemical oxygen demand (BOD) and chemical oxygen demand (COD) and in excess of 80% for suspended solids (SS) (Folkard *et al.,* 1999).

Subsequent laboratory work at the University of Ghent coupled an up flow anaerobic sludge blanket reactor (UASB) to CEPS (Kalogo *et al.,* 2000). The UASB process relies on the propensity of anaerobic biomass to aggregate into dense flocs or granules over time. Mixing is achieved by pumping influent wastewater from an entry at the base upwards through the sludge blanket. Above the blanket, finer particles flocculate in the upper settlement zones and settle back as sludge in the blanket thus preventing washout of biomass. The biogas, which has poor solubility in water, is separated at the top of the reactor. Domestic wastewater treatment in UASB reactors has proved particularly effective in tropical regions of the world. Effective removal of organic matter and suspended solids is evident at reduced excess sludge volume compared to aerobic treatment. The system is compact, requires minimal energy inputs and does not require support media normally associated with anaerobic systems (De Sousa *et al.,* 1996).

UASB is characterised by a very high mean cell retention time (MCRT) and a relatively low hydraulic retention time (HRT). *M. oleifera* coagulant in the CEPS pre-treatment unit beneficially increased the ratio of soluble COD to volatile SS by a factor of 10 compared to plain sedimentation and 3 when dosing ferric chloride as coagulant. The UASB yielded more biogas and gave 71% removal of total COD at 2 hours HRT. This compared with 54% removal of total COD at the same retention time when ferric chloride was used.

The loading capacity of an anaerobic wastewater treatment system is essentially determined by the amount of active biomass retained in the reactor. In UASB reactors, the microbial aggregates must combine two important characteristics, namely a high biodegradation activity and excellent settling properties, favoured by the formation of granular sludge particles. One of the main problems in the application of this treatment process so far has been the extensively long start-up periods needed for the development of granules (up to six months).

In a subsequent study, a water extract of *M. oleifera* seeds was used to enhance the start-up of a self-inoculated UASB reactor treating raw domestic wastewater (Kalogo et al, 2001). Two reactors labelled 'control' and 'test' were started without special inoculums. Both reactors were fed continuously for 22 weeks with domestic wastewater with an average total COD of 320 mgL^{-1} and SS of 165mgL^{-1}. The reactors operated during the entire experimental period at 29°C and at a HRT of 4 hours. The 'test' reactor received 2 mL of a 2.5% (w/v) *M. oleifera* seed stock solution per litre of influent wastewater.

The 'test' reactor gives the following enhanced performance advantages over the 'control';

1. Shortened the biological start-up period by 20%
2. Increased the acidogenic and methanogenic activity by factors of 2.4 and 2.2 respectively
3. Increased the specific biogas production by a factor of 1.6
4. Favoured fast growth of the sludge bed
5. Allowed the aggregation of coccoid bacteria and growth of microbial nuclei - the precursors of anaerobic granulation.

There are a number of food production processes where solid/liquid separation is an essential stage to achieve the final product quality. One such example is the production of sugar from sugar cane. In the production of organic sugar, the use of synthetic polyelectrolytes to remove extraneous solids suspended in the cane juice is not permitted. Coagulant derived from natural plant materials are used e.g. the bark of *Triumfetta lappula* and gum from *Lannea coromandelica*. A laboratory study was conducted at the Mauritius Sugar Research Institute to evaluate the efficacy of applying *M. oleifera* seed coagulant to clarify limed cane juice (Wong Sak Hoi *et al.*, 1999). In one test series, *M. oleifera* dosed at 0.48% gave a 37% increase in turbidity removal compared to a proprietary coagulant (Superfloc A2130). Other tests were conducted with the addition of bentonite in small quantities as a weighting agent to the *M. oleifera* flocs. The authors conclude that the quantities of *M. oleifera* seed that would be required for the daily production of cane juice are favourable compared to alternative natural coagulants in use.

Treating water with water extracts of *M. oleifera* seeds has one identified disadvantage. The coagulant-inactive seed material that is also water-soluble leads to elevated dissolved organic materials in the treated water (nitrates, orthophosphates etc.). If chlorination is adopted for final disinfection of the clarified water then the potential for the formation of disinfection by-products (DBP) is increased. DBPs such as chloroform are suspected carcinogens and are strictly regulated in Europe and the United States. Residual organic matter may also exert a chlorine demand at the treatment works and be utilised by microorganisms as substrate for re-growth in the distribution system. Therefore there has been much recent research work on the extraction and purification of only the coagulant-active proteins from within the seed

kernel. Protein extraction and purification from *M. oleifera* seed has been reported at laboratory scale only.

Studies were carried on by securing a few milligrams of pure protein for the characterisation of coagulant activity and structure. Extraction of the proteins using 1 M sodium chloride solution gave enhanced coagulation at significantly reduced dosage compared to water extracted material - 95% turbidity reduction at 4 ml L^{-1} compared to 78% reduction at 32 ml L^{-1} for a prepared test water comprising kaolin in water of initial turbidity 50 NTU (the dosage being expressed as volume of 1% stock seed solution, (Okuda *et al.,* 1999). The improvement in extraction is attributed to the 'salting-in' mechanism whereby increased ionic strength gives increased protein solubility. The extraction of seed proteins in other salts gave similar improvements. (Okuda *et al.,* 2001);

The purified material was deemed to be an organic polyelectrolyte of molecular weight around 3 kDa - but not to be a protein, polysaccharide or lipid. The authors claim that the 'specific coagulation efficiency' of this active material is up to 34 times more than that of a water extract of seed, that it is effective for low turbidity waters and that no increase in residual organic carbon is evident following application.

Bhuptawat1 *et al.,* (2007), achieved overall COD removals of 50% at both 50mg/l and 100 mg/l *M. oleifera* doses. When 50 and 100 mg/l seed doses were applied in combination with 10 mg/l of alum, COD removal increased to 58 and 64% respectively.

Studies by Eilert *et al.,* (1981) identified the presence of an active microbial agent in *M. oleifera* seeds. The active agent isolated was found to be 4 α-L-rharmnosyloxy-benzyl isothiocyanate, at present the only known glycosidic mustard oil. Madsen *et al.,* (1987) carried out coagulation and bacterial reduction studies on turbid Nile water in the Sudan using *Moringa oleifera* seed and observed turbidity reduction of 80-99.5% paralleled by bacterial reduction of (90-99.99%) within the first one to two hours of treatment, the bacteria being concentrated in the coagulated sediment. Also studies has shown that *Moringa oleifera* as a coagulant is non-toxic and biodegradable and usually presumed safe for human consumption (Grabow *et al.,* 1985).

Muyibi and Evision. (1995b), investigated into the possible use of *Moringa oleifera* seed suspension for the softening of hard water. Four water sources: synthetic water (distilled water spiked with calcium chloride), naturally hard surface water and groundwater from two tube wells at different locations were used for the study. Modified laboratory jar test procedures for coagulation studies were used for the experimental runs. Water hardness from the sources varied from 300 up to 1000 mg/l as $CaCO_3$. The mechanism for softening was found to be due to adsorption with the adsorption isotherm approximating to the Langmuir type, and conversion of soluble hardness-causing ions to insoluble products by precipitation reactions. Removal efficiency was found to increase with increasing dosage of *Moringa oleifera.* Higher dosages were required to achieve equivalent residual hardness for water samples with the same initial hardness but higher number of hardness-causing species in the water. Hardness removal was found to be independent of pH of the raw water.

Al-Khalili *et al.,* (1997) found low doses of *Moringa oleifera* extract to be effective in contact flocculation filters for low turbidity waters. Experiments were performed with laboratory sand contact flocculation filters at filtration rates of 10 and 20 m/hr and at raw water turbidities from 10 to 75 NTU. Experiments showed that the natural coagulant was effective on low turbidity water at filtration rates at or below 10m/hr.

Moringa oleifera seeds, an environmental friendly and natural coagulant are reported for the pretreatment of palm oil mill effluent (POME). In coagulation–flocculation process, the *M. oleifera* seeds after oil extraction (MOAE) are an effective coagulant with the removal of 95% suspended solids and 52.2% reduction in the chemical oxygen demand (COD). The combination of MOAE with flocculants (NALCO 7751), the suspended solids removal increased to 99.3% and COD reduction was 52.5%. The coagulation–flocculation process at the temperature of 30 °C resulted in better suspended solids removal and COD reduction compared to the temperature of 40, 55 and 70 °C. The MOAE combined with flocculants (NALCO 7751) reduced the sludge volume index (SVI) to 210 mL/g with higher recovery of dry mass of sludge (87.25%) and water (50.3%) (Bhatia *et al.*, 2007).

Ndabigengesere and Narasiah (1998) experimented with using *Moringa oleifera* seeds as a primary coagulant for the treatment of industrial and municipal wastewater. Extracts from pulverised *Moringa* seeds efficiently reduced the chemical oxygen demand, nitrogen and phosphorus concentrations of the wastewaters.

The coagulant of seeds could be used for wastewater treatment (Foidl *et al.*, 2001). Although many studies have been carried out on *Moringa oleifera's* efficiency as a coagulant (Muyibi and Okufu, 1995; Muyibi and Evison, 1995, 1996), studies on the

effects of its coagulation performance on wastewater for vegetable irrigated farms have not been established yet.

CHAPTER THREE

3. METHODOLOGY

3.1 STUDY AREA

Kumasi is the second largest and one of the fastest growing urban cities in Ghana with an estimated population of 1.2 million and an annual growth rate of 2.6% (Ghana Statistical Service, 2000). It lies between latitude 6° 42 North and longitude 1° 35 West and an altitude of 287m. It covers a total area of 57km^2 and the topography of the region varies from gently undulating to distinctly hilly and mountainous

Kumasi receives an annual rainfall of about 1350 mm. The major rainy season is between March and July with the dry season falling between November and February. Two urban vegetable farming sites (Gyinyase and Karikari) have been selected for this study based mainly on the irrigation water sources and their quality, crops grown and accessibility. Figure 3.1 shows the selected urban farming sites. Karikari is located in between residential houses while Gyinyase is at valley bottom lands in large open spaces. The main source of irrigation water is shallow wells although some farmers use over-land flows collected in ponds. Due to the location of farms in Karikari, some ponds collect wastewater from households. Watering cans are used for water collection from sources and also for irrigation.

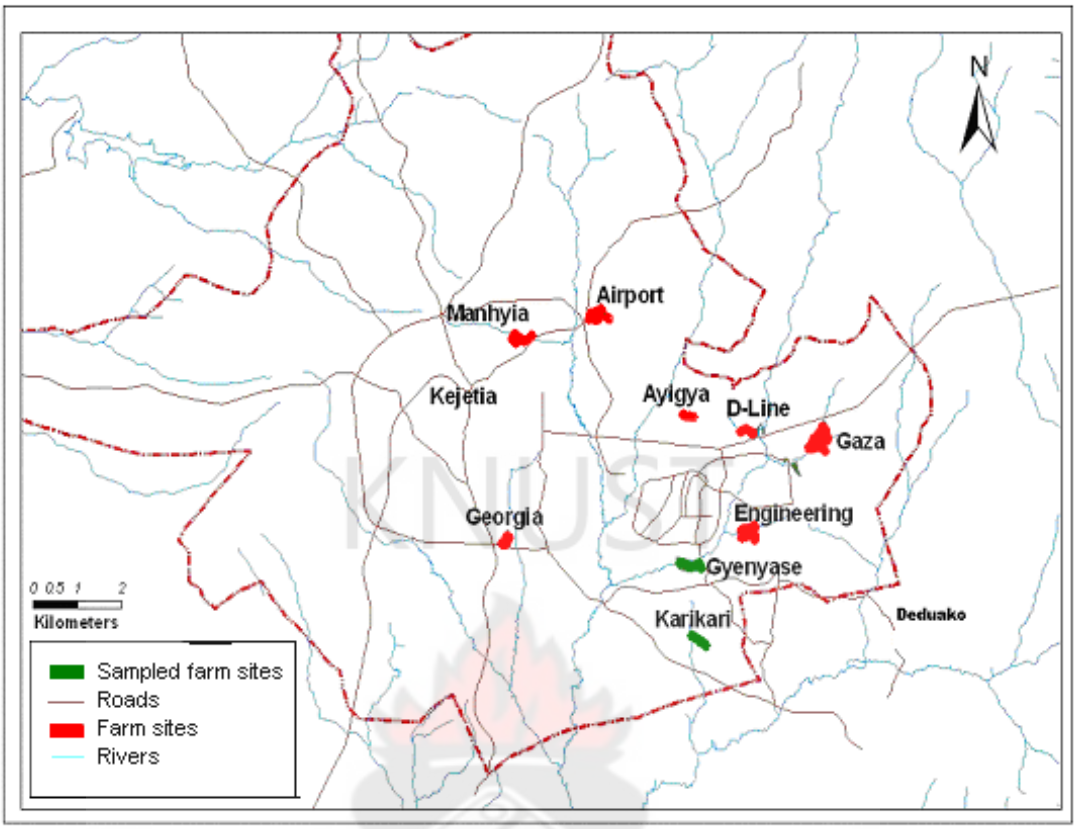

Figure 3.1: Map of urban farming sites in Kumasi

3.2 CHEMICALS AND EQUIPMENT

3.2.1 Chemicals

The materials used in the project are listed as follows

1. Analar grade Nitric Acid by BDH Laboratory Supplies, Britain, analytical grade
2. Hydrochloric Acid by BDH Laboratory Supplies, Britain, analytical grade
3. Ammonium Chloride by BDH Laboratory Supplies, Britain , analytical grade
4. Concentrated Ammonia Solution by BDH Laboratory supplies, Britain, analytical grade.
5. Disodium salt of Ethylenediaminetetraacetic acid by BDH Laboratory, supplies, Britain, analytical grade.

6. Magnesium sulphate heptahydrate by BDH Laboratory, supplies, Britain, analytical grade
7. Erichrome black T BDH laboratory supplies, Britain, analytical grade
8. Sodium carbonate by Fisons Laboratory , analytical grade
9. Silver Nitrate by BDH laboratory supplies, Britain, analytical grade
10. Potassium dichromate by Fisons laboratory, analytical grade
11. Sodium Hydroxide by BDH laboratory supplies, Britain, analytical grade
12. Tetraoxosulphate (VI) acid by BDH laboratory supplies, Britain, analytical
13. Sodium Chloride by BDH laboratory supplies, Britain, analytical grade
14. Sodium Nitrate by BDH laboratory supplies, Britain, analytical grade
15. Potassium Chloride by BDH laboratory supplies, Britain, analytical grade
16. Methyl orange indicator Fisons Laboratory, analytical grade
17. Phenolphthalein indicators Fisons Laboratory, analytical grade

3.2.2 Equipment

The equipment used in the project is listed as follows:

1. Suntex Sp – 707 pH metre
2. WTW conductivity meter
3. DREL/2010 spectrophotometer from Hach
4. 2100P turbidimeter from Hach

3.3.0 EXPERIMENTAL

The procedures that were used in the project are given below:

3.3.1 Preparation of coagulant and raw water

Dry *M. oleifera* seeds were obtained from a commercial seed supplier. Mature seeds showing no signs of discoloration, softening or extreme desiccation were used (Ndabigengesere and Narasiah, 1998). The seed kernels were ground to a fine powder of approximate size of 425 µm to achieve proper solubilization of active ingredients in the seed. Distilled water was added to the powder to make (1, 2, 3, 4 and 5) %w/v suspension. (E.g. 1 %w/v is prepared by 1g of *M. oleifera* powder in 100ml water). The suspension was vigorously shake for 30 min using a magnetic stirrer to promote water extraction of the coagulant proteins and this was then filtered through paper (Whatman No. 1). Fresh solutions were prepared daily and kept refrigerated to prevent any ageing effects (such as change in pH, viscosity and coagulation activity). Solutions were shaken vigorously before use (Ndabigengesere and Narasiah 1998; Jahn, 1988).

