UNIVERSITY OF NAIROBI

DEPARTMENT OF CHEMISTRY

DEVELOPMENT OF A LOW COST WATER PURIFICATION SYSTEM – A CASE STUDY CERAMIC FILTERS AND *MORINGA OLEIFERA* SEEDS

By

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DECLARATION

This thesis is my original idea and has not been submitted to any other university or institution for examination. Where other scholars' work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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DEDICATION

For my late mum, the sweet memories keep me going.

"Moses prayed earnestly to the Lord, and the Lord showed him a piece of wood, which he threw into the water; and the water become fit to drink"

Exodus 15:25

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LIST OF ABBREVIATIONS

AAS-Atomic Absorption Spectrometry

CFU-colony forming unit

DSTP- Dandora Sewerage and Treatment Plant

E. coli- Escherichia Coli

KEBS- Kenya Bureau of Standards

MDG- Millennium Development Goals

NEDA- N-alpha-naphthyl-ethylenediamine

NGO- Non-Governmental Organization

NIEHS – The National Institute of Environmental Health Sciences

NTU- Nephelometric Turbidity Units

POU – Point of Use

SODIS- Solar Disinfection

SWCEA- Safe Water Ceramic for East Africa

TDS- Total Dissolved Substances

TERI-The Energy and Resources Institute

TSS- Total Suspended Solids

UN- United Nations

UNESCO-United Nations Educational, Scientific and Cultural Organization

UNHCR-United Nations High Commision for Refugees

UNICEF-United Nations International Children's Emergency Fund

USEPA- United States Environment Protection Agency

UV-Ultra Violet

WHO- World Health Organization

WSP- Water and Sanitation Programme

XRF- X-ray Fluorescence

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ABSTRACT

Majority of people living in developing world do not have access to quality water. These people rely on readily available sources which are normally of low quality thus exposing them to waterborne diseases. This study was conducted to investigate the efficiency of clay filters and *Moringa oleifera* seeds in water purification. The study involved making porous clay pots by incorporating burnout material into the clay when moulding it and testing the coagulant and disinfectant ability of *M. oleifera* seeds. Four ration by volume i.e. 50:50, 55:45, 60:40 and 65:35 (Clay: Sawdust) were selected and filters prepared from them in triplicates. The filters were fired at 850°C for 8 hours by first drying them at 100°C for two hours. Another set of filters was prepared in the same way but fired at 650°C. The *M. oleifera* wood powder and seed husks were also used as the burnout material to prepare a different set of filters.

The efficiency of the filters and *M. oleifera* seeds in treating water was tested against selected microbial, chemical and physicochemical parameters and also by determining the flow rates. Turbidity and Feacal Coliforms were the most affected parameters by the two POU interventions.

The filters made from local sawdust had flow rates ranging between 28.0 and 104.5ml/hr. The filters made from *M. oleifera* wood and husks powder recorded the lowest flowrates of 11.5 – 17.8ml/hr. The filters reduced *Escherischia coli* with an efficiency ranging from 99.1 to 100%. This corresponded to an average numerical reduction from an initial *E coli* count of 390±10/ml to 0.08±0.1 CFU/ml. Turbidity was reduced by an efficiency ranging between 97.2 and 98.6%. For all the filters, turbidity of water was reduced to below 1.7 NTU. The filters were also found to adsorb lead and copper ions with an adsorption efficiency of 96.5-99.8 % and 99.5-99.98% respectively. The other parameters tested on the filters were TDS and pH. The filters had minimal effect on total dissolved substances with a reduction efficiency range of 10.1-12.5%. The effect on pH was negligible ranging between -0.34 and 1.7%.

All the filters were found to be equally effective in purifying water. Varying the combustible material, firing temperature and ratio of clay to the combustible material did not affect the

efficiency of the filters in removing contaminants. The variations only affected the flow rates of the filters.

Tests with *M. oleifera* seeds indicated that the seeds had both biocoagulant and phytodisinfectant ability. A dosage of 0.2 g/l reduced turbidity of artificial turbid water with a reduction efficiency of upto 99.2 %. With naturally occurring turbid water, the efficiency was lower at 59.0 % removal. Tests with *E. coli* and other Coliforms indicated that the seeds could reduce them with a reduction efficiency of 86.8% and 82.7% respectively. TSS removal was at 53.2% while TDS, pH, and conductivity removal was at approximately 5%. The seeds did not affect the alkalinity, nitrates and nitrites concentration of the sample. A test on the effect of pH revealed that the seeds were more effective in slightly basic conditions though the difference was minimal. Deoiling the seeds and using the seed cake residue showed similar efficiency and therefore the edible oil could be extracted first before the seeds are used in water treatment.

Sequential use of the two POU would produce quality water and also prevent clogging of filters. The seeds could be used in the pretreatment step to lower the turbidity of the water and also lower the Microbial contaminants. On passing this water through the filters, the *E. coli* would be completely eliminated and turbidity lowered to below 2 NTU.

CHAPTER ONE

INTRODUCTION

1.1 Background

Throughout history human progress has depended on access to clean water and on the ability of societies to harness the potential of water as a productive resource [UNDP, 2006]. The Millennium Development Goal relating to drinking-water and sanitation [MDG 7, Target 7c], is to: "Halve, by 2015, the proportion of people without sustainable access to safe drinking-water and basic sanitation". As also stressed in the post-2015 Global Thematic Water Consultation, access to water, sanitation and hygiene for all, food and energy production, disaster risk reduction, economic development and healthy people and ecosystems rely on the availability and sustainable management of water resources. According to WHO and UNICEF recent reports an estimated 768 million people did not use an improved source for drinking-water in 2011, including 185 million who relied on surface water to meet their daily drinking-water needs. In Kenya, about 39% of the rural population use unimproved sources of drinking water. Of this percent, 30 % use surface water without any treatment on the water [WHO and UNICEF, 2013]. These unimproved sources of drinking water pose a great challenge to a nation by causing water borne diseases since most of them contain harmful microbiological contaminants among other contaminants. These water borne diseases are reported to be related to malnutrition and retardation [CDC, 2012]. Access to clean water for life is a basic human need and a fundamental human right. Yet in our increasingly prosperous world, more than 1 billion people are denied the right to clean water and 2.6 billion people lack access to adequate sanitation. These headline numbers capture only one dimension of the problem. Every year some 1.8 million children die as a result of diarrhoea and other diseases caused by unclean water and poor sanitation [UNDP, 2006]. Diarrhoeal diseases resulting from drinking contaminated water claim the lives of 700,000 children under five each year [Walker *et al*., 2013].

Africa is one of the worst hit continents by this problem with most of its countries suffering either from water stress or water scarcity as illustrated by Figure 1. In 2009, Africa's population exceeded 1 billion [UNPF, 2009] and continues to increase at a rate of 2.4%

annually. Of this population, 341 million lack access to clean drinking water, and a further 589 million have no access to adequate sanitation [WHO/ UNICEF, 2008].

In addition African countries also suffer from critical water quality challenges.

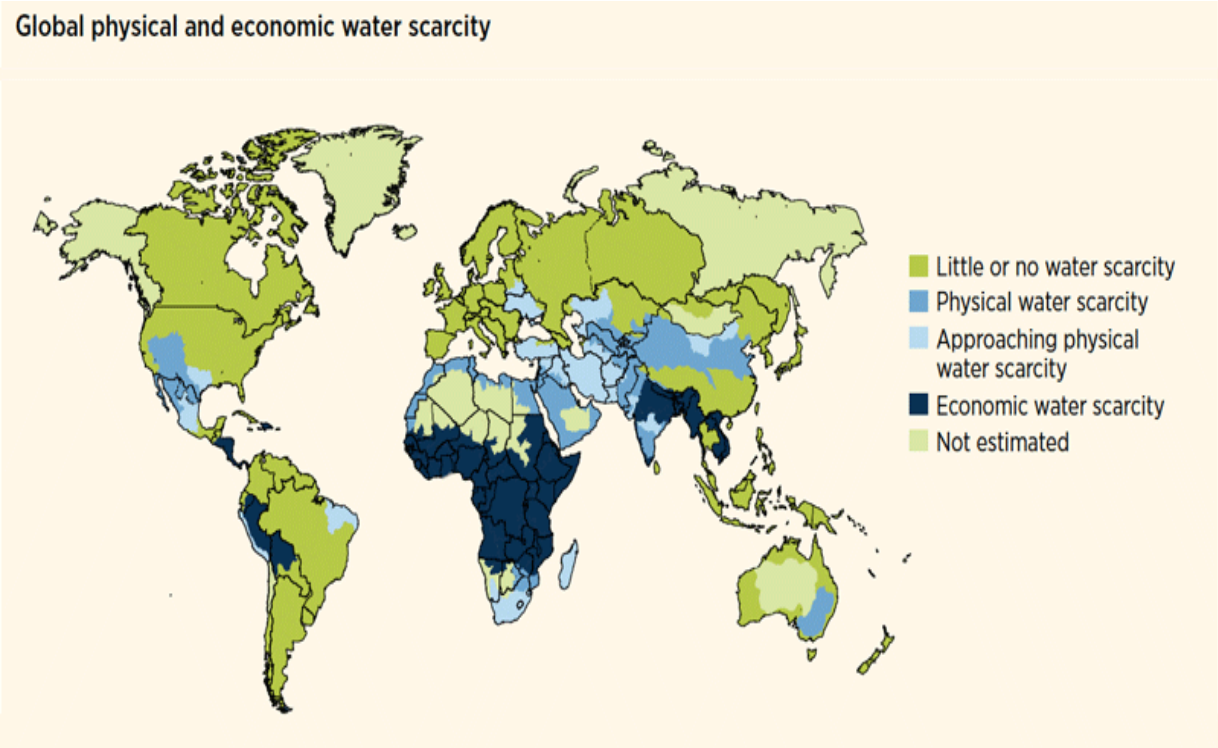


Figure 1. Global physical and economic water scarcity

Source: World Water Assessment Programme (WWAP), 2012

Africa is facing increasingly critical challenges in using and managing its water resources in a sustainable way. In addition to environmental threats including climate change, water resources in Africa are threatened by the growing population, rapid urbanization and economic development. Pollution of both surface and groundwater resources in Africa has been increasing from insufficiently treated, raw domestic and industrial effluents and agricultural runoff [UNESCO, 2011]. Due to climate change and variability and the growing population rates, it is estimated that by the year 2025 the situation will worsen: “14 African countries will suffer water scarcity while 11 of the countries will suffer water stress” [Africa Water Vision for 2025].

Kenya is one of the African countries grossly affected by the water quality and scarcity challenges. Currently, the country is categorized as a chronically water scarce country [World Bank, 2009], with a per capita water supply of less than 647 m^3/person per year [Olago, 2009], compared to the Global benchmark of 1,000 m^3/person per year [Onjala, 2002]. Further statistics project a drop to 235 m^3 per person per year by 2025 [Africa Water Vision for 2025]. Water quality poses an equally great challenge as water quantity. Out of the total population of 38.6 million, urban population constitutes 32.3% whereas 67.7% constitutes rural population. It is estimated that only 13.4% of the rural population and 38.4% of the urban population have access to piped water. More than 86% of the rural communities have no access to treated water [WHO and UNICEF 2010]. This clearly indicates that there is a water crisis in the country.

The constitution of Kenya Article 43(1) (d) also acknowledges the utmost importance of clean and safe water to a nation. In fact this article categorically states that adequate clean safe drinking water is a human right and as with other human rights, it should not be violated. Since no legislative framework has been put to place on how to deliver this basic right, then this remains to be a sweet dream yet to be achieved and in worst case scenario just a fantasy. The WHO report by Prüss *et al*., (2008) clearly demonstrates that water, sanitation and hygiene cause more deaths in Kenya than malaria and other MDG diseases. Increased investment in water would serve the interest of all as well as meet the constitutional requirement and the rights to water and sanitation (Rodrigues *et al*., 2014).

1.2 General quality of drinking water sources in Kenya

Majority of the rural population rely on surface and ground water for domestic use. Most of these sources are contaminated by both microbial and chemical contaminants. Studies conducted recently on the microbial quality of surface water in Nairobi River and the adjacent River Athi indicated that the waters were highly contaminated with human pathogenic bacteria. The most dominant bacteria in combined waters of the two rivers were *Escherichia coli* (100 ± 26 CFU/ml) while the least was *Shigella flexneri* (0.12± 0.12 CFU/ml). Other bacteria that were identified in the water were *Klebsiella aerogenes* (74±18 CFU/ml), *Enterococcus faecalis* (36± 32 CFU/ml), *Salmonella typhi* (21±13 CFU/ml), *Pseudomonas aeruginosa* (6.5 ± 1.1 CFU/ml), *Salmonella paratyphi* (0.16 ±0.11 CFU/ml), and *Vibrio cholerae* (5.6 ± 1.0 CFU/ml), (Musyoki *et al*., 2013). A study on River Awach in

Western Kenya recorded high level of *E.coli* contamination with the mean values ranging between 12.33 CFU/ml and 48.66 CFU/ml (Okoko *et al*., 2012). River Sabaki has also been reported to have high levels of nitrates with a mean concentration of 5.133 mg/l (Ongore *et. al*., 2013). Anthropogenic activities have been reported to be another cause contributing to poor quality surface water. Anyona and others (2014) investigated the effects of the anthropogenic activities on surface water and reported that they contributed to heavy loads of nutrients and microbial loads along the Amala and Nyangores tributaries of the Mara River in Kenya.

1.3 Problem Statement

Most people especially in the rural communities do not have access to quality water. The high cost of treated water makes them resort to readily available sources which are normally of low quality exposing them to waterborne diseases. One of the targets of the MDG goals was to reduce by 50% by the year 2015 the proportion of people without access to safe water. However, Kenya and other developing countries still lags much behind in provision of improved water especially to rural communities.

The lack of access to piped water has sparked interventions into alternative Point Of Use (POU) technologies, (Sobsey, 2002).Various POU methods such as filtration, Solar Disinfection (SODIS), biocoagulation, chlorination, and flocculation have been extensively studied and reported. However, these methods have their limitations. For instance, Chlorine is known to produce trichloromethane, a cancer precursor [Yongabi, 2004] while Aluminium sulphate, a common flocculant has been linked to Alzheimer's disease [Zhang *et al*., 2006]. Furthermore, the cost of purchasing synthetic coagulants and disinfectants is high leading to high pricing for treated water in Africa [Kebreab *et al*., 2005]. Among the extensive studies done on biocoaggulants, *M. oleifera* has been reported to have high disinfectant abilities. But, it is not 100% effective in removal of microbiological pollutants thus cannot be relied on to eliminate waterborne diseases. Filtration, another POU has not been found to have any side effects but, some filtration systems are not cost effective and cannot be advocated as the solution to the water quality challenge in developing countries. Some of the filtrations systems that can be prepared within a local community such as ceramic, sand and bone char filtration among others could be the solution to the problem.