The raw water used throughout the study was obtained from the Gyinyase and Karikari farms. Water samples were collected approximately every second to third day, and stored in a plastic tank in the lab. The experiment took place from January to May.

3.3.2 Treatment of Sample Containers

Sampling was done with plastic containers. These were cleaned by washing with soap and tap water. The containers were disinfected with (1 + 1) HNO_3 and finally rinsed with double distilled water.

The glass containers were washed by soaking in Aqua Regia (3 parts conc. HCl and 1 Part HNO_3) and followed by a thorough wash with tap water and finally with distilled water.

3.3.3 Sampling

A total of 5 different samples with three (3) replicates were taken from both Gyinyase and Karikari farms. Each sample was treated with 1.5 %w/v of *Moringa oleifera* coagulant (MOC) with the following volumes (20, 40, 60, 80, 100 and 120) mL. Different concentrations; (2, 3, 4, 5) % w/v with same volumes was applied to the rest of the samples.

One hundred samples were also collected randomly from the two vegetable farming sites for dosage simulation. These samples were treated with 5 different concentrations (1.5, 2, 3, 4 and 5) %w/v and 100mL of *Moringa oleifera* coagulant (MOC). 100mL of *Moringa oleifera* samples were used because it showed the optimum volume for the first treatment.

Lastly, field trials were carried on 6 selected shallow wells in the two farming sites for four months. These samples were treated with 5 different concentrations (1.5, 2, 3, 4 and 5) %w/v and 100mL *Moringa oleifera* coagulant (MOC).

3.3.4 Analysis

3.3.3.1 Water quality and Characteristics (Removal efficiencies)

Samples were treated with 1.5% weight/volume MOC with 7 different dosages (0, 20, 40, 60, 80,100 and 120) ml/L. The same process was repeated with (2, 3, 4 and 5) % weight/volume but same volumes. Parameters determined were grouped under water quality and characteristics - physicochemical, anions, and microbiological analysis. The physicochemical parameters that were determined were pH, Conductivity, Settleable solids, TDS, turbidity, total hardness and alkalinity. Anions determined were chloride, sulphate, phosphate and nitrate.

All samples including replicates were analysed for settleable solids.

3.3.3.2 Dosage simulation

Hundred (100) water samples were collected randomly from both sites Gyinyase and Karikari farms. Samples were treated with 2different concentrations (1.5 and 5) %w/v with 100ml dosage. Parameters tested were turbidity and pH.

3.3.3.3 Field trials

Six shallow wells were monitored for four months (February to May). The water samples were collected from each well weekly and turbidity and pH were tested before and after treatments.

Table 3.1 Summary of sampling frame and parameters

Sub-study	Measured parameter	No of Samples	Replicates	Total
1. Water quality				
(i) Physicochemical	Settleable solids	160	3	480
	Turbidity	160	0	160
	pH	160	0	160
	Conductivity	160	0	160
	TDS	160	0	160
	Alkalinity	160	0	160
	Total Hardness	160	0	160
(ii) Anions	NO_3-N	160	0	160
	PO_4^{-3}	160	0	160
	SO_3^{2-}	160	0	160
	Chloride	160	0	160
(iii) Microbiological	Faecal coliform	160	0	160
2. Dosage Optimization	Turbidity	100	0	100
3. Field trials	Turbidity	16	3	48
	pH	16	3	48

All samples were treated with 5 different concentrations of *Moringa oleifera* coagulant (MOC) (1.5, 2, 3, 4 and 5) % weight/volume with 6 dosages (20, 40, 60, 80 100 and 120) ml/L. Raw and settled water inclusive.

3.3.5 Storage of samples

All the samples were temporarily stored in a cold box at the time of sampling until they were finally transferred into a refrigerator. Samples were stored at a temperature below 4^0C

3.3.6 Jar tests

Jar test is the most commonly used method for determining the efficiency of a coagulant, since it is easy to perform (Ndabigengesere and Narasiah 1998). The equipment used in this study was Aqua Lytic jar test apparatus with 6 beakers (Figure 3.2). Each jar was filled with 1L of raw water with identical turbidity level, and the initial stirring rate was set to 110 rpm. Different volumes (20, 40, 60, 80,100 and 120) ml of the selected coagulant were then added to 6 of the jars (number 1-6, Figure 3.2) respectively. After 3 minutes the stirring was lowered to 35 rpm and this rate was kept for 20 minutes. Then the propellers were stopped completely. The same experiment was carried on by the 5 categories of concentrations (1, 2, 3, 4 and 5) %w/v.

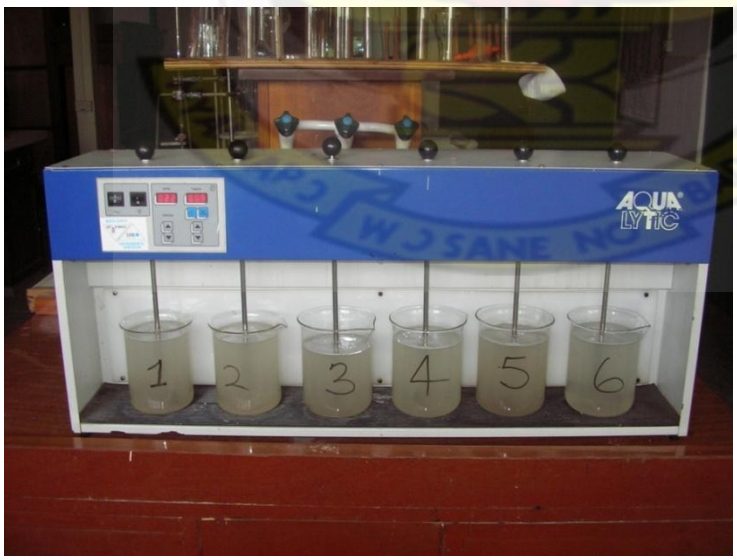

Figure 3.2 Jar test equipment

3.3.7 Water quality

After 1 hour of sedimentation of the treated water, supernatant samples were collected from each of the 6 beakers for physicochemical analyses. 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, due to restricted time and cost of materials.

3.3.7.1 Physicochemical

3.3.7.1.1 Settleable Solids

After the jar test analysis, the treated samples (1-6) and the raw or untreated sample (RW) were poured into the Imhoff apparatus and the levels of settleable solids recorded in mL/L with time interval of 10 minutes for 2 hours. (Figure 3.3)

Figure 3.3 Imhoff apparatus for settleable solids

3.3.7.1.2 Turbidity

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 starting value of raw water (RW). 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. In order to eliminate any differences in turbidity due to different sedimentation times, samples were taken from jars 1-6 into separate beakers before measurements were taken in the following order: (RW, 20, 40, 60, 80, 100 and 120) mL.

3.3.7.1.3 Total Dissolved Solids (TDS)/ Conductivity Determination

Method

A 50ml well-mixed sample was measured into a beaker.

The WTW TDS/Conductivity meter probe was immersed in sample and its conductivity and TDS recorded. This was after calibration with 0.01N KC1

3.3.7.1.4 Temperature Determination

Method

This was determined at the time of analysis. An aliquot of 50m1 of sample was measured into a 100m1 beaker and its temperature recorded with $0 – 60^0$C thermometer. All samples were analyzed at room temperature.

3.3.7.1.5 Alkalinity Determination

Reagent

1. 0.1M HC1

A 2.1m1 solution of 12M concentrated HC1 was added to a 200m1 of distilled water in a 1000m1 volumetric flask. To this mixture was added more distilled water until it got to the 1000m1 mark.

2. 0.05N Na_2CO_3 solution

A litre of the carbonate solution was prepared by dissolving a 4.5g of dried Na_2CO_3 in double distilled water and transformed into a 1L volumetric flask. The solution was made to the mark with double distilled water.

3. Standardization of HC1

The approximate 0.1M HC1 prepared was titrated against 40m1 of 0.05N Na_2CO_3 diluted with 60mL of water. The acid was added until a pH of 5 was reached. The solution was boiled for 5 minutes and cooled in a desiccator at room temperature. The titration was then continued to the pH inflection point.

$$\text{Normality, } N = \frac{W \times V}{53 \times C}$$

W = weight in grams of sodium carbonate

V = mL of sodium carbonate solution taken for titration

C = mL of acid used.

Method

A 50mL sample was measured sample into a conical flask. Two drops of methyl orange indicator was added and the resulting mixture titrated against the standard 0.1M HC1 solution to the permanent pink colour at pH 4.5. The following equation was used in the calculation.

$$\text{Alkalinity mg } (CaCO_3)/L = \frac{V \times M \times 50{,}000}{\text{mL sample}}$$

where V = m1 of acid used

M = Molarity of standard acid used

A reagent blank titration was performed without the sample

3.3.7.1.6 Total hardness Determination

Reagents

1. Buffer

The determination of the total hardness of water is based on a complexometric titration of calcium and magnesium with an aqueous solution of the disodium salt of EDTA at pH value of 10. The buffer solution was prepared by dissolving 16.9g of ammonium chloride (NH_4Cl) in 143mL of conc. Ammonium hydroxide solution (NH_4OH). This was diluted to 250mL with distilled water.

2. 0.01M Sodium salt of EDTA

A 0.01M solution of disodium salt of EDTA (Analar grade) were prepared by dissolving 3.7222g of the salt in distilled water and diluting to 1000m1. To this 780mg of magnesium sulphate heptahydrate ($MgSO_4.7H_2O$) was added.

Method

A 50m1 sample was measured into a conical flask. To this was added a portion of ammonium chloride buffer solution and followed by 30mg enrichrome black T indicator crystals. The resulting solution was titrated with 0.01M EDTA solution with continuous stirring until the end point was reached. The end point is reached when the last reddish tinge disappeared.

Calculation: (Total hardness) mg/L $CaCO_3$ = $\frac{V \times W \times 1000}{m1 \text{ of sample}}$

Where V = m1 of titrant

W = mg $CaCO_3$ equivalent to 1m1 EDTA titrant

A reagent blank without the sample was performed.

3.3.7.2 Anions

3.3.7.2.1 Nitrate Determination

DREL/2010 spectrophotometer was used for the nitrate analysis. It adopts Cadmium reduction method by using powder pillow. 500 nm wavelength was set for high range nitrate nitrogen (NO_3^--N). After the correct wavelength was dialed in, the display quickly showed zeroing then mg/L NO_3^--N HR. 25 mL of the sample was poured into

the sample cell. One Nitra Ver 5 Nitrate reagent powder pillow was added into the contents of the cell (the prepared sample). The prepared sample in the cell was vigorously shaken until the timer beeps in one minute. When the timer beeps, a five-minute reaction period began. Another sample cell was filled with 25mL of the sample (the blank). After the 5-minutes reaction, the spectrophotometer displayed mg/L NO_3^-—N HR. The blank was placed into the cell holder then the light shield was closed. The display showed zeroing 0.0 mg/L NO_3^-—N HR. The stopper was removed. The prepared sample was placed into the cell holder and the light shield closed tightly. The display showed the result in mg/L nitrate nitrogen ($NO3^-$—N) after pressing the "Read" button.

3.3.7.2.2 Phosphate Determination

DREL/2010 spectrophotometer was used for the phosphate analysis. It is also called Orthophosphate (PhosVer 3) (Ascorbic Acid) method. 890nm wavelength was set for Phosphorus (PO_4^{3-}). After the correct wavelength was dialed in, the display quickly showed zeroing then mg/L PO_4^{3-} PV. A 10-mL Cell riser was inserted into the cell compartment. 10 - mL of the sample was poured into a clean sample cell. One PhosVer 3 Phosphate Powder Pillow was added into the contents of the cell (the prepared sample). The sample was swirled immediately to mix; a blue colour formed showing the presence of phosphate. When the timer beeps, a two-minute reaction period began. Another sample cell was filled with 10 mL of the sample (the blank). After the 2-minutes reaction time, the spectrophotometer displayed mg/L PO_4^{3-} PV. The blank was placed into the cell holder then the light shield was closed. The display showed 0.00 mg/L PO_4^{3-} PV. The stopper was removed. The prepared sample was

placed into the cell holder and the light shield closed tightly. The display indicated the amount of mg/L PO_4^{3-} after pressing the "Read" button.

3.3.7.2.3 Sulphate Determination

DREL/2010 spectrophotometer was used for the sulphate analysis. It is Sulfa Ver 4 method by using powder pillow. A 450 nm wavelength was set for sulphate (SO_4^{2-}). After the correct wavelength was dialed in, the display quickly showed zeroing then mg mg/L SO_4^{2-}. 25 mL of the sample was poured into a clean sample cell. One Sulfa Ver 4 Sulphate Reagent Powder Pillow was added into the cell containing the sample and swirled to get dissolved in the cell white turbidity developed which shows the presence of sulphate. When the timer beeps, a five-minute reaction period began and the prepared sample in the cell was allowed to stand undisturbed. Another sample cell was filled with 25mL of the (the blank). After the 5-minutes reaction, the spectrophotometer displayed mg/L SO_4^{2-}. The blank was placed into the cell holder then the light shield was closed. The display showed zeroing 0.0 mg/L SO_4^{2-}. The stopper was removed. The sample was placed into the cell holder and the light shield closed tightly. The display showed the result in mg/L sulphate (mg/L SO_4^{2-}) after pressing the "Read" button.

3.3.7.2.4 Chloride Determination

Reagents

1. 5% K_2CrO_4

This was prepared by dissolving 5g of K_2CrO_4 powder and in a beaker with double distilled water and poured into a 100mL volumetric flask. The mixture was then diluted to the mark using double distilled water.

2. 0.01M $AgNO_3$

A one litre solution of sliver nitrate was prepared by weighing 1.699g of solid silver nitrate. It was then dissolved with double distilled water in a beaker and then transferred into a 1000mL volumetric flask and diluted to the mark.

Method: Argentometric Titration

A 50mL sample was measured into a conical flask. The pH was then adjusted to a range of 7 – 10 with H_2SO_4 for high pH sample and NaOH for low pH sample. Two drops of K_2CrO_4 indicator was added.

A standard $AgNO_3$ solution of 0.01M was titrated against the resulting mixture above to a pinkish yellow end point. A blank titration with only reagents and no water sample was also performed.

$$\text{Chloride (mg chloride per litre)} = \frac{\text{Vx M x 1000 x 35.5}}{\text{m1 of sample}}$$

V = end point volume

M = molarity of $AgNO_3$

3.3.7.3 Microbiological Analysis

3.3.7.3.1 Faecal Coliform

To assess the effect of sedimentation on removal of faecal coliforms. Supernatant samples were taken from the 6 beakers after 1 hour treatment with a concentration of 1 %w/v and dosages (20, 40, 60, 80, 100 and 120) mL. The same experiment was carried out with concentrations of (2, 3, 4 and 5) % w/v with the same corresponding dosages as indicated above.