1. 4 Objectives

1.4.1 General objective

To develop a Point Of Use water treatment system using clay, sawdust and *Moringa oleifera* seeds.

1.4.2 Specific objectives

1. Characterise the clay to be used.
2. Develop filters using different ratios by volume of plant powder and clay.
3. Test the water purification capacities of the filters and their flow rates.
4. Investigate the biocoagulant and disinfectant capacities of *M. oleifera* seeds.

1.5 Justification

Access to clean drinking water is of paramount importance to every community. Safe water is a key resource in all forms of human development (social, cultural, economic etc). Communities in rural Kenya mostly rely on surface water that has been reported to be contaminated with microbial, pesticides, heavy metals, nutrients among other contaminants. There is therefore need to treat the water before consumption. However, the current technologies in water treatment are not cost effective and have therefore not helped in reducing mortalities related to consumption of low quality water. Chlorination which is a major POU method of water treatment system employed in this area may produce by products which are carcinogenic. Chlorination also does not address the turbidity issue which is a major problem in most parts of the country. A cost effective system that addresses both the microbial and turbidity challenges among other threats to quality drinking water should be sought. It is in this light that this research was carried out to investigate the effectiveness of ceramic (fired clay) filters and biocoaguant and disinfectant abilities of *M. oleifera* seeds as a cost effective method of accessing safe water in the rural communities. This is in line with the vision 2030 for Water and Sanitation which is to ensure that improved water and sanitation are available and accessible to all. As a result it will reduce health inequalities and improve key areas where Kenya is lagging behind, especially in lowering mortality rates in accordance with The Kenya Vision 2030.

Furthermore since ceramic filters can be crafted by local ceramists and most of the materials required for filters are available locally, ceramic water filtration will provide local economic opportunities thus empowering the rural population financially.

1.6 Hypothesis

The clay filters prepared would improve the quality of drinking water by eliminating/lowering the selected water contaminants. Varying the ratio of the clay- sawdust used would result in different flowrates.

The dried ground *Moringa oleifera* seeds would also lower the levels of selected water contaminants, and their performance would depend on the dosage value.

CHAPTER TWO

LITERATURE REVIEW

2.1 Selected water variables

Quality drinking water is determined by the levels of some physico-chemical, chemical, and microbial parameters in the water. The levels determine how safe the water is for consumption and the best treatment option to be employed. A few examples from the three categories are discussed.

2.1.1 Physico-chemical parameters

pH

pH is obtained as the logarithm of the reciprocal of hydrogen ions. It is a measure of the acidity or alkalinity of water and it is usually measured using a colorimetric test - litmus paper changes colour with increased acidity or alkalinity. For a numeric value of the pH, a pH meter which has a range of 0-14 is used [Hui and Sherkat, 2005]. KEBS recommend a pH range of 6.5 – 8 for drinking water.

Turbidity

Turbidity is a measure of the degree to which water loses its transparency due to the presence of suspended particulates. The more total suspended solids in the water, the murkier it seems and the higher the turbidity [Perissinotto *et al*., 2013] . It is determined using a turbid meter and the common units are NTU. Both KEBS and WHO establish that the turbidity of drinking water should not be more than 5 NTU, and should ideally be less than 1 NTU.

Total Suspended Substances (TSS)

This indicates the particles in water that never settles but remains suspended [USEPA 2012]. TSS is determined by filtering a known amount of the water sample through an accurately weighed piece of filter paper. The filter paper is dried completely and reweighed. The change in weight is the amount of the total suspended solids and it is commonly expressed in ppm (mg solids per litre of water). USEPA gives a limit value of 30 ppm for quality drinking water while KEBs recommend that quality drinking water should have nil suspended matter.

Total Dissolved Solids (TDS)

TDS refer to any minerals, salts, metals, cations or anions dissolved in water. This includes anything present in water other than the pure water (H_2O) molecule and suspended solids [Spellman R. 2008]. In general, the total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) ions in the water. A maximum contamination level (MCL) of 500 mg/litre (500 parts per million (ppm)) for TDS is the ideal value as per EPA Secondary Regulations. However, WHO and KEBS recommend TDS maximum limits of upto 1000 and 1,500 mg/l respectively.

Conductivity

Conductivity is a measurement of the ability of an aqueous solution to carry an electrical current due to the presence of inorganic dissolved ions. Conductivity measurements are taken in water quality to determine the general mineralization which give an indication of the Total Dissolved Substances (TDS). High level of TDS may cause mineral taste in water. It is determined using a conductivity meter and the basic unit of measurement is the mho or siemens. Conductivity is expressed as micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µs/cm). Drinking water should have an electrical conductivity of 50 – 500 µs /cm, (APHA 1992).

Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acids due to the presence of alkaline compounds in the water such as bicarbonates, carbonates, and hydroxides. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. Total alkalinity is determined by measuring the amount of acid needed to bring the sample to a pH of 4.2. At this pH all the alkaline compounds in the sample are "used up." The result is reported as milligrams per litre of calcium carbonate (mg/l $CaCO_3$) (APHA 1992). .

2.1.2 Microbial contaminants

The contamination of drinking water by pathogens causing diarrhoeal diseases is another important aspect of drinking water quality. The problem arises as a consequence of contamination of water by faecal matter, particularly human faecal matter, containing pathogenic organisms. Testing of microbial drinking-water quality is usually limited to that of indicator organisms since testing for pathogens is complex and expensive. The most common indicators are total coliform bacteria, faecal coliform bacteria and *Escherichia coli*

(*E.coli*) [Rahel K., 2011]. According to the World Health Organization (WHO) drinking-water guideline (2008), bacterial indicator of faecal pollution should fulfil the following criteria:

- be associated with disease-causing organisms, but not be pathogen themselves
- be universally present in faeces of humans and animals in large numbers
- not multiply in natural waters
- persist in water in a similar manner to faecal pathogens
- respond to treatment processes in a similar fashion as faecal pathogens
- be easily, reliably and cheaply detectable.

In many parts of the developing world feacal contamination of drinking water remains a major cause of disease [Fawell and Nieuwenhuijsen, 2012]. Both WHO and KEBS recommend that drinking water should contain zero *E. coli* for every 100 ml sampled.

3M Petrifilm *E. coli* plates

The 3M Petrifilm *E. coli* kits could be used to monitor the presence of the *E. coli*. The Count plates contain violet red bile nutrients, a cold water soluble gelling agent, a glucuronidase indicator to identify *E. coli*, and a tetrazolium indicator to enhance the visualization of other Coliforms bacteria. Coliforms ferment the lactose in the medium to produce gas. This gas is trapped around the Coliforms colony and allows the differentiation of Coliforms bacteria from other gram negative bacteria. In addition, glucuronidate, produced by most *E. coli* will react with the glucuronidase indicator in the medium to produce a blue precipitate around the colony allowing visual identification of *E. coli*. Blue colonies associated with entrapped gas are confirmed as *E. coli* while blue colonies without gas bubbles are not counted as *E. coil*. Other Coliforms colonies will be red and associated with gas bubbles. Colonies not associated with gas (with a distance greater than one colony diameter from gas bubble) are not counted as Coliforms. The total Coliforms count consists of both the red and blue colonies associated with gas at 24 hours, (Watterworth and Schraft, 2005).

2.1.3 Nitrates and Nitrites

Nitrates and nitrites are nitrogen-oxygen chemical units which combine with various organic and inorganic compounds. They are well-known contaminants of ground and stream water and important environmental and human health analyte, and thus their detection and quantification are considered to be essential. The major sources of nitrates and nitrites in

drinking water include runoff from fertilizer use, sewage, and erosion of natural deposits. Nitrogen is an important parameter to monitor. Excessive amounts of nitrate or nitrite in water can cause methemoglobinaemia (blue baby syndrome) which can potentially be fatal [Fan and Steinberg, 1996]. These contaminants can also cause adult illness and produce spontaneous miscarriage in cows. KEBS recommended limit for nitrates is 10 mg/l and 1 mg/l for nitrites.

Determination of these ions mostly involves complexation with other compounds to form colored complexes that can be analysed spectrophotometrically.

Nitrates

The USEPA approved Brucine method (Method 352.1) is one of the method that can be used to determine the concentration of nitrates ions in water. The method is based upon the reaction of the nitrate ion with brucine sulphate [$(C_{23}H_{26}N_2O_4)_2$ $H_2SO_4.7H_2O$] in an acidic medium at a temperature of 100°C resulting in a yellow complex that is analysed at 410 nm.

Nitrites

One of the methods that can be used to determine the concentration of nitrites is the Griess reaction. The reaction involves the formation of a diazonium salt by reacting nitrites ions with sulphanilamide. The diazonium salt is then reacted with N-alpha-naphthyl-ethylenediamine (NEDA) to form a pink complex that is analysed via UV-Vis at 540nm.

2.1.4 Lead and Copper

Lead

Lead is a highly toxic metal found in small amounts in the earth's crust. Because of its abundance, low cost, and physical properties, lead and lead compounds have been used in a wide variety of products including paint, ceramics, pipes, solders, gasoline, batteries, and cosmetics [NHIES, 2012]. Lead, like all other heavy metals such as Cadmium (Cd), Chromium (Cr) and Copper (Cu) occur naturally in water, soil and biota. Their concentrations depend on local geology, local addition from mining and industry and /or globally distributed pollution [Okoth *et al*., 2010].

While extreme lead exposure can cause a variety of neurological disorders such as lack of muscular coordination, convulsions and coma, much lower lead levels have been associated with measurable changes in children's mental development and behaviour. These include

hyperactivity; deficits in fine motor function, hand-eye coordination, and reaction time; and lowered performance on intelligence tests. Chronic lead exposure in adults can result in increased blood pressure, decreased fertility, cataracts, nerve disorders, muscle and joint pain, and memory or concentration problems [NHIES, 2012]. Drinking water should not contain more than 0.05 mg/l of lead metal as per the KEBS guidelines.

Copper

Copper is a metal found in natural deposits such as ores containing other elements. It has many practical uses in our society and is commonly found in coins, electrical wiring, and pipes. It is an essential element for living organisms, including humans, and-in small amounts-necessary in our diet to ensure good health. However, too much copper can cause adverse health effects, including vomiting, diarrhea, stomach cramps, and nausea. It has also been associated with liver damage and kidney disease (USEPA, 1991). These many sources coupled with the common nutritional deficiencies in Zinc, Manganese and other trace minerals that keep levels of Copper from getting too high can lead to elevated levels of copper in our bodies. KEBS maximum permissible limit in drinking water is 0.1 mg/l.

2.2 Point Of Use Water Treatment Systems

In most developing countries, high quality piped water for households is still years away for many of the citizens. The lack of access to this water has sparked interventions into alternative Point Of Use (POU) technologies [Sobsey, 2002]. With these types of technologies, water for consumption is treated at household levels thus each household is responsible for the quality of the water they consume. When used correctly POU systems reduce the risks of recontamination and have been reported to reduce the risks of waterborne diseases. The other advantage is that POU do not require significant start-up capital and can therefore be afforded by the majority of people living in developing countries [Simonis and Basson, 2011]. Four POU have been commonly employed in treating water and are described below.

2.2.1 Chlorination

Chlorination is the most common disinfection POU applied. Chlorine treatment mainly consists of adding dilute sodium hypochlorite solution to the water to be treated. Other forms such as chlorinating chemicals such as calcium hypochlorite (tablets or granules) can be used. Each of these forms produces free chlorine that attack pathogenic microorganisms that cause

such illnesses as typhoid fever, dysentery, cholera, and gastroenteritis. It is effective against many pathogenic bacteria, but at normal dosage rates it does not kill all viruses, cysts, or worms. To treat water, 1ml solution per every litre of contaminated water is added to the water, and the users must wait 30 minutes prior to consuming the treated water. As a POU option it eliminates the majority of waterborne pathogens and can limit in-home contamination through the persistence of free chlorine in stored water. It is promoted by the World Health Organization (WHO) and the United States Centers for Disease Control and Prevention (CDC) for household water treatment, and comprises the most common form of water treatment, after boiling, in areas lacking clean piped water [Rosa and Clasen, 2010].

This method costs anywhere between 0.01-0.05 US cents per litre of water and generally has high user acceptance rates in people who do not object to the slight chemical taste and odor. Diarrhoeal reductions in users range from 22% to 84%. For high turbid water, a pre-filtration treatment would be required for the chlorination to be effective (Levy *et al*., 2014) and therefore this treatment method is not ideal for people living in rural areas, since most of them rely on surface water that is turbid. In addition, chlorine has been reported to have the potential of forming carcinogenic and mutagenic disinfection by-products (DBPs) (Bichi *et. al*., 2012).

2.2.2 Solar disinfection (SODIS)

SODIS disinfection requires sunlight and a plastic bottle (Figure 2). The bottles are filled with water, shaken to oxygenate the water, and placed in the sun for at least six hours on a sunny day or longer on cloudy day [CDC, 2008b]. Increased temperatures, UV light, and oxidative chemistry inactivate most bacteria, viruses, and protozoa. SODIS uses two components of the sunlight for the water disinfection. The first, UV-A radiation has a germicidal effect. The second component, infrared radiation, raises the water temperature and is known as pasteurisation when the water temperature is raised to 70°C- 75°C. The combined use of both UV radiation and heat produce a synergetic effect enhancing the efficiency of the process. The only cost for this treatment method is that of the plastic bottle. Reductions in diarrhoea vary between 9% and 86%. Although the treatment process is simple, users may be unsatisfied with the limited quantity of water produced and length of time necessary to treat water. SODIS disinfection is not effective with highly turbid water unless it is pretreated (SANDEC, 2002).

Figure 2. A sodis experiment set up

Source: www.The Water Climb 2012.com/ The Water School accessed on 28th Aug- 2014.

2.2.3 Coagulation

During the coagulation process, coagulants are added to the water to aid in floc formation. Coagulants act by reducing or eliminating the charged particles that are normally discharged in water causing turbidity. These particles then come together first forming small groups, then larger aggregates and finally into visible floc particles which settle rapidly and can be filtered out easily, (Louis R, 1993).

The major coagulant employed is Aluminium sulphate commonly referred to as Alum.

Alum

Alum is an aluminium sulphate salt with the chemical formula $Al_2(SO_4)_3.18H_2O$. It is a common chemical coagulant used in treating water. When added to water, hydrous oxides of aluminum are formed. The simplest of these is aluminum hydroxide ($Al(OH)_3$) which is an insoluble precipitate. The hydroxides are formed as a result of a chemical reaction between alum and bicarbonates as illustrated in equation 2.1

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 + 6H_2O \rightarrow 3CaSO_4 + 2Al(OH)_3 + 6H_2CO_3 \qquad \textbf{Equation 2.1}$$

Other positively charged hydroxides that are soluble are also formed:

i. $Al_6(OH)_{15}^{+3}$
ii. $Al_7(OH)_{17}^{+4}$
iii. $Al_8(OH)_{20}^{+4}$ (Louis R, 1993).