3.3.8 Analytical method

Water samples were analysed for faecal coliforms. The Most Probable Number (MPN) method was used to determine faecal coliforms numbers. Ten fold serial dilutions were done and a set of triplicate tubes of Mackonkey broth supplied by MERCK (Darmstadt, Germany) was inoculated with subsamples from each dilution and incubated at 44^{o}C for 24 to 48 hours. (APHA-AWWA-WEF 1998) The number and distribution of positive tubes (acid or gas production or color change in broth) were used to obtain the population of coliform bacteria in water samples from the MPN table.

3.3.9 Data analyses

Statistical analysis was done by Microsoft Excel and SPSS 13 for windows (SPPS Inc., Technologies) The SPSS statistical package (Version 13.0) was used for all statistical analysis. All statistical significance was considered when $p < 0.05$. One-

way analysis of variance (ANOVA), with Tukey_ HSD test was carried out to verify the significance of differences among the means.

CHAPTER FOUR

4. RESULTS

4.1. INFLUENCE OF MORINGA OLEIFERA COAGULANT (MOC) ON WATER QUALITY AND CHARACTERISTICS

4.1.1 Influence of MOC on sedimentation (settleable solids)

Figures 4.1, 4.2, 4.3, 3.4 and 4.5 show the influence of *Moringa oleifera* coagulant (MOC) on sedimentation (settleable solids) within a two hour period. It was observed from these figures that increasing MOC concentrations leads to an increase in the sediments formed. It can also be seen from these graphical representations that the levels of sediments produced slowly reaches for a constant value after 1 hour of standing. Hence there is no significant change in levels of sediment produced after 2 hours settling time. It is seen from the graphs that increase in concentration and volume increases sedimentation. Therefore sediments obtained from the raw water samples were low as compared to when treated with MOC. This is as a result of the coagulation properties of the *Moringa* seed which is able to settle most of the particles in the raw water within a short time.

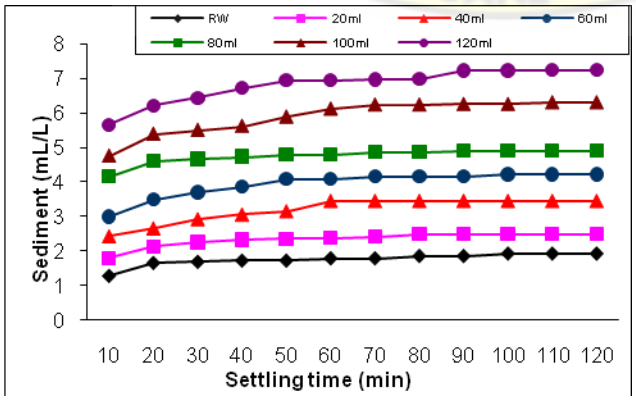

Figure 4.1 Water sedimentation by 1.5 % w/v MOC (N=120)

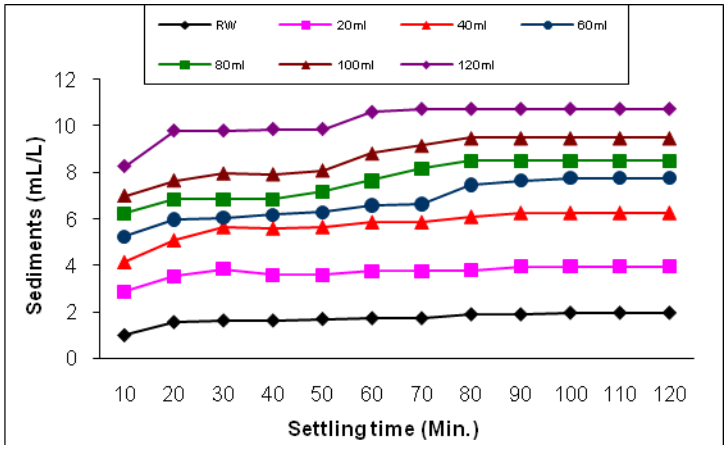

Figure 4.2 Water sedimentation by 2 % w/v MOC (N=120)

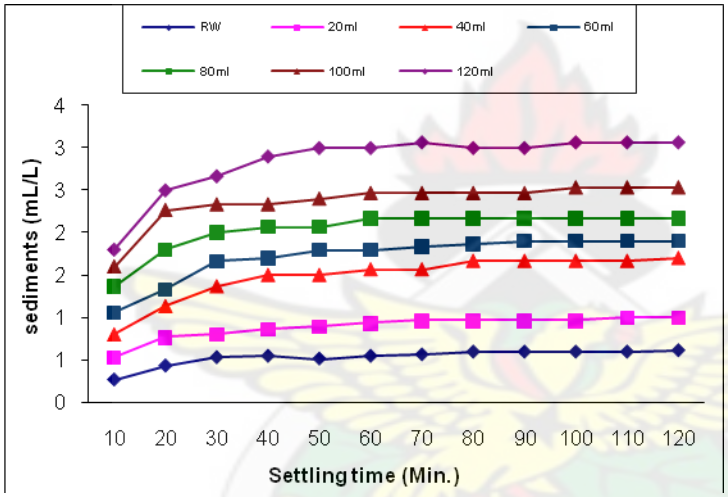

Figure 4.3 Water sedimentation by 3 % w/v MOC (N=120)

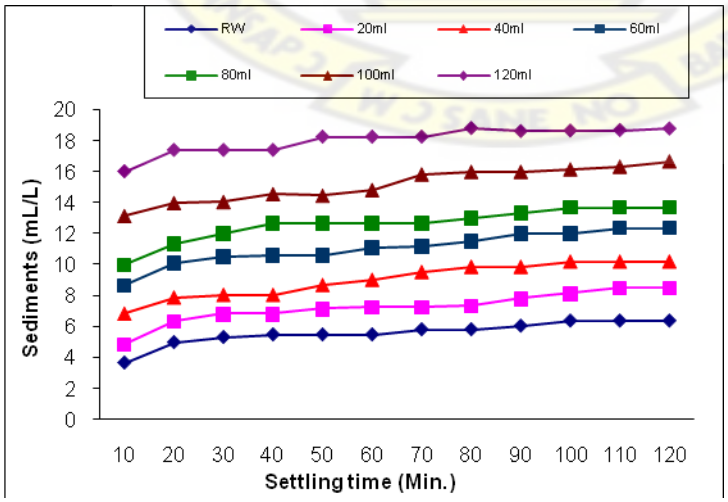

Figure 4.4 Water sedimentation by 4 % w/v MOC (N=120)

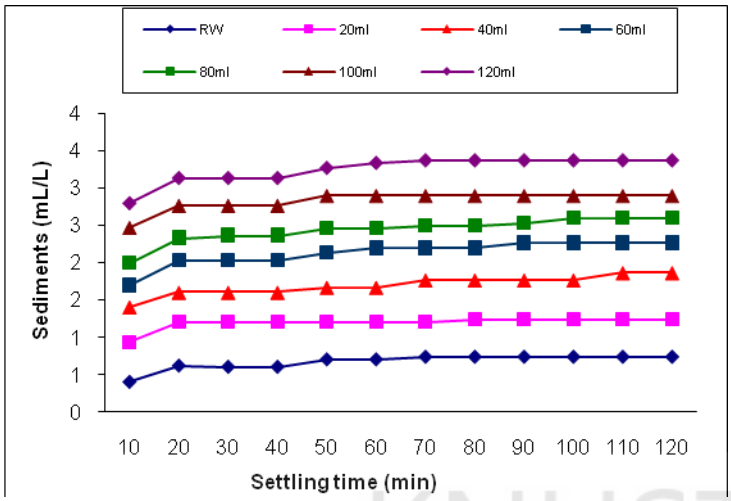

Figure 4.5 Water sedimentation by 5 % w/v MOC (N=120)

4.1.2 Influence of MOC on Turbidity

Figure 4.6 shows the influence of *Moringa oleifera* coagulant (MOC) on turbidity. From the graph, *Moringa oleifera* coagulant (MOC) concentrations of 4% (w/v) and 5 % (w/v) rapidly reduced the turbidities from the 250-350 NTU range to 10NTU at a volume of 20mL. With the same MOC concentrations an increase in dosage from 60 to 120 mL showed reduction in turbidities from 250-350NTU to 2-5 NTU. The graph also reveals that MOC concentration of 1.5, 2 and 3 % (w/v) could reduce the turbidities of 250-300 NTU to 80-120NTU at 20mL. It is also evident from the graph that, with MOC concentrations of (1.5, 2, 3) % (w/v) one can obtain residual turbidities of 5-20NTU from 250-300NTU at increased dosages of 80mL to 120mL per litre of wastewater. Therefore increasing concentrations and volumes of MOC reduces turbidity. Hence levels of particulate matter or sediments in wastewater reduced appreciably.

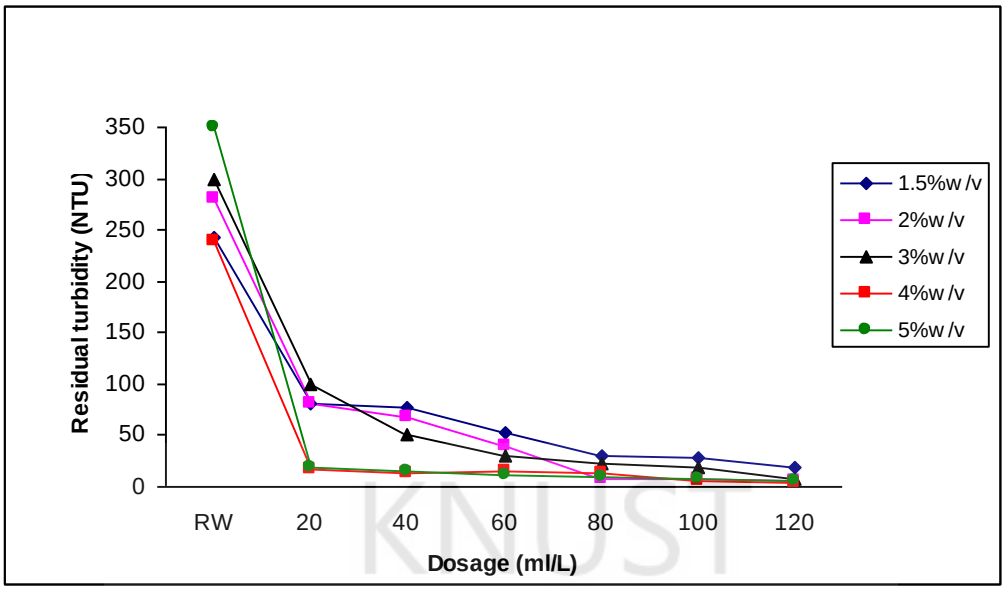

Figure 4.6: Turbidity removal by MOC (N=120)

4.1.3 Influence of MOC on pH

Table 4.1 shows influence of *Moringa oleifera* coagulant (MOC) on pH. From the table it could be observed generally that the pH of raw water (RW) does not show a remarkable change in pH for all samples with different dosages (20, 40, 60, 80, 100, and 120) ml/L. This finally shows that RW and samples treated with different concentrations and dosages do not show a significant change in pH. The pH for raw water (RW) and treated water is still within the FAO value of 6.5 to 8 of wastewater.

Table 4.1 Mean pH of raw water (RW) and treated water after *Moringa oleifera* coagulant (MOC) treatment (N=120)

	Different conc. of MOC (%w/v)				
Dosage(ml/L)	**1.5**	**2**	**3**	**4**	**5**
RW	6.50	7.08	6.02	6.47	6.90
20	6.55	7.28	6.44	6.93	6.80
40	6.47	7.13	6.02	6.85	6.60
60	6.45	7.00	5.87	6.74	6.30
80	6.42	6.89	5.74	6.72	6.00
100	6.42	6.82	5.58	6.81	6.60
120	6.39	6.77	5.49	6.75	6.60

4.1.4. Influence of MOC on Conductivity

Figure 4.7 shows the effect of *Moringa oleifera* coagulant (MOC) on conductivity. From the graph it is observed generally that change in concentrations of MOC at 20mL do not affect the conductivity of raw water (RW). The conductivity increases slightly from a dosage of 40mL/L to 120mL/L in all the treatments. But this increase does not affect the quality of the water since the changes do not exceeded the WHO permissible limit of 1000µs/cm for wastewaters (WHO 2006). The trend of concentrations cannot be compared among each other since all the samples used for the treatment are from different sources and therefore have different conductivities.

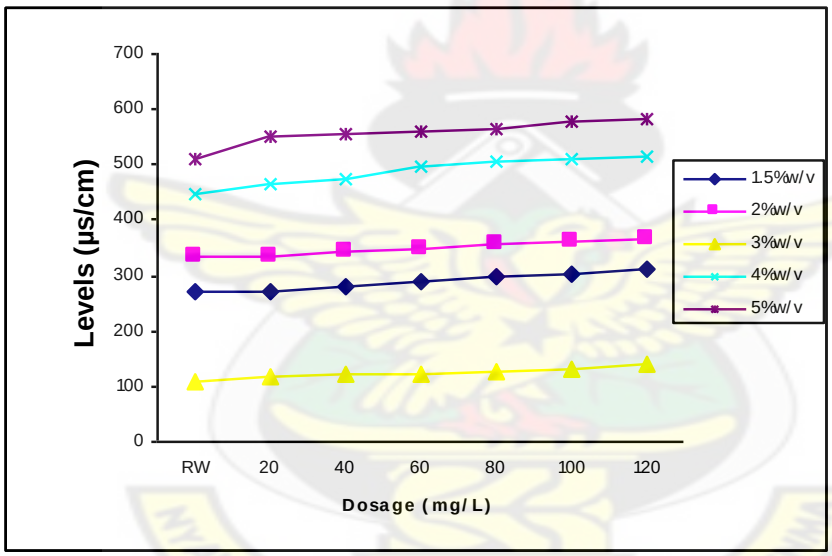

Figure 4.7 Changes in conductivity with dosage of MOC (N=120)

4.1.5 Influence of MOC on Total Dissolved Solids (TDS)

Figure 4.8 shows the influence of *Moringa oleifera* coagulant (MOC) on TDS. The graph shows that increase in concentration of MOC does increase the TDS. But increase in coagulant dosage does not affect the TDS levels in the water. It is within the FAO value of 1000mg/L-2000mg/L for water for agricultural purposes (WHO 2006).