The mechanism of coagulation by alum includes both charge neutralization and sweep floc. The complex, positively charged hydroxides of aluminium that rapidly form will adsorb to the surface of the negative turbidity particles, neutralizing their charge. Simultaneously, aluminium hydroxide precipitates formed enhance the rate of flocculation by increasing the chances of a collision occurring. The precipitate also grows independently of the colloid population, enmeshing colloids in the sweep floc mode and dragging colloids down with them.

The carbonic acid formed as a by-product lead to lowered pH values and therefore a base must be added to adjust it the allowed pH values for drinking water.

2.2.4 Filtration

A number of low cost filters have been in use in most developing countries. They vary in the type of materials they are made from thus varying in the performances. Some are developed to generally improve the quality of water while others are developed to remove specific contaminants. Examples of general filters are the sand filter and the ceramic filter while specific filters are the Arsenic and the Fluoride filters made of Iron oxide and bone char respectively.

Bone char filter

Bone char filters are prepared by charring of bones. The charring can basically be done in two ways: As calcinations where bones are heated in the presence of continuous supply of oxygen from the atmospheric air or as pyrolysis where no oxygen is present during the heating. In calcination the organic carbon is converted to CO_2 that is stripped off while in pyrolysis the organic carbon is converted to inorganic carbon that remains in the bone char. Pyrolysed bones are therefore always totally black while calcined bones are brown -grey - white, depending of the access of oxygen and thereby degree of charring (Dahi and Bregnhøj, 1995). Pyrolysis is much more fuel demanding and therefore more expensive.

The bone char consists primarily of apatite II (hydroxyapatite) ($Ca_{10}(PO_4)_6(OH)_2$) and approximately 10% elemental carbon with some carbonate arising from the formation of CaO during the ashing process and subsequent reaction with atmospheric CO_2.

Uptake of contaminants can occur via three processes. Firstly, species can become incorporated within the hydroxyapatite lattice substituting for Ca or CO_3. Secondly, species can interact with reactive groups on the surface of either carbon or hydroxyapatite

(Physisorption and Chemisorption). Lastly free phosphate can form stable compounds with contaminates leading to their precipitation.

The bone char filters are highly effective in removal of fluoride and heavy metals. Korir and others (2009) reported that the filters could lower fluoride concentrations from 6 mg/l in distilled water and 6.2 mg/l in the Kenyan groundwater to below 0.1 mg/l. This type of filter is therefore ideal for fluoride removal. However, a few cultural issues are associated with it and some communities and individuals are hesitant about using something derived from bones.

2.3 Ceramic Water Filtration

Ceramic filtration which is a form of POU method of water treatment is the use of porous ceramic to filter microbes or other contaminants from drinking water. Ceramic filters generally consist of a porous ceramic membrane, a plastic or ceramic receptacle, and a plastic tap. Water is poured into the upper portion of the receptacle, or directly into the membrane, where gravity pulls it through the pores in the ceramic and into the lower portion of the receptacle. Water is safely stored in the receptacle until it is accessed through the tap (CDC 2008a). Sobsey (2002) reports that out of 37 water treatment options, ceramic water filters (CWF) proved to be one of the five best treatment options available for reducing turbidity and bacteria by more than 99%. In developing countries household-scale ceramic filters are being used as a better treatment option for both unpurified and insufficiently disinfected water in households (Lantagne, 2001; Clasen and Boisson, 2006).This method has proven to be effective as a household water treatment procedure that is cost effective [WSP and UNICEF, 2007]. Use of ceramic filters is becoming widespread, especially with involvement of governments and international NGO efforts (Simonis and Basson, 2011).

Ceramic filters are made of clay mixed with water and a combustible material, like sawdust and then fired. The physical make up of filter is a simple one – filtration material enclosed inside a plastic casing. Firing burns out the sawdust leaving out tiny pores that allow water molecules to pass through but retain other particles. The pore size and flow rate of these filters varies depending on the size of combustible material used in the mixture [Sobsey *et al*., 2008]. The pores can be made small enough to remove virtually all bacteria and protozoa by size exclusion, down to 0.2μm, in the range referred to as microfiltration. Small-scale ceramic filtration has a long history, having been used in various forms since antiquity [Sobsey 2002].

Millions of these porous clay ceramic filters are in use in several countries in African, Asian, and South American continents [Plappally *et al*. 2009]. In Tanzania a non-governmental organization Safe Water Ceramic for East Africa (SWCEA) has been established to explore the unique ability of clay to purify water. SWCEA uses the ceramicist's craftsmanship to create water filtration systems that are affordable to the communities [Lemons A., 2009].

Studies on performance of clay ceramic filters in Bolivia conducted under the non-governmental organization Food for the Hungry International showed a decrease in the cases of diarrhea by around 45% [Clasen *et al*., 2006]. In some studies conducted recently, ceramic filters and biosand filters were found to best fit the sustainability criteria in the field with consumers [Sobsey *et al*., 2008].

Porous ceramics are marked by a high level of porosity. This results in properties such as high specific area, high permeability and high tortuosity. Pore size can be made to submicron sizes, making porous filters dependable in the removal of suspended solids, pathogenic bacteria and other organisms in drinking water, (Simonis and Basson, 2011). From figure 3, the pore size of filter is big enough to allow water molecules to pass through while small enough to restrain bacteria and other suspended particles.

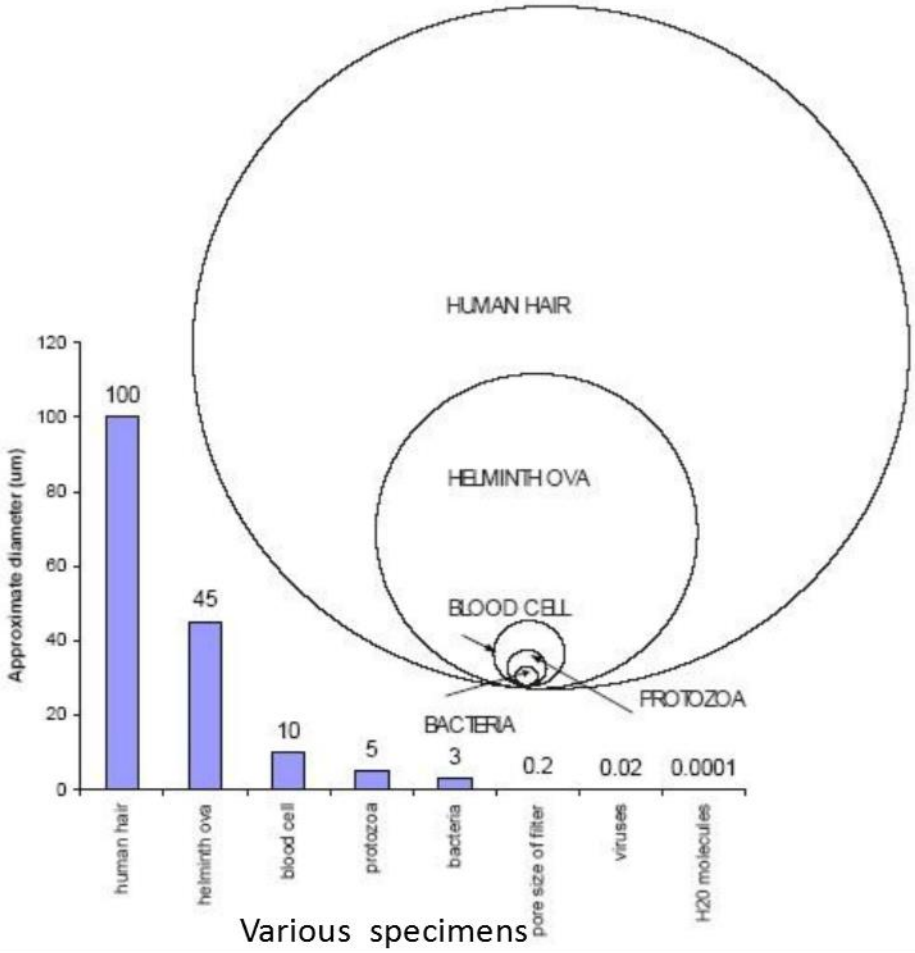


Figure 3. Relative sizes of cells, water molecule, filter's pores and microorganisms