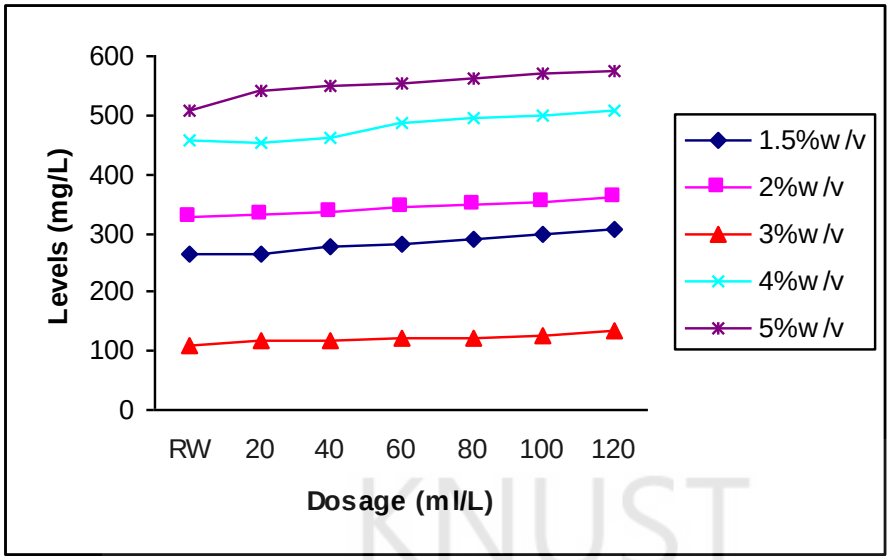

Figure 4.8 Levels of TDS to dosage of MOC (N=120)

4.1.6 Influence of MOC on Alkalinity

Table 4.2 shows the effect of *Moringa oleifera* coagulant (MOC) on alkalinity. Raw water (RW) and water treated with 1.5 to 5 % weight per volume of MOC dosed with 20-60 ml/L and 80-120 ml/L clearly shows that MOC does not affect the alkalinity of the water.

Table 4.2: Mean levels of Alkalinity (N=120)

Conc.	**Dosages (ml/L)**		
(%w/v)	**RW**	**20-60**	**80-120**
1.5	120	100 (100)	60-100(73)
2	120	60-80 (67)	100-120 (107)
3	60	40-100(60)	20-20(20)
4	150	60-100(80)	100-125(117)
5	100	100-150(133)	80-200(135)

4.1.7 Influence of MOC on Total Hardness

Table 4.3 shows influence of *Moringa oleifera* coagulant (MOC) on Total hardness. Raw water (RW) and water treated with 1.5 to 5 % weight per volume of MOC dosed with 20-60 ml/L and 80-120 ml/L shows MOC does not affect the total hardness of the raw water.

Table 4.3: Mean levels of Hardness (N=120)

Conc.	**Dosages (ml/L)**		
% (w/v)	**RW**	**20-60**	**80-120**
1.5	20	12-16(15)	13-17(15)
2	22	20-23(22)	20-23(21)
3	30	13-22(17)	17-20(20)
4	27	19-24(22)	23-26(25)
5	20	13-29(20)	15-50(30)

4.1.8 Influence on anions by MOC

Table 4.4 show range and mean values of anions (Nitrate-nitrogen, phosphate, sulphate and chloride). Raw water with nitrate levels of 3.5 mg/L gave a mean nitrate level of 2.97 and 5.63 mg/L at coagulant dosage of 20-60 and 80-120 ml/L respectively. From this result MOC dosage does not affect nitrate with increase in concentration and dosage as it is confirmed in the following concentrations (1, 2, 3, 4, 5) %w/v on Table 4.4.

In the case of phosphate MOC showed a corresponding increase with increase in concentration of MOC. This is seen from Table 4.4. The increase amount of phosphate in the treated water is as a result of the MOC, but this does not pose any much risk but could serve as a fertilizer or soil enrichment provided it does not shift to unacceptable levels.

Levels of sulphate increase with increase in concentration of MOC but do not affect the quality of water as it does not increase above the unacceptable levels. Chloride is not affected by MOC. Some of the results had a reduction in chloride levels as compared to the raw water values as seen from Table 4.4 below.

Table 4.4 Mean levels of anions after dosage of MOC (N=120)

Conc. % (w/v)	**Dosage (ml/L)**	**NO_3-N (mg/L)**	**PO_4^{3-} (mg/L)**	**SO_3^{2-} (mg/L)**	**Cl^- (mg/L)**
1.5	RW	3.50	1.30	20.40	6.00
	20-60	2.50-3.70 (2.97)	2.50-4.80 (3.77)	54.00-66.00 (62.00)	4.26-7.10 (5.21)
	80-120	4.90-6.40 (5.63)	2.00-6.00 (3.60)	53.00-55.00 (53.67)	2.84-9.94 (5.66)
2	RW	1.40	8.50	25.00	16.00
	20-60	1.50-2.20 (1.83)	8.50-12.60 (10.03)	33.00-54.00 (43.67)	10.00-11.00 (10.67)

	80-120	2.80-3.20 (3.00)	11.5-16.8 (14.27)	49.00-63.00 (56.67)	10.00-14.00 (12.33)
3	RW	2.80	6.80	21.00	6.88
	20-60	2.70-4.10 (3.37)	3.50-8.60 (6.03)	29.00-58.00 (41.00)	5.00-6.00 (5.67)
	80-120	6.40-10.80 (8.00)	9.60-10.90 (10.31)	72.00-90.00 (78.67)	5.40-8.50 (6.59)
4	RW	5.40	9.00	18.00	16.00
	20-60	3.90-4.70 (4.40)	6.40-9.80 (8.57)	20.00-40.00 (30.00)	12.00-13.00 (12.67)
	80-120	4.40-4.90 (4.60)	8.80-9.40 (9.13)	43.00-64.00 (52.33)	14.00-18.00 (16.00)
5	RW	4.00	11.90	22.00	20.00
	20-60	4.40-6.20 (5.33)	10.30-11.00 (10.77)	26.00-44.00 (34.33)	18.00-22.00 (19.67)
	80-120	5.80-6.80 (6.20)	8.00-12.00 (9.60)	43.00-49.00 (46.67)	18.00-33.00 (23.33)

4.1.9 Effect of MOC on Faecal coliforms (FC)

Figure 4.9 shows the effect of *Moringa oleifera* coagulant (MOC) on faecal coliforms. From the graph MOC concentration of 5%w/v reduced faecal coliform levels between log 6-7 to log 3.5 at 20mL. MOC of lower concentrations (1.5, 2, 3 and 4) %w/v also reduced the faecal coliforms levels from log 6-7 close to log 4. From these results, it is evident that effective reduction will be achieved at a dosage of 60mL/L of 5% w/v concentration. A reduction of log 4.5 is obtained at a dosage of 60mL/L with 5% w/v concentration (log 6.5 FC to log 2 FC). Table 4.5 shows percentage reduction in Faecal coliforms of raw water treated with MOC.

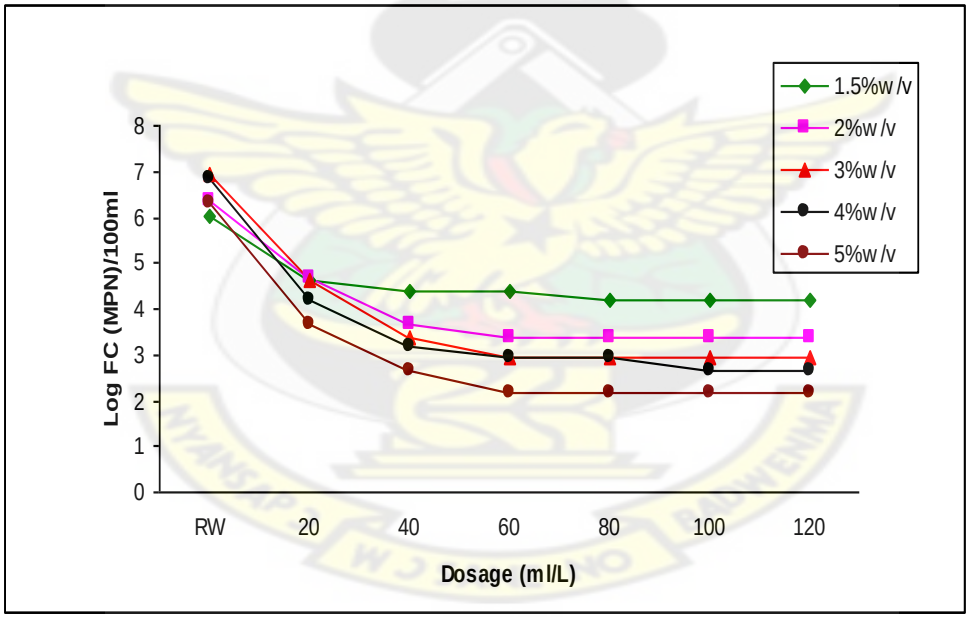

Figure 4.9: Log FC related to MOC dosage (N=120)

Table 4.5: Percentage reduction in Faecal coliforms of settled water (SW) and treated waters (N=120)

Conc.(%w/v)	% FC Removal	Log FC Removal
SW	45.60	0.28±0.18
1.5	97.88	1.71±0.51
2	99.58	2.74±0.66
3	99.91	3.66±0.57
4	99.96	3.76±0.60
5	99.96	3.82±0.14

4.2 DOSAGE SIMULATION (OPTIMUM MOC DOSAGE)

4.2.1 Turbidity: Low (10-50NTU), Medium (55-155NTU) and High (150-350NTU) (N=50)

Figures 4.10, 4.11, 4.12, 4.13 are graphical representations of the effect of increasing MOC concentrations on low turbid waters (<50NTU), medium turbid waters (50-150NTU) and high turbid waters (>150NTU) at 100ml dosage. It is observed from these figures that, increasing coagulant dosage leads to a reduction in residual turbidity until an optimum point (1.5 %w/v to 2 %w/v) is reached which corresponds to the minimum residual turbidity. Increasing coagulant concentration from this point leads to increase in residual turbidity.

It can also be seen that medium turbid waters showed an optimal turbidity removal at a concentrations of 2% w/v to 3% w/v. In the case of high turbid waters, it could be seen that the effective turbidity removal is observe at MOC concentration of 4%w/v and 5%w/v. The sets (1, 2, 3 and 4) are replicates.

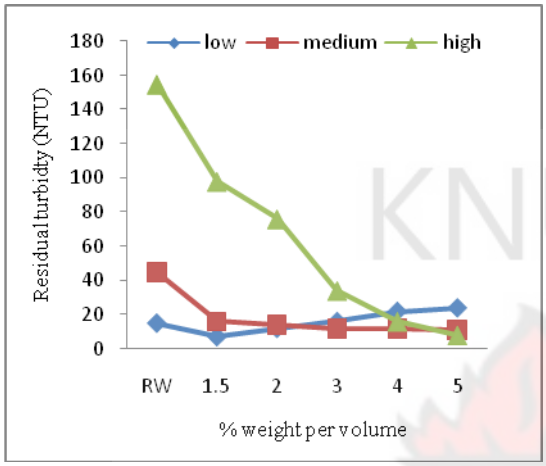

Figure 4.10 Variation of turbidity with % w/v MOC (Set 1)

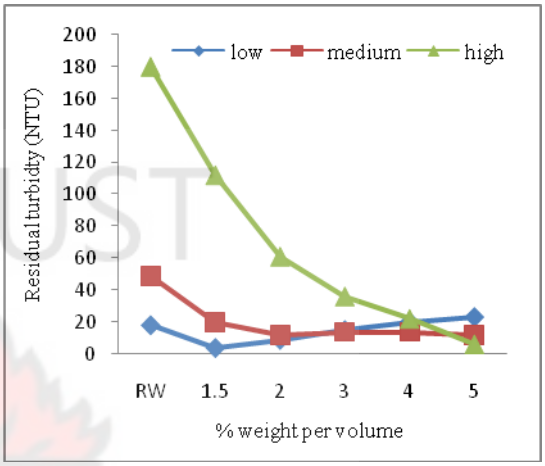

Figure 4.11 Variation of turbidity with % w/v MOC (Set 2)

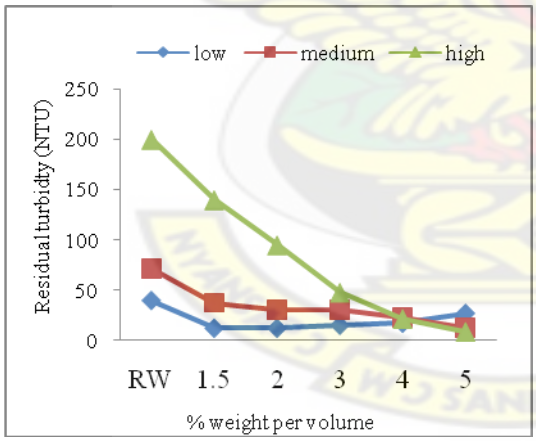

Figure 4.12 Variation of turbidity with % w/v MOC (Set 3)

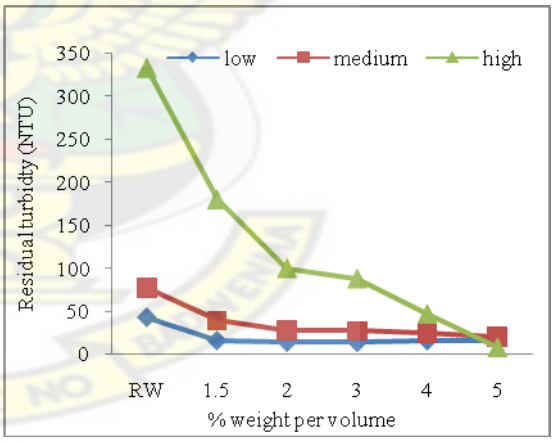

Figure 4.13 Variation of turbidity with % w/v MOC (Set 4)

4.2.2 Percentage Turbidity Removal by MOC

Figure 4.14 shows percentage removal of turbidity in low, medium and high turbid waters. It is evident that for low turbid water (<50NTU), MOC dosage of 1.5 - 2 %

w/v is recommended for efficient percentage turbidity removal of 70%. Whereas MOC dosage of 3 % w/v - 4 %w/v is needed to achieve the optimal percentage removal of 80%. For high turbid waters (>150NTU) a dosage of 4 to 5 %w/v of the MOC is required for percentage efficient removal of 95%.