Source: Brown J., 2003

Table 1 shows the laboratory and field effectiveness of various filters that have been studied. The effectiveness has been reported either as Log Reduction Value (LRV) or percentage efficiency. The LRV is calculated as

$$LRV=\text{Log}\,(N°/N) \qquad \textbf{Equation 2.2}$$ [Simonis and Basson (2012)]

Where N° is the initial coliforms count (CFUs/ml) and

N is the residue coliforms count (CFUs/ml) after filtration.

Table 1. Summary of laboratory and field effectiveness of low cost ceramic filters

Microbial contaminant	**Reduction**	
	%	**LRV (log_{10})**
Escherichia coli	88-100	3-6.8
Total coliforms	94-99.9	
Giardia lamblia		4.6
Cryptosporidium parvum		4.3
Viruses	20-90	
Bacteriophages MS2	90-99	1.2-4.1
Clostridium spores		3.3-4.9

Source: Simonis and Basson (2012)

Note:

The Log Reduction Values (LRV) can be converted to Percentage efficiency by using the conversion factors below.

1 LRV = 90% reduction, 2 LRV = 99%, 3 LRV = 99.9%, 4 LRV = 99.99%, 5 LRV = 99.999% and 6 LRV = 99.9999%. (Simonis and Basson, 2012).

The ceramic filters have the advantages of being light, portable, relatively inexpensive, and chemical free, low-maintenance, effective, and easy to use. The filters provide for removal of microorganisms from water by gravity filtration through porous ceramics, with typical flow rates of 1-3 litres per hour. They cool the treated water through evapotranspiration and, used with a proper storage receptacle, safely store water for use. There are no significant taste issues, as have been the case with chlorine-based disinfection [Clasen *et al*. 2006].

2.3.1 Forming Process

The three common processes used to form filters are pressing, slip casting and throwing. (Hbalze and Gaukler, 2003). Each fabrication method results in a specific range of pore size distribution, porosity, as well as varying levels of interconnectedness among the pores (Dobrovolskiy, 1977). The amount, size and shape of defects in the ceramic are also dependent on the processing method used.

Slip casting

Slip casting is a method for powder-based shaping of ceramic components that has been used for a long time in the traditional ceramic industry for the manufacture of tableware and sanitaryware. It is occasionally also used in the manufacture of advanced (technical) ceramics (Somiya, 2003). Slip casting is a filtration process, in which a powder suspension – usually a water-based suspension – is poured into a plaster mould, which by its porosity creates capillary forces and removes liquid from the suspension (slip). When the liquid (filtrate) is sucked into the plaster mould, the powder particles are forced towards the mould walls and a consolidated layer (filter cake) is gradually built up. When a desirable layer thickness has been obtained, the casting process is stopped either by having the excess slip removed, or by letting the casting fronts approach each other in the centre of the piece to form a solid body. After a certain period of drying the shaped piece is released from the mould for further drying and firing (sintering) [Kartavya J., 2007].

Pressing

This method involves forming the wet clay mould into cubes and then pressing the cubes to filters using a hydraulic press. The press could either be manually or electrically operated and it consists of a ‘female’ and ‘male’ part. The hydraulic press incorporates a fixed plate in the bottom mold which pushes the pressed filter element out as the mould opens up. The end product determines the type of moulds to be incorporated [WSP and UNICEF, 2007]. Figure 4 shows an example of a hydraulic press that can be used to make frustum shaped ceramic filters.

Figure 4. A hydraulic press for making frustum shaped filters

Source: WSP and UNICEF, 2007

Throwing

This is an ancient method that was developed in southern Iraq (Mesopotamia) at around 3rd Millennium BC, (Bryan V, 2014). The method requires a potter's wheel that could either be manually or electrically operated. The mould of clay is placed on the potter's bat which is a flat circular plane. The mould is then shaped into the desired shape with the hands while one foot regulate the rotation speed of the wheel. A typical potter's wheel is illustrated in figure 5.

Figure 5. A potter's wheel

Source: Jane Macharia, 2014

2.3.2 Types of ceramic filters

The two common methods of the ceramic filter media are the candle and the pot as illustrated in figure 6.

a)

b)

Figure 6. A ceramic candle (a) and a frustum shaped ceramic filter (b) with its reservoir bucket

Source:potterswithoutborders.com –accessed on 28th Aug-2014

The two filters differ in the shape and assemblage of the ceramic membrane (figure 6). Candle filter systems consist of an upper receptacle that sits above, and is separated from the storage receptacle. Candle elements, which are cylindrical, hollow ceramic membranes, are attached to the barrier that divides the two receptacles. The only way in which water can flow into the lower receptacle is if it enters the candle elements, where filtration takes place. The pot filter system is simpler, and consists of a single concave membrane, which sits inside the rim of the receptacle [Klarman M, 2009].

a) b)

Figure 7. The candle (a) and pot (b) filters in their receptacles

Source: www.potterswithoutboarders.com accessed on 28th Aug. 2014

A ceramic candle filter with pore size of 0.2–0.5 μm has been used for drinking water treatment by Mwabi *et al*., (2011). It can remove pathogenic bacteria (98% *Escherichia coli*, 99% *Vibrio cholera*, 98% *Salmonella typhimurium* and 99% *Shigella dysenteriae*, [Mopoung *et al*., 2014].

2.4 Biocoagulants

Native plants have traditionally been used to improve quality of water in many countries in Africa and Latin America. It has been reported that dried beans (*Vicia fave)* and peach seeds (*Percica vulgaris*) have been used in Bolivia and other countries in water treatment. Similarly, *Schoenoplectus tatora*, an aquatic plant has been used in Bolivia and Peru for Water Quality improvement [Miller *et al*., 2008]. Biocoagulants from *Moringa oleifera*, *Jatropha curcas*, calyx of *Hibiscus sabdarifa*, sclerotium of *Pleurotus tuberregium* have been reported to show good coagulation activity too [Yongabi *et al.*, 2011].

2.4.1 Moringa oleifera

Moringa oleifera is the most widely cultivated species of a monogeneric family, the Moringaceae. It is a perennial softwood tree with timber of low quality, but which for centuries has been advocated for traditional medicinal and industrial uses. It is already an

important crop in India, Ethiopia, the Philippines and Sudan, and is being grown in West, East and South Africa, tropical Asia, Latin America, the Caribbean, Florida and the Pacific Islands. Figure 8 illustrates the *M. oleifera* plant, its seeds ponds and the seeds before and after grinding.

Figure 8. The *M. oleifera* plant, its seed ponds and seeds before shelling and after shelling and grinding.

Source: Pritchard *et al*., 2010-b

The plant's agroforestry is increasingly being adopted by farmers in Kenya particularly in Mombasa, Kilifi, Baringo and Laikipia. All parts of the M. oleifera tree are edible and have long been consumed by humans [Fahey J. W., 2005]. The Moringa tree, sometimes referred to as the Indian miracle tree or Mother's best friend, has long been known to offer amazing health benefits in its own right. Its leaves contain four times the Vitamin A of carrots, four times the calcium in milk, more iron than spinach, seven times as much vitamin C as oranges and three times the potassium in bananas, as well as more protein than either milk or eggs [Price M., 1985]. But its use as a water purifier amounts to a new bonus again from one of the world's most extraordinary trees. The seed kernels of *M. oleifera* contain significant quantities of low molecular-weight (water-soluble proteins) that carry a positive charge.

When the crushed seeds are added to raw water, the proteins produce positive charges acting like magnets and attracting the predominantly negatively charged particles (such as clay, silt, bacteria, and other toxic particles in water) [Sutherland *et al*., 1990]. Since bacteria in water are generally attached to solid particles, treatment with *Moringa* powder can leave water clear with 90 to 99% of the bacteria removed [Bukar *et al.*, 2010].

Interest in isolating and purifying bioactive *M. oleifera* coagulant ingredient has grown and outweighed efforts on taking inventory of other potential plant coagulants and disinfectants. Plant disinfectants provide useful insight for the production of natural disinfectants and coagulants which are environment friendly and with much reduced risk of handling [Yongabi *et al*., 2011]. These coagulants unlike the commercial coagulants do not pose any environmental risk since they are biodegradable.

The coagulative effect of *M. oleifera* seeds has been reported to be even better than Alum since *M. oleifera* seeds exhibited strong antimicrobial activity. [Yongabi *et al*., 2011]. In addition alum lowers the pH of the treated water and may cause stomach ulcers to those consuming such water. *M. oleifera* extract is not known to lower or raise the pH of the water by a significant value and it is therefore a better coagulant than alum [Arama *et al*., 2011]. The use of the plant in the treatment of drinking water has been known in a number of countries with reports of some using two grams of the crushed seeds to treat 20 L of water and obtaining about 90% reduction in turbidity and particles removal [Yongabi *et al*., 2011]. In Tanzania, water purification using this biocoagulant and disinfectant has been applied. The country has developed a procedure, which allows the large scale production of protein extracts from the seeds and press-cake of *M. oleifera* to evaluate its purified seed protein extracts as a potential substitute for inorganic coagulants used in water treatment processes [Schneider *et al*., 2006]. Studies carried out in Nyatike district of Nyanza province in Kenya have shown that both water soluble and ethanol soluble extract of *M. oleifera* seeds have activity against *E. coli*, the most common faecal water contaminant [Arama *et al*., 2011]. Locally the plant's biocoagulant activity has been utilised. For instance a group of women from Kirinyaga district of Central Kenya purify water with the seed kennel for their domestic use and for other people at a fee. The purification process involves grinding *M. oleifera* seeds into a paste, mixing that paste with untreated water, waiting for the paste particles to bind with the impurities and settle to the bottom, and then decanting or siphoning the pure water off the top [FarmbizAfrica 2014].

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials Collection

a) *Moringa oleifera* seeds

M. oleifera seeds were obtained from the International Centre for Research in Agroforestry (ICRAF) in Nairobi and dried under shade for two weeks. The seeds kennels were removed using a scalpel and the seeds further dried for five days. These dried seeds were ground and sieved with a 425 µM sieve to obtain fine powder. The powder was stored in brown paper bags ready for use.

b) Clay

Clay was obtained from the department of fine Arts at Kenyatta University. It was dried under shade for ten days, then ground manually to obtain fine powder. The powder was sieved with a 425 µM sieve to obtain fine powder and stored in paper bags ready for use. The powder was characterized using XRF to obtain the mineralogy composition.

c) *M. oleifera* powder and local sawdust powder

M. oleifera stems were obtained from Maseno University, Kenya and used to prepare *M. oleifera* powder after drying them under shade for three weeks. Local sawdust was purchased from industrial area in Nairobi and dried under shade for a week. Fine powder was prepared by grinding each type of plant material separately using a manual mill and sieving it through a 425 µM sieve.

d) Water

Water samples for microbial and physicochemical parameters experiments were collected by grab method into 2.5 litres amber glass bottles that were previously washed with detergent and rinsed thoroughly with distilled water. Sampling was done at Nairobi river at the Chiromo bridge (coordinates 1º 16.27’ S, 36º 48.436’ E and elevation 1711m). Sampling was done against the flow to obtain a representative sample. The samples were immediately analyzed on arrival to the laboratory.

3.2 Chemicals and Instruments

Chemicals

All chemicals used in this work were of analytical grade

Nitric acid and sodium hydroxide of 65% and 96.0% purity respectively sourced from UNI-CHEM®, Sulphuric acid and Hydrochloric acid of 95% and 37% purity respectively sourced from Panreac Quimica, Sulphanilamide and sulphanilic acid of 99.0% purity sourced from Panreac Quimica, Brucine sulphate and N-(1-napthyl) ethylenediamine dihydrochloride (NEDA) of 98% purity sourced from Loba Chemie and Panreac Quimica respectively, Potassium nitrate and sodium nitrite of of 99% purity from Loba Chemie chemicals, Sodium acetate of 99.0% purity sourced from UNI-CHEM, Lead Nitrate and copper metal both of 99.5% purity sourced from BDH chemicals, 95% HPLC grade hexane from Sigma Aldrich, Salifert Alkalinity kit, 3M Petrifilm *E.coli* Coliform count plates from 3M Microbiology products, U.S.A.

Instruments

AAS-SpectraAA.10, Philips Minipal2 XRF from Shimadzu, Furnace, Potter's wheel, Uv-Vis spectrophotometer 1700 from Shimadzu, pH meter model IQ 150pH Meter from Scientific Instruments, An Mi 306 Conductivity/TDS/Nacl/Temp meter from Martini instruments, Mini orbital shaker model S05 from Stuart Scientific, Turbidity meter model LaMotte TC-3000e Tri-Meters, Oven, Incubator- DNP-9022 A, Manual mill.

3.3 Stock solutions, Standards and Complexing Reagents preparation

All standards and reagents were prepared using distilled water.

KNO_3 stock solution

1000mg/l stock solution of NO_3^- ions was prepared by dissolving 0.1690g of anhydrous KNO_3 salt in water and topping it up to 100 ml. Prior to using the salt, a few grams were, dried in an oven at 105°C for 24 hours.

The KNO_3 working standard was prepared from this stock by diluting 10 ml of the stock to 1000ml. From this working standard, calibration standards of concentration 0.0, 0.1, 0.2, 0.3, 0.4, 0.6 and 1 mg/l were prepared.

$NaNO_2$ stock solution

1000mg/l stock solution of NO_2^- ions was prepared by dissolving 0.1500 g of $NaNO_2$ in water and topping it up to 100ml. A working standard of concentration 10mg/l was prepared from this stock by diluting 10 ml to 1000 ml. From this working standard calibration standards of 0.0, 0.02, 0.04, 0.08, 0.2 and 0.5 mg/l were prepared.