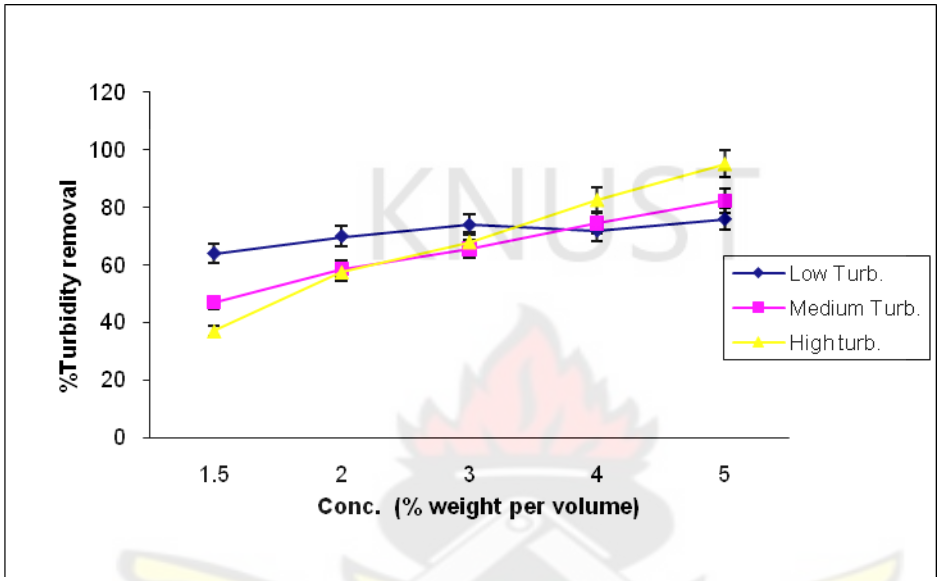

Figure 4.14: Percentage Turbidity Removal by MOC (N=100)

Summarized data presented in Table 4.6 below, revealed that the optimum concentration of *Moringa oleifera* coagulant gave the lowest residual turbidity ($p < 0.05$) and was dependent on the initial turbidity. As initial turbidity of water sample was increased, the required optimum dosage of coagulant also increased ($r^2 = 0.985$). For high turbidities, the optimum concentrations of *Moringa oleifera* was 4.0-5.0 % (w/v), while for medium water produced highest turbidity removal (significantly, $p < 0.05$). In the case of low turbidities increasing dosage of coagulant did not improve the removal of turbidity, in fact this increased significantly ($p < 0.05$) the residual turbidity of the coagulated sample. This overdosing resulted in the saturation of the polymer bridge sites and caused restabilization of the destabilized particles due to

insufficient number of particles to form more interparticle bridges (Muyibi and Evison, 1995, 1996).

Table 4.6 Optimum concentrations for turbidity removal (N=100)

Turbidity (NTU)	Optimum concentration (% weight per volume)	Turbidity removal (%)
Low (<50)	1.5-2.0	70.0
Medium (50-150)	3.0-4.0	80.0
High (>150)	4.0-5.0	95.0

4.3 FIELD TRIALS

4.3.1 Effect of MOC on turbidity of water monitored weekly for 4 months

Table 4.7 shows weekly mean residual turbidity over a period of four months (February to May) in six vegetable farms in Genyasi (, KAK 1, KAK 2, GYN 1, GYN 2, GYN 3, GYN 4). It was evident that, with 3%w/v and 100ml dose showed an appreciable reduction in turbidity. From farm location 1 to 6 recorded the following mean turbidities after treatment of MOC in the month of February, (raw water turbidity values in parenthesis): 14(519) NTU, 24(602) NTU, 16(80) NTU, 11(158) NTU, 22(58) NTU, 8 (113) NTU. These reductions in turbidities were not different from the subsequent months. Treatments in other locations showed a significance

difference of >0.05, this is as a result of wide variations in levels of turbidity in farm locations.

Table 4.7 Mean monthly raw water turbidity and treated water turbidity from 6 farming sites (N=48)

Sampling Sites	**Months**			
	Feb	**Mar**	**Apr**	**May**
KAK 1				
Raw water	499-546 (519)	450-512 (489)	477-600 (529)	477-600 (530)
3% (w/v)	12-16 (14.15)	16-23 (18)	18-28 (22)	18-28 (22)
KAK 2				
Raw water	490-696 (602)	466-599 (548)	456-590 (506)	456-590 (520)
3% (w/v)	20-30 (24)	16-30 (22)	20-37 (28)	20-37 (25)
GYN 1				
Raw water	70-89(80)	70-99 (85)	87-97 991)	87-97 (97)
3% (w/v)	10-22 (16)	16-24 (20)	12-20 (17)	12-20 (18)
GYN 2				
Raw water	140-174(158)	122-155 (136)	133-167 (145)	133-167 (141)
3% (w/v)	8-12 (11)	11-16 (14)	11-18 (15)	11-18 (15)

GYN 3				
Raw water	50-66 (58)	55-70 9 (63)	45-74 (61)	45-74 (64)
3% (w/v)	20-24 (22)	18-30 (26)	15-30 (24)	15-30 (20)
GYN 4				
Raw water	98-144 (113)	88-122 (109)	98-131 (113)	98131 (106)
3% (w/v)	6-10 (8)	8-14 (12)	8-20 (14)	8-20 (12)

Table: 4.8 Summary of mean turbidity of raw water and treated water in 6 farming site in 4 months period (N=48)

Sampling sites	**Raw water**	**3**% (w/v)
KAK 1	450-600(517)	12-28(19)
KAK 2	456-696(544)	16-37(25)
GYN 1	70-100(88)	10-24(18)
GYN 2	122-174(145)	8-20(13)
GYN 3	45-77(61)	15-30(23)
GYN 4	75-144(110)	6-20(11)

4.3.2 Effect by MOC on pH of water monitored weekly for 4 months

Table 4.9 shows weekly mean residual pH over a period of four months (February to May 2008) in six vegetable farms in Genyasi. It could be seen that, there were no or slight changes after 3%w/v and 100ml/L dosage treatment. In February the 6 farming sites gave the following mean pH's 6.5, 6.36, 5.76, 5.84, 5.58 and 5.63 for raw water with corresponding pH after treatment; 6.58, 5.83, 5.61, 6.34, 5.72 and 6.88. There

are slight differences in the resultant pH's. The subsequent months showed similar results as in February. The total rainfall in the month of February to May obtained from the meteorological services is as follows; 61.7, 134.1, 117.1 and 185.8 (Ghana meteorological Agency 2008). The different rainfall patterns for the months might have resulted in different raw water turbidities at the locations used in this work.

Table 4.9: Mean monthly pH of raw water and treated water from 6 farming sites (N=48)

Sampling Sites	Months			
	Feb	**Mar**	**Apr**	**May**
KAK 1				
Raw water	6.40-6.78(6.54)	5.80-6.70(6.26)	5.70-7.40(6.58)	5.70-7.40(5.80)
3% (w/v)	6.40-6.78(6.58)	5.80-6.70(6.28)	5.80-7.40(6.65)	5.80-7.40(5.93)
KAK 2				
Raw water	6.04-6.94(6.36)	6.20-7.00(6.55)	6.00-6.80(6.40)	6.00-6.80(6.43)
3% (w/v)	6.20-6.94(5.83)	6.20-7.00(6.58)	6.20-6.80(6.45)	6.20-6.80(6.50)
GYN 1				
Raw water	5.54-6.10(5.76)	5.58-6.60(6.11)	6.70-6.90(6.80)	6.70-6.90(6.53)
3% (w/v)	5.65-6.10(5.61)	5.58-6.60(6.15)	6.70-7.00(6.83)	6.70-7.00(6.73)
GYN 2				
Raw water	5.51-6.00(5.84)	6.11-6.55 (6.34)	5.70-5.90(5.83)	5.70-5.90(5.83)
3% (w/v)	5.51-6.20(6.54)	6.11-6.55(6.34)	5.70-6.20(5.95)	5.70-6.20(5.95)
GYN 3				
Raw water	5.25-6.09 (5.58)	5.04-6.03(5.61)	5.60-6.30(6.03)	5.60-6.30(6.33)
3% (w/v)	5.37-6.09(5.76)	5.04-6.03(5.72)	5.60-6.30(6.03)	5.60-6.30(6.45)

GYN 4				
Raw water	5.50-6.20(5.63)	6.80-7.20(6.98)	6.40-6.90(6.65)	6.40-6.90(6.75)
3% (w/v)	5.55-6.20(5.73)	6.80-7.00(6.88)	6.40-6.90(6.65)	6.40-6.90(6.88)

NB: figures in bracket are mean

Table 4.10 Summary of mean pH of raw water and treated water in 6 farming site in 4 months period (N=48)

Sampling sites	**Raw water**	**3**% (w/v)
KAK 1	5.40-7.40 (6.29)	5.60-7.40 (6.36)
KAK 2	6.00-7.00 (6.43)	6.20-7.00 (6.49)
GYN 1	5.54-6.90 (6.31)	5.58-7.00 (6.40)
GYN 2	5.51-6.55 (5.96)	5.51-6.55 (6.04)
GYN 3	5.04-7.00 (5.89)	5.04-7.00 (5.95)
GYN 4	5.40-7.20 (6.50)	5.50-7.20 (6.53)

4.4. RELATIONSHIP BETWEEN MEASURED PARAMETERS

4.4.1 Relationship between Turbidity and Faecal Coliform

Figure 4.15 shows a correlation between faecal coliform and turbidity. It is seen from the graph that increases in turbidity increases levels of faecal coliform levels. It can be concluded that Log FC has a positive correlation with turbidity.

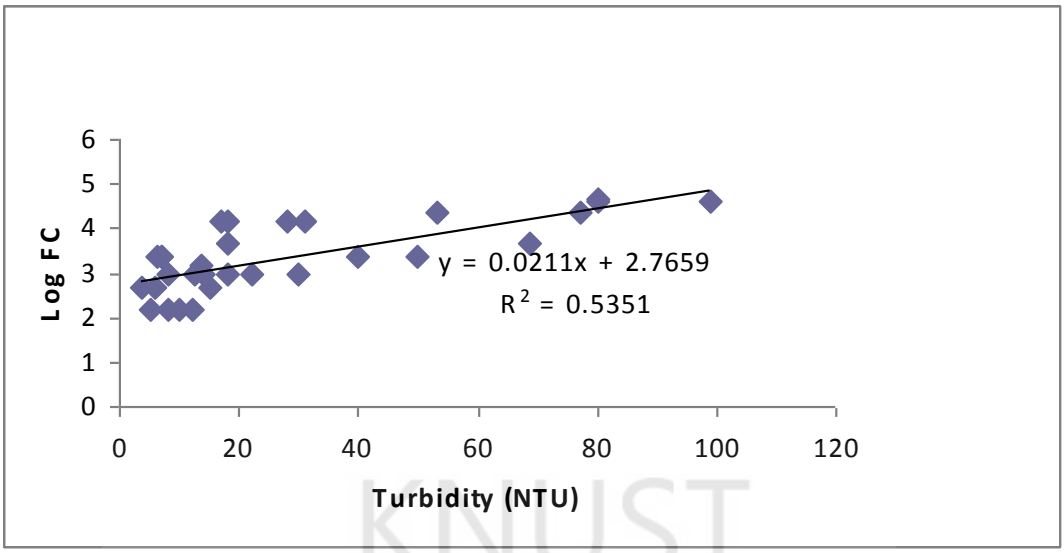

Figure 4.15 Relationship between turbidity and log faecal coliform

4.4.2 Relationship between Turbidity and Settleable Solids

Figure 4.16 is a relationship between turbidity and setttleable solids. It is evident that increasing concentration of MOC increases sedimentation. It could be seen from the graph in Figure 4.16 that as levels of settleable solids decreases turbidity also increases, hence the more sediment (particles) that can be settled or sediment the better the turbidity. It can therefore be concluded that settleable solids has a negative correlation with turbidity.

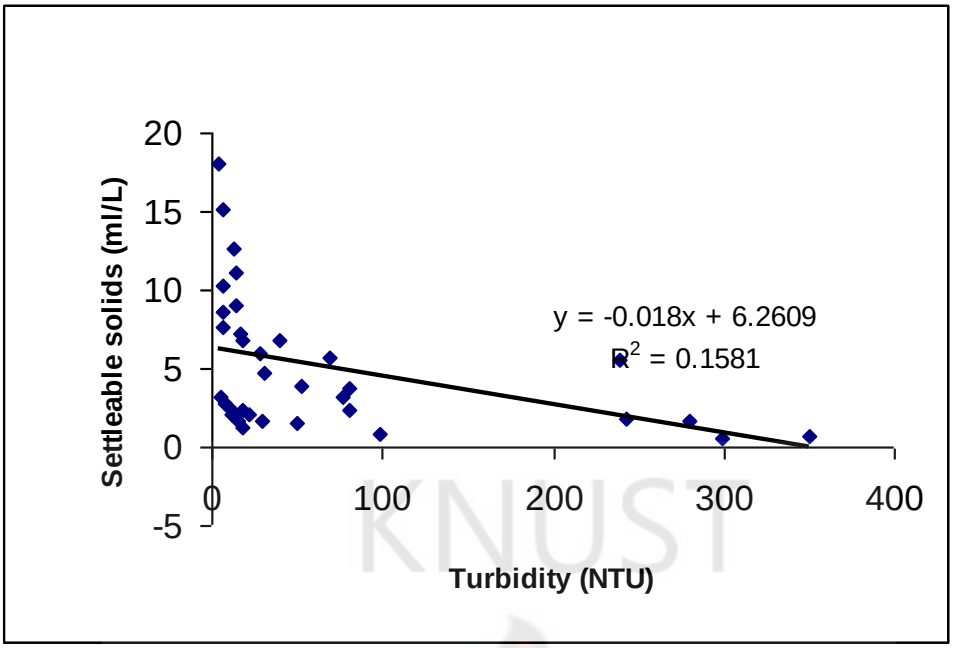

Figure 4.16 Relationship between turbidity and settleable solids

CHAPTER FIVE

5 DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSIONS

5.1.1 Influence on sedimentation/Settling time by *Moringa oleifera* coagulant (MOC)

Figures 4.1-4.5 indicates that there is a general reduction in sediments after *Moringa oleifera* coagulant (MOC) treatment with time. The average settling time obtained was 1 hour for *M. oleifera.* According to Muyibi and Evison (1994), the flocs formed from *M. oleifera* application are generally pin-like and light and therefore settle slowly because of the mechanism of coagulation. Coagulation of water with *Moringa oleifera* consists of adsorption and charge neutralization while that with alum consists of adsorption and inter-particle bridging resulting in larger flocs which settle faster. A study carried on the suspended solids of the raw palm oil mill effluent (POME) by Bhatia *et al.,* 2007 achieved a settling time of 114 min with *M. oleifera* dosage of 3469 mg/L and 6736 mg/L which is close to the results obtained for this work. 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 (Emelie and Maria, 2007).

5.1.2 Influence on Turbidity by MOC

From this study, there was 70 - 95% turbidity removal. A study conducted by Boateng (2001) on the use of Alum and *Moringa oleifera* in surface water treatment recorded 68.8-98.9% reduction in turbidity. Muyibi and Evison (1995a) also reported that MO

could achieve turbidity removal between 92 and 99%. Sani (1990) carried out jar tests with *Moringa oleifera* as the primary coagulant using water from four different sources (viz two surface and two shallow wells) with turbidities from 100 to 800 NTU and 80 to 150 NTU respectively. It was observed that he achieved a turbidity reduction of 92-99%.

Previous researchers documented 80–99% turbidity removal by *Moringa oleifera* as primary coagulant both for raw waters and synthetics turbid waters (Muyibi and Okufu, 1995; Ndbigengesere *et al.,* 1995; Muyibi and Evison, 1996) which agrees with this work, where there was 70 - 95% turbidity removal.

Figure 4.6 revealed that 20mL of 4% (w/v) and 5 % (w/v) MOC concentrations will be very effective in removing turbidity of 250-350NTU to 10 NTU. Concentrations of (1.5, 2, 3) % (w/v) lower the turbidity from 250-300 NTU to 10-50NTU at 80-100ml dosages. Coagulation effectiveness of MO varies depending on the initial turbidity. However, Muyibi and Okufu (1995) found that *Moringa oleifera* might not be an efficient coagulant for low turbid water. They documented that the residual turbidity of samples increased with the decrease in initial turbidity at optimum dosage of *Moringa oleifera.* They achieved only 50% turbidity removal from low turbidity surface waters (23–90 NTU) which is not different from results obtained for this work, in Figures 4.10-4.13, Low (<50), medium (50-150) and high (>150) turbid waters at optimum dosages gave a percentage turbidity removal of 70%, 80% and 95% respectively. Muyibi and Alfugara (2003) also reported a reduction of turbidity in low-turbid water of 21.5-49.3 NTU to 2.7 NTU, water of medium turbidity of 51.8-114 NTU to 2.9 NTU and that of high turbidity of 163-494 NTU to 1.4 NTU.

In general, the higher the initial turbidity the higher the reduction in turbidity. This is due to increase in suspended particles available or adsorption and colloidal charge neutralization. The net effect is an increase in particle collision frequency and agglomeration rate (LaMer and Healy, 1964, Birkner and Morgan, 1968). Muyibi and Evison have also documented that at the optimum dosage of *Moringa oleifera* residual turbidities decreased and removals increased with increasing initial turbidity. Turbidity removal of up to 98.5% was recorded for a water sample with high initial turbidity of 600 NTU (Muyibi and Evison, 1995). Increase in suspended particles available for adsorption and inter-particle bridge formation in water sample with higher initial turbidity may contribute in higher turbidity removal efficiency (Birkner and Morgan, 1968). Okuda *et al.,* (1999) concluded that use of *Moringa oleifera* for drinking water treatment may not be appropriate since turbidity of raw water for drinking water is usually low. This therefore suggests that MO will be good in treating shallow wells or ponds from vegetable farms which have high turbid waters.

5.1.3 Influence of MOC on pH

From Table 4.1, it could be observed that the average pH for (raw water, 1.5 % (w/v) and 5 % (w/v)) at a dosage of 100mL/L 6.5, 6.42, 6.6 respectively, which is within the WHO value of 6.5 to 8 (WHO 2006). All the other dosages were within WHO standards. The pH of the final water was not significantly affected because, according to Muyibi and Evison (1994), *Moringa oleifera* extracts appear to have natural buffering capacity and therefore the pH of the water does not alter much.

Raw water with average pH's of (6.29, 6.43, 6.31, 5.96 and 6.50) monitored gave the following mean results when treated with 3 % (w/v) MO; 6.36, 6.49, 6.40, 6.04 and

6.53 respectively. This result agrees with a study by Ndabigengesere and Narasiah (1998) which showed that MO can be maintained over a wide range of pH values – no pH correction is required. In a related study, Muyibi (1993) observed that in a completely randomized factorial experiment (five factors viz; dosage of *Moringa oleifera*, pH, rate and time of rapid mix, initial hardness), pH did not have a significant effect on the rate of hardness. In general the pH of the treated water for the water samples was within the recommended standards (WHO, 2006). Emelie and Maria (2007) also reported that MO has no effect on pH.

5.1.4 Influence on Conductivity by MOC

Conductivity increases with increasing MOC (Figure 4.7). But this increase does not affect the quality of the water since it does not go beyond the degree of restriction on use: none (< 700 µs/cm), slight to moderate (700- 3000 µs/cm), and severe (> 3000 µs/cm)(WHO 2006). The high conductivity value obtained in this work after treatment was <700 µs/cm which falls in a category of none restriction (Table 2.1). On the order hand, *Moringa oleifera* does not affect the conductivity of water.

5.1.5 Influence on Total Dissolved Solids (TDS) by MOC

Increase in concentration of MOC does increase the TDS (Figure 4.8), but increase in coagulant dosage does not affect TDS. Table 2.1 shows degree of restriction on use; none (< 450), slight to moderate (450 – 2000), and severe (> 2000). The values obtained after treatment was below 600mg/L. Emelie and Maria (2007) study on

assessment of drinking water treatment using *Moringa oleifera* natural coagulant showed that MO does not influence TDS.

5.1.6 Influence on Alkalinity by MOC

The results, presented in Table 4.2 shows clearly that *Moringa* has no effect on the alkalinity of the treated water, which is in agreement with all results from previous research (Bengtsson, 2003, Ndabigengesere and Narasiah 1998). They showed that natural alkalinity of the raw water is unchanged following coagulation by MOC.

5.1.7 Influence on Total Hardness by MOC

Table 4.3 revealed that MOC does not affect water quality as some of the treated water was below or above the values for raw water after treatment. This result shows a variation with Sani (1990). He carried out a jar tests with *Moringa oleifera* as the primary coagulant using water from four different sources (viz two surface and two shallow wells) with hardness from 180 to 300 mg/l as $CaCO_3$. It was observed that, the hardness was reduced to between 60-70% after coagulation and two hours settling. For the surface and two well water samples with initial hardness of 1017, 495 and 494.8 mg/l as $CaCO_3$ respectively, increasing the *Moringa oleifera* dosage from 900 to 2400 mg/l results in decreasing hardness. The rate of hardness reduction was found to be higher at lower dosages for the surface water samples than the two well water samples. This departure from the result obtained for this work might be as a result of low values of hardness of raw water used for this experiment and probably short settling time of 1 hour as compared to his which was done in 2 hours. MO is known to act as a polyelectrolyte, it may therefore be postulated that *Moringa oleifera* removes

hardness in water through adsorption and inter-particle bridging (LaMer and Healy, 1964).

5.1.8 Influence on nutrients/anions by MOC

The anions analysed are those which can affect crop yield. From Table 4.4, Levels of nitrate-nitrogen does not show any increase with increase in MOC. But Phosphate levels increased with increase in MO concentration. It has been reported that crude MO extract increases the organic, nitrate and phosphate contents of water, whereas purified MO does not (Ndabigengesere and Narasiah 1998; Okuda *et al.*, 2001). The rate of phosphorus (P) uptake by plants is not high and usually supressed by immobilization processes in the soil. However excessive levels of available P, if they occur, may result in nutrient imbalances such as Cu, Fe and Zn deficiencies (Feigin *et al.*, 1991) and runoff of agricultural soils into surface waters can induce eutrofication.

Nitrogen overdose in the form of excessive nitrates and water – soluble ammonium may seriously affect the quality of crop production; plant physiological disorders, reduced carbohydrate metabolism, enhanced vegetative growth, increased tissue succulence (Feigin *et al.*, 1991).

Chlorine and Sulphate were not affected; some of the treated waters recorded a reduction in chlorine values.

5.1.9 Influence on Faecal Coliforms by MOC

Apart from turbidity removal MO also possesses antimicrobial properties (Olsen, 1987; Madsen *et al.*, 1987 Broin *et al.*, 2002; Ghebremichael *et al.*, 2005). The mechanism by which MO acts upon microorganisms is not yet fully understood.

From the results obtained, concentrations of 1.5 - 5% (w/v) gave 1.71-3.82 log units (97.88%-99.96%) reduction of faecal coliform within one hour. This is not different from a result obtained by research by Madsen *et al.* (1987). They carried out coagulation and bacterial reduction studies on turbid Nile water in the Sudan using *Moringa oleifera* seeds and observed a bacterial reduction of 1-4 log units (90-99.9%) within the first one to two hours of treatment. Boateng (2001) also reported the 90-99% reduction in faecal coliform in drinking water. Ghebremichael, (2004) also documented an average of 1.1–4.0 log reductions of several microorganisms including E. *coli*.

Broin et al., 2002 reported that a recombinant MO protein was able to flocculate gram-positive and gram-negative bacteria cells. On the other hand, MO may also directly act upon microorganisms and result in growth inhibition. For example, Sutherland *et al.,* (1990) reported that MO could inhibit replication of bacteriaphage. Caceres *et al.,* (1991) also observed growth inhibition of *Pseudomonas aeruginosa* and and *Staphylococcus aureus*. Others have also reported antimicrobial effects of recombinant (heterologous) form of MO protein expressed in E. *coli* (Broin *et al.,* 2002; Suarez *et al.,* 2003). Most of the reports on the antimicrobial effect of MO are based on crude extract, and it is difficult to identify the exact nature of the component that carries out the effect. Eilert *et al.,* (1981) attributed the antimicrobial effects to the compound 4 (α - L – Rhamnosyloxy) benzyl isothiocyanate synthesized by the plant.

5.1.10 Applicability and Availability of *Moringa oleifera* in large scale

In Ghana a seed of *Moringa* weighing (3-4g) will cost 1 pesewa and 3.0kg can treat 30,000L of water (Doerr, 2005). In a favourable environment an individual tree can yield 50 to 70 kg of pods in one year (Schwarz, 2000). According to Goh (2005), the cost of producing 1 kg (3400 seeds) of *Moringa oleifera* is approximately US$2 and this could be more beneficial to communities in terms of health and economy. A community could gain income from the sale of the seeds to companies or institutions involved in processing them for the coagulant or oil. Apart from being inexpensive, natural coagulants produced for the plant are readily biodegradable and for less voluminous sludge. For example a sludge produced from *M. oleifera for* coagulating turbid water is only 20 – 30% of that of alum for treating water (Ndabigengesere *et al*., 1995; Narasiah *et al*., 2002).

The cake residue, after coagulant extraction, can be processed for use as animal fodder or plant fertilizer. The multiple uses of the seed imply that the coagulant is obtained at a very low cost. Solutions of *Moringa* seeds for water treatment may be prepared from seed kernels or from the solid residue left over after oil extraction (presscake). *Moringa* seeds, seed kernels or dried presscake can be stored for long periods but *Moringa* solutions for treating water should be prepared fresh each time Doerr (2005). In a study by Berger *et al.,* (1984) it was concluded that *Moringa oleifera* seeds as water purifiers may not constitute a serious health hazard.

The multiple uses of the MO plant indicate the significant potential for commercial applications to generate income. Technically speaking the part that is used for water treatment is a waste product after oil extraction called pressed cake and it can be acquired at a very low cost. Several studies have reported the use of the crude and

purified extracts from the MO seed for coagulation (Olsen, 1987; Jahn, 1988; Ndabigengesere *et al.,* 1995; Muyibi and Evison, 1995).

5.1.11 Correlation between Turbidity and Faecal Coliform

From figure 4.15 there was interrralation between faecal coliforn and turbidity. Removal of turbidity resulted in appreciable reduction in faecal coliform (r^2 = 0.5351). A study conducted by Boateng (2001) on the use of Alum and *Moringa oleifera* in surface water treatment recorded 68.8-98.9% and 90-99% reduction in turbidity and faecal coliform respectively. Madsen *et al.* (1987) also carried out coagulation and bacterial reduction studies on turbid Nile water in the Sudan using *Moringa oleifera* seeds and observed turbidity reduction of 80-99.5% paralleled by a bacterial reduction of 1-4 log units (90-99.9%) within the first one to two hours of treatment, the bacteria being concentrated in the coagulated sediment.

5.1.12 Correlation between Turbidity and Settleable solids

It is clearly seen from Figure 4.16 that as the levels of settlable materials increases (increase sedimentation) turbidity reduces. Levels of biodegradable organic matter and suspended solids are often used for classification of treated wastewater intended for irrigation because there are fairly effective and efficient methods for measurement of BOD/COD/TSS respectively, and, because it gives an overall assessment of the treatment performance. Removal of biodegradable organic matter and suspended solids may coincide with the removal of clogging agents, part of the pathogenic microorganisms, toxic and trace elements and plant macro-nutrients. The extent of this correlation, however, depends on the type of treatment system applied. The levels

of BOD/COD/TSS can be monitored indirectly turbidity measurements. Turbidity (NTU), which can be monitored on-line, is thus often used as a parameter for water quality monitoring (Crook 1998; Feigin *et al.*, 1991). Low levels of turbidity or TSS however do not indicate that reclaimed water is, for example, devoid of microorganisms. As such, NTU and TSS are not used as an indicator of microbial quality, but rather as a quality criterion for wastewater prior to disinfection (Crook 1998). The effluent must be low in NTU and TSS prior to disinfection to reduce shielding of pathogens and also reduce chlorine demand (Metcalf and Eddy 1995)

5.2 CONCLUSIONS

The *Moringa oleifera* seed coagulant (MOC) show good coagulating properties, especially for treatment of very high turbidity waters. It does not affect the pH, alkalinity, TDS or conductivity of the water except phosphate and nitrogen which can also act as fertilizer when controlled during application. A prolonged sedimentation time of at least one hour together with MOC improved the treatment by reducing turbidity. *Moringa oleifera* seed coagulant (MOC) can reduce turbidity close to the World Health Organization's guideline value of 5 NTU from raw water with average turbidities during test runs ranging from 10-560 NTU. High concentrations of MOC 4-5% (w/v) can reduce faecal coliform levels to below log 3. *Moringa* is found to be a sustainable, cheap solution for coagulation in water treatment. *Moringa oleifera* seed can be produced locally at low cost therefore the use of *Moringa oleifera seed* would have several technical benefits, especially in tropical developing countries and rural communities. It will help them treat water for small scale vegetable farming. The possibility of using *Moringa oleifera* seed at farm level is good, and provides a realistic alternative to conventional methods, presuming that an adequate amount of

plantations are established. It is a method that certainly can be considered as a good, sustainable and cheap solution for farmers, if the supply of *Moringa oleifera* seeds can be guaranteed.

5.3 RECOMMENDATIONS

The use of irrigation water with low physicochemical and microbial quality is common in many urban areas in Ghana, as also in other low-income countries worldwide. In Ghana, this project should be carried on pilot scale by local authorities and farmers as a risk reduction measures to reduce health risks from irrigated urban vegetable farming.

Moringa oleifera is now widely grown in Ghana. While the other plant parts like leaves, barks and roots may be used for medicinal purposes, the press-cake which is obtained after oil extraction is equally efficient for coagulation. Therefore more people should be encouraged to engage in the plantation and oil extraction of *Moringa oleifera* business so that farmers can obtain the press-cake at very cheap cost or at no cost for wastewater treatment.

Once plantations are established and the supply of seeds secured, *Moringa* provides a good, cheap and sustainable coagulant in treating water for urban vegetable farming.

Guidelines for farmers on best practices for extraction and use of *Moringa oleifera* for efficient water treatment should be researched into on-farm, with farmer's participation in order to promote its adoption by farmers.

However, this experiment was only performed for a short period, and further studies need to be carried out to draw definite conclusions on this project.

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APPENDICES

APPENDIX 1: WATER QUALITY AND CHARACTERISTICS

1a. Settleable solids

Dosage		Time (min.)											
(%) w/v	Vol(ml/L)	10	20	30	40	50	60	70	80	90	100	110	120
Sed1.5	0.00	1.85	1.90	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
1.5	20.00	2.00	2.20	2.50	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
1.5	40.00	1.50	2.00	2.20	2.40	2.50	2.70	2.70	2.70	2.70	2.70	2.70	2.70
1.5	60.00	2.00	2.60	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
1.5	80.00	5.00	5.60	5.60	5.60	5.80	5.80	5.80	5.80	5.80	5.80	5.80	5.80
1.5	100.00	4.85	5.00	5.25	5.40	5.50	6.00	6.25	6.25	6.30	6.30	6.45	6.45
1.5	120.00	6.00	6.25	6.50	6.80	6.85	6.85	6.85	6.90	6.90	6.90	6.95	6.95
Sed1.5	0.00	1.65	1.70	1.70	1.80	1.80	1.80	1.80	2.00	2.00	2.20	2.20	2.20
1.5	20.00	1.80	2.00	2.00	2.20	2.30	2.40	2.50	2.50	2.50	2.50	2.50	2.50
1.5	40.00	1.30	2.00	2.40	2.40	2.50	3.00	3.00	3.00	3.00	3.00	3.00	3.00
1.5	60.00	2.00	2.50	2.80	3.00	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
1.5	80.00	4.85	5.00	5.25	5.40	5.50	6.00	6.25	6.25	6.30	6.30	6.45	6.45
1.5	100.00	5.00	5.40	5.50	5.50	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
1.5	120.00	6.00	6.00	6.25	6.40	6.50	6.50	6.60	6.60	6.80	6.80	6.80	6.80
Sed1.5	0.00	1.60	1.80	1.80	1.80	1.80	2.00	2.00	2.00	2.00	2.00	2.00	2.00
1.5	20.00	2.20	2.20	2.30	2.40	2.40	2.40	2.40	2.60	2.60	2.60	2.60	2.60
1.5	40.00	1.50	2.00	2.20	2.40	2.50	2.70	2.70	2.70	2.70	2.70	2.70	2.70
1.5	60.00	2.40	2.40	2.50	2.80	3.00	3.00	3.20	3.20	3.20	3.40	3.40	3.40

1.5	80.00	4.85	5.00	5.25	5.40	5.50	6.00	6.25	6.25	6.30	6.30	6.45	6.45
1.5	100.00	5.60	5.80	5.80	6.00	6.20	6.40	6.50	6.50	6.50	6.50	6.50	6.50
1.5	120.00	6.00	6.40	6.60	7.00	7.50	7.50	7.50	7.50	8.00	8.00	8.00	8.00
Sed2	0.00	1.50	1.60	1.70	1.70	1.75	1.80	1.80	1.80	1.90	1.90	1.90	1.90
2	20.00	5.50	5.00	5.50	5.50	5.60	6.00	6.00	6.50	7.00	8.50	9.50	11.00
2	40.00	6.20	6.50	6.50	6.50	6.60	7.00	7.00	8.00	8.50	10.00	12.00	15.00
2	60.00	3.10	3.00	3.00	3.00	3.00	3.50	3.50	3.00	4.00	4.50	6.50	12.00
2	80.00	6.50	6.50	7.00	7.00	7.50	8.00	8.50	9.00	10.00	11.00	12.00	15.00
2	100.00	6.50	7.00	7.90	7.90	7.50	8.00	8.50	9.00	10.00	11.00	12.50	15.00
2	120.00	7.00	7.50	7.80	7.90	7.50	8.00	8.50	9.00	10.00	11.50	12.50	14.50
Sed2	0.00	1.50	1.60	1.70	1.70	1.75	1.80	1.80	1.80	1.90	1.90	1.90	1.90
2	20.00	5.70	5.80	5.80	5.80	5.80	6.00	6.00	6.20	6.30	6.30	6.40	6.40
2	40.00	6.00	6.00	6.20	6.60	6.80	7.00	7.00	7.40	7.50	7.80	8.00	8.00
2	60.00	5.00	5.40	5.40	6.00	8.00	8.00	8.00	9.00	9.00	9.00	9.00	10.00
2	80.00	5.50	5.50	6.00	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	14.00
2	100.00	8.50	9.00	9.00	9.00	9.00	9.00	9.50	9.50	10.50	11.00	11.00	12.00
2	120.00	7.00	7.50	7.80	7.90	7.50	8.00	8.50	9.00	10.00	11.50	12.50	14.50
Sed2	0.00	1.50	1.60	1.70	1.70	1.75	1.80	1.80	1.80	1.90	1.90	1.90	1.90
2	20.00	5.50	5.00	5.50	5.50	5.60	6.00	6.00	6.50	7.00	8.50	9.50	11.00
2	40.00	6.20	6.50	6.50	6.50	6.60	7.00	7.00	8.00	8.50	10.00	12.00	15.00
2	60.00	3.10	3.00	3.00	3.00	3.00	3.50	3.50	3.00	4.00	4.50	6.50	12.00
2	80.00	6.50	6.50	7.00	7.00	7.50	8.00	8.50	9.00	10.00	11.00	12.00	15.00
2	100.00	6.50	7.00	7.90	7.90	7.50	8.00	8.50	9.00	10.00	11.00	12.50	15.00
2	120.00	7.00	8.00	8.00	9.00	9.00	9.00	9.00	9.00	10.00	11.00	12.00	14.50
Sed3	0.00	0.30	0.40	0.50	0.50	0.40	0.50	0.50	0.50	0.50	0.50	0.50	0.50
3	20.00	0.30	1.00	1.00	0.60	0.50	0.70	0.80	0.80	0.80	0.80	0.80	0.80
3	40.00	0.80	1.50	1.70	1.70	2.00	2.00	2.20	2.20	2.00	2.00	2.00	2.00

	3	60.00	0.70	1.20	1.50	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
	3	80.00	1.00	1.90	2.50	1.80	1.80	1.80	1.70	1.70	1.70	1.70	1.70	1.70
	3	100.00	1.80	2.50	2.50	2.20	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	3	120.00	1.80	3.00	3.00	3.50	3.40	2.20	2.20	2.20	2.50	2.50	2.50	2.50
Sed3		0.00	0.30	0.50	0.50	0.55	0.55	0.55	0.60	0.60	0.60	0.60	0.60	0.60
	3	20.00	0.30	1.00	1.00	0.60	0.50	0.70	0.80	0.80	0.80	0.80	0.80	0.80
	3	40.00	0.60	1.50	1.70	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	3	60.00	0.70	1.00	1.30	1.50	1.50	1.70	1.70	1.90	2.00	2.00	2.00	2.00
	3	80.00	1.20	1.50	2.50	1.80	1.80	1.80	1.70	1.70	1.80	1.80	1.80	1.80
	3	100.00	1.80	2.00	2.00	2.00	2.00	2.20	2.20	2.20	2.20	2.40	2.40	2.40
	3	120.00	1.80	2.50	2.60	3.00	3.20	3.20	3.20	3.00	3.00	3.00	3.00	3.00
Sed3		0.00	0.40	0.40	0.60	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.75
	3	20.00	0.30	1.00	1.00	0.60	0.50	0.70	0.80	0.80	0.80	0.80	0.80	0.80
	3	40.00	0.40	1.00	1.60	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
	3	60.00	1.00	1.60	2.00	2.20	2.20	2.20	2.00	2.00	2.00	1.80	2.00	2.00
	3	80.00	1.00	2.00	2.20	2.00	2.00	2.00	1.80	1.80	1.80	1.80	1.80	1.80
	3	100.00	1.80	3.00	3.00	2.20	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	3	120.00	1.80	2.00	2.40	2.40	2.40	2.40	2.40	2.40	2.60	2.80	2.80	2.80
Sed4		0.00	9.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.20	8.20	8.20	8.20

4	20.00	12.00	10.00	10.00	10.00	9.00	9.00	9.00	9.00	9.00	9.10	9.10	9.10
4	40.00	13.00	10.00	8.00	8.00	8.00	8.00	8.00	8.00	7.00	7.20	7.20	7.20
4	60.00	16.00	13.00	12.00	12.00	12.00	11.00	11.00	10.00	10.30	10.50	10.50	10.50
4	80.00	16.00	13.00	13.00	12.00	11.00	11.00	11.00	10.00	10.10	10.10	10.10	10.10
4	100.00	18.00	18.00	18.00	16.00	16.00	16.00	14.00	14.00	14.10	14.10	14.20	14.20
4	120.00	18.00	18.60	18.70	18.70	18.80	18.00	18.00	18.00	18.00	18.20	18.20	18.20
Sed4	0.00	7.00	8.00	8.00	8.20	8.20	8.20	8.40	8.40	8.40	8.40	8.40	8.40
4	20.00	14.00	12.00	12.00	12.00	9.00	9.00	9.00	9.00	9.00	9.20	9.30	9.30
4	40.00	14.00	12.00	12.00	10.00	10.00	10.00	9.00	9.00	9.00	9.00	9.00	9.20
4	60.00	14.00	13.00	12.00	12.00	11.50	11.50	11.20	11.20	11.20	11.00	11.00	11.00
4	80.00	16.00	13.00	13.00	12.00	11.00	11.00	11.00	10.00	10.10	10.20	10.20	10.20
4	100.00	16.00	18.00	18.00	18.00	17.00	17.00	16.00	15.00	15.00	14.00	14.00	14.00
4	120.00	18.50	18.60	18.60	18.60	18.60	18.20	18.20	18.20	18.20	18.40	18.40	18.40
Sed4	0.00	9.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
4	20.00	12.00	10.00	10.00	10.00	9.00	9.00	9.00	9.00	9.00	9.40	9.40	9.40
4	40.00	13.00	10.00	8.00	8.00	8.00	8.00	8.00	8.00	7.90	7.90	7.90	7.90
4	60.00	16.00	13.00	12.00	12.00	11.00	11.00	11.00	10.00	10.00	10.00	10.00	10.00
4	80.00	16.00	13.00	13.00	12.00	11.00	11.00	11.00	10.00	10.10	10.20	10.20	10.20
4	100.00	18.00	18.00	18.00	16.00	16.00	16.00	14.00	14.00	14.00	14.00	14.00	14.00
4	120.00	18.50	18.60	18.70	18.70	18.80	18.00	18.00	18.00	18.00	18.20	18.20	18.20
Sed5	0.00	0.50	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
5	20.00	1.50	1.70	1.70	1.70	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
5	40.00	1.80	2.00	2.00	2.00	2.20	2.20	2.20	2.20	2.20	2.20	2.30	2.30
5	60.00	2.20	2.30	2.30	2.30	2.50	2.60	2.60	2.60	2.60	2.60	2.60	2.60
5	80.00	2.40	2.50	2.50	2.50	2.60	2.60	2.70	2.70	2.70	2.70	2.70	2.70
5	100.00	2.40	2.60	2.60	2.60	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70
5	120.00	2.50	2.60	2.60	2.60	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80

Sed5		0.00	0.60	0.60	0.60	0.60	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80
	5	20.00	1.60	1.70	1.70	1.70	1.80	1.80	1.80	1.90	1.90	1.90	1.90	1.90
	5	40.00	2.00	2.20	2.20	2.20	2.20	2.20	2.30	2.30	2.30	2.30	2.30	2.30
	5	60.00	2.00	2.40	2.50	2.30	2.50	2.60	2.60	2.60	2.60	2.60	2.60	2.60
	5	80.00	2.20	2.30	2.30	2.30	2.40	2.40	2.40	2.40	2.50	2.50	2.50	2.50
	5	100.00	2.40	2.60	2.60	2.60	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70
	5	120.00	2.50	2.60	2.60	2.60	2.80	2.80	2.90	2.90	2.90	2.90	2.90	2.90
Sed5		0.00	0.65	0.65	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	5	20.00	1.50	1.70	1.70	1.70	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
	5	40.00	1.60	1.80	1.80	1.80	1.80	1.80	2.00	2.00	2.00	2.00	2.20	2.20
	5	60.00	2.20	2.30	2.30	2.30	2.50	2.60	2.60	2.60	2.60	2.60	2.60	2.60
	5	80.00	2.40	2.40	2.50	2.50	2.60	2.60	2.60	2.60	2.60	2.80	2.80	2.80
	5	100.00	2.20	2.60	2.60	2.60	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
	5	120.00	2.50	2.80	2.80	2.80	2.80	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Sed= Sedimentation of raw water without treatment

1b. Results of physicochemical parameters and anions after 1 hour

Dosage(%w/v)	Volume(ml)	pH	Turb. (NTU)	Cond. (µs/cm)	TDS(mg/l)	NO_3-N	PO^{-3}_4	SO^{2-}_3	Alkalinity	Tot Hard.	Chloride
-	RW	6.50	243	270	263	3.50	1.30	20.40	120	20.00	6.00
-	SW	6.64	108	265	259	3.20	1.40	18.00	120	22.00	8.00
1.5	20	6.55	80	271	266	3.70	4.00	66.00	100	12.00	4.26
1.5	40	6.47	77	280	275	2.70	4.80	54.00	100	16.00	7.10
1.5	60	6.45	53	288	282	2.50	2.50	66.00	100	16.00	4.26
1.5	80	6.42	31	296	291	4.90	2.00	55.00	60	13.00	2.84
1.5	100	6.42	28	303	297	5.60	2.80	53.00	60	14.00	9.94
1.5	120	6.39	18	312	307	6.40	6.00	53.00	100	17.00	4.20
-	RW	7.08	280	333	326	1.40	8.50	25.00	120	22.00	16.00
-	SW	7.05	186	332	322	1.10	7.80	23.00	100	22.00	14.00
2.0	20	7.28	68	336	330	1.50	9.00	33.00	60	20.00	11.00
2.0	40	7.13	69	343	336	2.20	12.60	44.00	60	22.00	10.00
2.0	60	7.00	31	350	343	1.80	8.50	54.00	80	23.00	11.00
2.0	80	6.89	7	356	349	2.80	11.50	58.00	100	20.00	14.00
2.0	100	6.82	7	360	354	3.00	14.50	63.00	100	23.00	13.00
2.0	120	6.77	6	368	361	3.20	16.80	49.00	120	20.00	10.00
-	RW	6.02	299	110	108	2.80	6.80	21.00	60	30.00	6.88
-	SW	5.79	140	110	108	3.10	6.60	19.00	40	25.00	6.40
3.0	20	6.44	99	119	117	2.70	6.00	29.00	100	13.00	6.00
3.0	40	6.02	50	145	142	3.30	3.50	36.00	40	16.00	5.00
3.0	60	5.87	30	184	180	4.10	8.60	58.00	40	22.00	6.00
3.0	80	5.74	22	222	217	6.80	9.60	72.00	20	19.00	8.50
3.0	100	5.58	18	248	243	6.40	10.90	90.00	20	17.00	5.40

3.0	120	5.49	8	282	277	10.80	10.42	74.00	20	25.00	5.88
-	RW	6.47	239	449	458	5.40	9.00	18.00	150	27.00	16.00
-	SW	6.87	105	445	445	4.00	8.30	15.00	150	27.00	12.00
4.0	20	6.93	17	465	455	3.90	6.40	20.00	60	19.00	12.00
4.0	40	6.85	14	476	460	4.70	9.80	30.00	80	22.00	13.00
4.0	60	6.74	14	495	485	4.60	9.50	40.00	100	24.00	13.00
4.0	80	6.72	13	505	495	4.40	9.40	43.00	100	25.00	16.00
4.0	100	6.81	6	510	500	4.90	8.80	50.00	125	26.00	18.00
4.0	120	6.75	4	515	508	4.50	9.20	64.00	125	23.00	14.00
-	RW	6.90	353	512	520	4.00	11.90	22.00	100	20.00	20.00
-	SW	6.70	200	502	480	4.20	7.30	13.00	100	21.00	19.00
5.0	20	6.80	18	551	560	4.40	11.00	26.00	150	29.25	19.00
5.0	40	6.60	15	557	568	6.20	10.30	33.00	150	18.25	22.00
5.0	60	6.30	12	561	575	5.40	11.00	44.00	100	13.20	18.00
5.0	80	6.00	10	566	574	6.00	8.80	43.00	125	25.25	19.00
5.0	100	6.60	8	580	595	5.80	8.00	49.00	80	50.50	33.00
5.0	120	6.60	5	583	590	6.80	12.00	48.00	200	15.00	18.00

RW=Raw water without treatment and **SW =** Settled water without treatment

1c. Results of Faecal Coliforms

Dosage(%)	TVol(ml)	RAW FC	TRT FC/100ML	%red Fc	LOG RAW FC	LOGTRT FC
-	RW					6.02
-	SW	1050000	915000	12.86	6.02	5.96
1.5	20	1050000	41500	96.05	6.02	4.62
1.5	40	1050000	23500	97.76	6.02	4.37
1.5	60	1050000	23500	97.76	6.02	4.37
1.5	80	1050000	15000	98.57	6.02	4.18
1.5	100	1050000	15000	98.57	6.02	4.18
1.5	120	1050000	15000	98.57	6.02	4.18
-	RW					6.37
-	SW	2350000	915000	61.06	6.37	5.96
2	20	2350000	45000	98.09	6.37	4.65
2	40	2350000	4500	99.81	6.37	3.65
2	60	2350000	2350	99.90	6.37	3.37
2	80	2350000	2350	99.90	6.37	3.37
2	100	2350000	2350	99.90	6.37	3.37
2	120	2350000	2350	99.90	6.37	3.37
-	RW					6.96
-	SW	9150000	4150000	54.64	6.96	6.62
3	20	9150000	41500	99.55	6.96	4.62
3	40	9150000	2300	99.97	6.96	3.36
3	60	9150000	915	99.99	6.96	2.96
3	80	9150000	915	99.99	6.96	2.96
3	100	9150000	915	99.99	6.96	2.96
3	120	9150000	915	99.99	6.96	2.96
-	RW					6.86
-	SW	7250000	4150000	42.76	6.86	6.62
4	20	7250000	15000	99.79	6.86	4.18
4	40	7250000	1500	99.98	6.86	3.18
4	60	7250000	915	99.99	6.86	2.96
4	80	7250000	915	99.99	6.86	2.96
4	100	7250000	450	99.99	6.86	2.65
4	120	7250000	450	99.99	6.86	2.65
-	RW					6.32
-	SW	2100000	910000	56.67	6.32	5.96
5	20	2100000	4500	99.79	6.32	3.65
5	40	2100000	450	99.98	6.32	2.65
5	60	2100000	150	99.99	6.32	2.18
5	80	2100000	150	99.99	6.32	2.18
5	100	2100000	150	99.99	6.32	2.18
5	120	2100000	150	99.99	6.32	2.18

APPENDIX 2. Dosage simulation

2. Turbidity

Turbidity (NTU)	% turbidity removal analysis											
	samples	WW	1.5%	% RED	2%	% RED	3%	% RED	4%	% RED	5%	% RED
10 - 50	1	10	6	40.0	18	-80.0	20	-100.0	32	-220.0	33	-230.0
	2	15	5	66.7	12	20.0	14	6.7	22	-46.7	22	-46.7
	3	15	7	53.3	12	20.0	16	-6.7	22	-46.7	24	-60.0
	4	16	2	87.5	8	50.0	15	6.3	22	-37.5	28	-75.0
	5	17	4	76.5	8	52.9	13	23.5	18	-5.9	21	-23.5
	6	18	4	77.8	9	50.0	15	16.7	20	-11.1	23	-27.8
	7	20	5	75.0	11	45.0	12	40.0	22	-10.0	28	-40.0
	8	20	4	80.0	12	40.0	17	15.0	21	-5.0	24	-20.0
	9	21	6	71.4	9	57.1	12	42.9	18	14.3	23	-9.5
	10	22	9	59.1	16	27.3	20	9.1	28	-27.3	40	-81.8
	11	22	6	72.7	8	63.6	21	4.5	23	-4.5	35	-59.1
	12	23	5	78.3	10	56.5	18	21.7	24	-4.3	30	-30.4
	13	23	5	78.3	12	47.8	22	4.3	22	4.3	28	-21.7
	14	25	4	84.0	16	36.0	20	20.0	22	12.0	26	-4.0
	15	25	3	88.0	8	68.0	20	20.0	24	4.0	31	-24.0
	16	29	6	79.3	7	75.9	23	20.7	26	10.3	28	3.4

	17	30	12	60.0	18	40.0	18	40.0	21	30.0	23	23.3
	18	33	11	66.7	16	51.5	20	39.4	22	33.3	27	18.2
	19	33	12	63.6	14	57.6	14	57.6	16	51.5	30	9.1
	20	33	11	66.7	12	63.6	18	45.5	22	33.3	28	15.2
	21	33	14	57.6	12	63.6	14	57.6	16	51.5	21	36.4
	22	33	16	51.5	20	39.4	17	48.5	22	33.3	22	33.3
	23	33	12	63.6	13	60.6	14	57.6	22	33.3	26	21.2
	24	33	10	69.7	12	63.6	14	57.6	15	54.5	17	48.5
	25	33	10	69.7	11	66.7	12	63.6	18	45.5	22	33.3
	26	34	4	88.2	6	82.4	10	70.6	18	47.1	26	23.5
	27	34	5	85.3	6	82.4	15	55.9	22	35.3	28	17.6
	28	35	8	77.1	12	65.7	16	54.3	17	51.4	21	40.0
	29	37	10	73.0	16	56.8	20	45.9	24	35.1	25	32.4
	30	37	12	67.6	18	51.4	21	43.2	22	40.5	23	37.8
	31	37	10	73.0	14	62.2	20	45.9	20	45.9	21	43.2
	32	37	16	56.8	16	56.8	18	51.4	24	35.1	25	32.4
	33	37	8	78.4	12	67.6	16	56.8	20	45.9	23	37.8
	34	43	5	88.4	9	79.1	13	69.8	14	67.4	18	58.1
	35	43	8	81.4	10	76.7	13	69.8	17	60.5	21	51.2
	36	44	10	77.3	12	72.7	16	63.6	18	59.1	22	50.0
	37	44	10	77.3	13	70.5	16	63.6	16	63.6	18	59.1
	38	44	10	77.3	11	75.0	15	65.9	16	63.6	20	54.5
	39	45	10	77.8	12	73.3	14	68.9	18	60.0	21	53.3
	40	46	12	73.9	12	73.9	15	67.4	17	63.0	27	41.3
	41	47	20	57.4	23	51.1	24	48.9	25	46.8	27	42.6
	42	50	18	64.0	16	68.0	14	72.0	12	76.0	12	76.0

	43	50	16	68.0	14	72.0	14	72.0	16	68.0	16	68.0
	44	50	18	64.0	15	70.0	13	74.0	14	72.0	12	76.0
54-144	45	54	16	70.4	14	74.1	12	77.8	12	77.8	11	79.6
	46	55	18	67.3	14	74.5	16	70.9	12	78.2	10	81.8
	47	55	18	67.3	13	76.4	14	74.5	14	74.5	12	78.2
	48	55	18	67.3	14	74.5	16	70.9	12	78.2	10	81.8
	49	55	20	63.6	12	78.2	14	74.5	14	74.5	12	78.2
	50	55	19	65.5	18	67.3	16	70.9	12	78.2	8	85.5
	51	60	16	73.3	12	80.0	14	76.7	14	76.7	8	86.7
	52	63	20	68.3	18	71.4	16	74.6	14	77.8	10	84.1
	53	65	22	66.2	18	72.3	17	73.8	16	75.4	10	84.6
	54	66	28	57.6	28	57.6	20	69.7	16	75.8	12	81.8
	55	66	39	40.9	34	48.5	25	62.1	20	69.7	14	78.8
	56	66	39	40.9	34	48.5	25	62.1	20	69.7	14	78.8
	57	67	39	41.8	34	49.3	25	62.7	20	70.1	14	79.1
	58	67	40	40.3	39	41.8	35	47.8	22	67.2	10	85.1
	59	67	36	46.3	32	52.2	30	55.2	22	67.2	12	82.1
	60	70	37	47.1	30	57.1	31	55.7	20	71.4	18	74.3
	61	70	33	52.9	33	52.9	32	54.3	19	72.9	16	77.1
	62	71	37	47.9	30	57.7	30	57.7	22	69.0	12	83.1
	63	71	33	53.5	33	53.5	28	60.6	20	71.8	13	81.7
	64	73	33	54.8	30	58.9	30	58.9	19	74.0	12	83.6
	65	77	37	51.9	30	61.0	30	61.0	22	71.4	12	84.4
	66	77	39	49.4	35	54.5	28	63.6	25	67.5	20	74.0
	67	78	39	50.0	35	55.1	30	61.5	25	67.9	20	74.4
	68	78	40	48.7	34	56.4	32	59.0	30	61.5	26	66.7

	69	80	43	46.3	36	55.0	34	57.5	28	65.0	20	75.0
	70	85	46	45.9	40	52.9	38	55.3	30	64.7	25	70.6
	71	87	47	46.0	43	50.6	22	74.7	23	73.6	12	86.2
	72	88	40	54.5	44	50.0	30	65.9	28	68.2	11	87.5
	73	90	40	55.6	33	63.3	20	77.8	14	84.4	10	88.9
	74	90	50	44.4	30	66.7	18	80.0	16	82.2	12	86.7
	75	90	48	46.7	33	63.3	20	77.8	14	84.4	10	88.9
	76	99	45	54.5	40	59.6	33	66.7	15	84.8	12	87.9
	77	99	50	49.5	43	56.6	40	59.6	18	81.8	13	86.9
	78	122	100	18.0	76	37.7	70	42.6	44	63.9	30	75.4
	79	122	102	16.4	70	42.6	66	45.9	50	59.0	30	75.4
	80	123	98	20.3	68	44.7	60	51.2	25	79.7	20	83.7
	81	130	100	23.1	53	59.2	30	76.9	28	78.5	18	86.2
	82	130	102	21.5	58	55.4	32	75.4	20	84.6	20	84.6
	83	133	100	24.8	58	56.4	30	77.4	25	81.2	10	92.5
	84	140	100	28.6	50	64.3	36	74.3	28	80.0	15	89.3
	85	140	98	30.0	68	51.4	48	65.7	26	81.4	14	90.0
	86	140	100	28.6	50	64.3	36	74.3	25	82.1	13	90.7
	87	144	98	31.9	68	52.8	48	66.7	20	86.1	13	91.0
155-333	88	155	98	36.8	76	51.0	60	61.3	29	81.3	8	94.8
	89	164	100	39.0	88	46.3	60	63.4	28	82.9	8	95.1
	90	177	120	32.2	90	49.2	65	63.3	32	81.9	10	94.4
	91	180	118	34.4	80	55.6	60	66.7	28	84.4	10	94.4
	92	180	112	37.8	61	66.1	48	73.3	28	84.4	10	94.4
	93	185	114	38.4	67	63.8	44	76.2	28	84.9	8	95.7
	94	190	108	43.2	65	65.8	40	78.9	32	83.2	12	93.7

	95	200	150	25.0	100	50.0	88	56.0	45	77.5	8	96.0
	96	200	140	30.0	95	52.5	59	70.5	38	81.0	13	93.5
	97	220	135	38.6	90	59.1	76	65.5	43	80.5	11	95.0
	98	221	135	38.9	98	55.7	66	70.1	38	82.8	9	95.9
	99	250	150	40.0	95	62.0	86	65.6	40	84.0	8	96.8
	100	333	180	45.9	100	70.0	88	73.6	47	85.9	9	97.3

APENDICE 3: FIELD TRIALS

3a. Turbidity

Parameter	Sample site	February				March				April				May			
Treated	KAK 1	14	12	16	15	16	16	23	17	22	18	28	18	23	20	22	22
	KAK 2	30	22	22	20	30	24	19	16	37	33	20	22	21	34	24	22
	GYN 1	20	12	22	10	22	16	24	16	12	18	20	18	19	15	22	14
	GYN 2	10	8	12	12	11	16	14	15	16	14	18	11	8	12	18	20
	GYN 3	20	22	21	24	28	30	28	18	30	26	24	15	28	20	16	17
	GYN 4	8	6	10	8	12	14	8	13	16	20	10	8	8	10	18	13
Untreated	KAK 1	546	521	512	499	502	490	512	450	600	488	551	477	555	497	567	500
	KAK 2	696	600	490	620	555	570	466	599	456	590	477	500	478	600	500	502
	GYN 1	79	89	70	81	80	99	70	89	88	97	87	90	99	100	99	90
	GYN 2	174	150	167	140	155	122	143	122	167	133	136	145	159	144	130	130
	GYN 3	56	60	50	66	59	66	55	70	55	70	45	74	67	65	48	77
	GYN 4	109	100	144	98	102	122	122	88	98	131	125	98	79	140	130	75

3b. pH

Parameter	Sample site	February				March				April				May			
Treated	KAK 1	6.42	6.78	6.70	6.40	6.00	6.61	6.70	5.80	6.40	5.80	7.40	7.00	6.50	5.60	6.00	5.60
	KAK 2	6.20	6.94	6.40	6.26	6.40	6.70	6.20	7.00	6.80	6.20	6.40	6.40	6.60	6.50	6.50	6.40
	GYN 1	5.70	5.65	5.86	6.10	5.58	6.26	6.60	6.80	6.70	7.00	6.80	6.80	6.80	6.80	6.70	6.60
	GYN 2	6.00	6.00	6.20	5.51	6.11	6.46	6.22	6.55	5.70	5.80	6.20	6.10	5.60	6.00	6.30	5.90
	GYN 3	5.40	5.59	5.37	6.09	6.00	5.04	5.80	6.03	6.30	6.22	5.60	6.00	6.60	6.40	5.80	7.00
	GYN 4	6.20	5.60	5.62	5.50	6.80	6.90	7.00	6.80	6.50	6.80	6.40	6.90	6.80	6.50	7.00	7.20
Untreated	KAK 1	6.42	6.78	6.56	6.40	5.92	6.61	6.70	5.80	6.20	5.70	7.40	7.00	6.30	5.40	5.90	5.60
	KAK 2	6.20	6.94	6.04	6.26	6.31	6.70	6.20	7.00	6.80	6.00	6.40	6.40	6.60	6.50	6.30	6.30
	GYN 1	5.54	5.55	5.86	6.10	5.58	6.16	6.60	6.80	6.70	6.90	6.80	6.80	6.20	6.60	6.70	6.60
	GYN 2	5.90	5.94	6.00	5.51	6.11	6.46	6.22	6.55	5.90	5.80	5.90	5.70	5.60	5.80	6.00	5.90
	GYN 3	5.40	5.59	5.25	6.09	5.58	5.04	5.80	6.03	6.30	6.22	5.60	6.00	6.30	6.20	5.80	7.00
	GYN 4	5.90	5.60	5.62	5.40	6.80	6.90	7.20	7.00	6.50	6.80	6.40	6.90	6.80	6.50	6.80	6.90