Nitrate complexing reagents

14 M H_2SO_4 was prepared by adding 500 ml concentrated H_2SO_4 to 125 ml of distilled water in a 1000 ml volumetric flask. The flask was then cooled and stoppered to prevent absorption of moisture. The nitrate complexing reagent was prepared by dissolving 1 g brucine sulphate $[(C_{23}H_{26}N_2O_4)_2\ H_2SO_4.7H_2O]$ and 0.1 g sulfanilic acid ($NH_2C_6H_4SO_3H.\ H_2O$) in 70 ml warm distilled water. 3 ml concentrated HCl acid was added to this solution and the mixture cooled and diluted to 100 ml with water.

Nitrite complexing reagents

The buffer color reagent was prepared by adding 52.5 ml of concentrated HCl acid to 125ml of distilled water in a 250 ml volumetric flask, 2.5 g of sulphanilamide and 0.25 g of NEDA. This was swirled until everything dissolved. 68 g of Sodium Acetate was added to this mixture and dissolved by swirling. The mixture was filled to the mark with distilled water.

Copper ions standards

500 mg/l stock solution of copper ions was prepared by reacting 0.5025g of copper metal with 2 mls concentrated nitric acid in a 1000ml volumetric flask. The solution was then topped up to the 1000ml mark. From this solution, calibration standards of 1, 2, 5 and 10 mg/l were prepared. Samples to be filtered through the ceramic filters were also prepared. The samples were of concentration 5, 10, 20, 50 and 100 mg/l.

Lead ions standards

A stock solution of 500mg/l lead ions was prepared by dissolving 0.8028g of lead nitrate in water in a 1000ml volumetric flask. The solution was then topped up to the mark. From this solution, calibration standards of 1, 5, 10 and 20 mg/l concentration of lead ions were prepared. Samples to be filtered through the filters of concentration 5, 10, 20, 50 and 100 mg/l were prepared too.

3. 4 Ceramic Filters preparation

a. **Clay- local sawdust filters**

Molds of clay were prepared on a clay- sawdust powder (C-S) volume ratio basis by mixing the clay and appropriate amount of sawdust powder with water. The wet molds were developed into frustum-shaped filters using a potter's wheel. Four ration i.e. 50:50, 55:45, 60:40 and 65:35 of clay to sawdust ration were selected and filters prepared from them in triplicates. These sample filters were dried under shade for five days. They were then fired by first preheating at 100 °C for two hours followed by sintering at 850°C for 8 hours.

Another set of filters was prepared in the same way but fired at 650°C.

b. Clay- *M. oleifera* (stem and seed husks) filters

Moulds of clay and *M. oleifera* stem and seed husks were prepared on clay: *M. oleifera* volume ratio. Three ration i.e. 55:45, 60-40, and 65-35 were selected and filters prepared in triplicate.

3.4.1 Determination of flow rates

The filters were first soaked in distilled water for one hour to get rid of any ashes that could be trapped in the pores and also to saturate the filters so as to ensure correct readings of the flow rates. To avoid clogging of the filters, distilled water was used to determine the flow rates. The distilled water was put into filters and the amount collected after five hours noted. An average was done to determine the flow rate per hour. This was done for the various categories of the filters prepared.

3.4.2 Filtration experiments

Water of known levels of contamination was passed through the filters and the filtrate collected in glass beakers for microbial, nitrates and nitrites ions and physicochemical parameters. For heavy metal analysis, the filtrate was collected into plastic containers.

3.5 Jar tests experiments

200 mls of the contaminated water was put in 250 mls conical flasks. Various amount of ground *M. oleifera* seeds powder ranging from 5 to 200 mg were added to the conical flasks. The flasks were shaken in an orbital shaker at 150 rpm for 4 minutes. This was followed by slow mixing at 50 rpm for ten minutes. A blank sample was treated in a similar way to act as a control. The conical flasks were then removed from the orbital shaker and left to stand on

the bench for one hour. At this point the measurements were taken for the various target contaminants to determine the coagulative effects and change in Coliforms loads. Figure 9 shows the setup for the water samples in an orbital shaker.

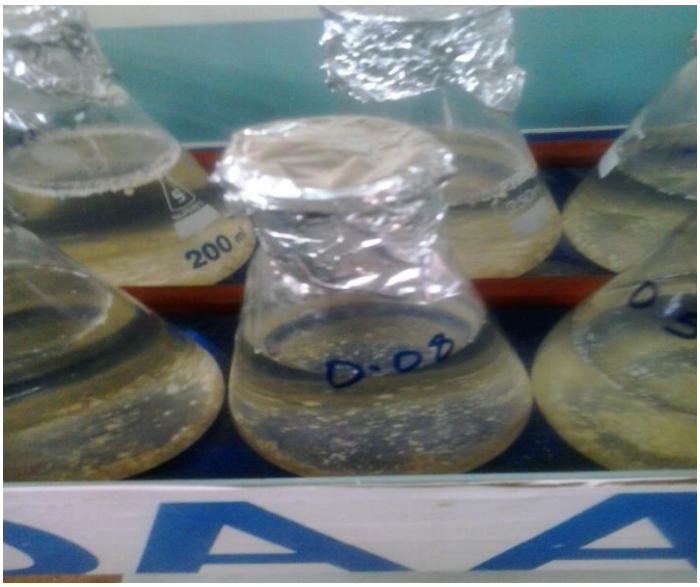


Figure 9. Water samples with various amount of *M .oleifera* seed powder on an orbital shaker.

3.6 Extraction of hexane soluble oil from *M. oleifera* Seeds

Hexane soluble oil was extracted from the seeds by soaking 5 g of the *M. oleifera* seeds powder in 50 ml HPLC grade hexane in 100ml beaker. The seed powder had been previously dried in oven at 105°C for two hours and cooled in a dessicator to room temperature. The contents of the beaker were shaken for 15 minutes in an orbital shaker before being allowed to stand overnight. Whatman filter paper was used to filter out the seed cake residue. This seed cake residue was dried in the air for one hour before drying in an oven at 105°C for another two hours and cooling it to room temperature. The weight difference of the seed cake was used to compute the percentage composition of the hexane soluble oil.

3.7 Water analyses

3.7.1 Physico-chemical parameters

pH, conductivity, TDS, Turbidity, and alkalinity were chosen as the indicator physicochemical parameters. They were determined using various meters.

pH: The pH of the water samples was determined immediately after sampling using a pH meter. The meter was calibrated using standard buffer solutions of pH 4.01, 6.8, and 10. The electrode was thoroughly rinsed with distilled water before every reading. The tip was dipped into the sample until a stable reading was obtained and recorded.

Conductivity: A Conductivity/TDS meter was used to determine the conductivity of the samples. A standard conductivity solution of 12.88 mS/cm was used to calibrate the meter, while determining the conductivity with the probe in the air was taken as the zero point calibration. The probe was rinsed with distilled water before every reading. The conductivity readings were taken by immersing the probe into the samples ensuring to cover the probe up to the indicated level and waiting for a stable reading.

Total Dissolved Substances: the conductivity meter was used to determine the TDS. The meter converted the conductivity values to TDS values by multiplying them with a conversion ratio factor which is always specific for every water sample.

Turbidity: Turbidity of the water samples was determined using a turbidity meter. The spectrophotometric turbidity meter was calibrated using standard solutions of turbidity 1 and 10 NTU. Zeroing of the meter was also done using distilled water. Water samples were placed in the glass bottles provided and the bottles placed into the sample holders. The turbidity readings were taken and recorded.

Alkalinity: The alkalinity of the samples was determined using the Salifert KH/Alk Profi Test kit. 5 ml of sample was added to a test vial using the syringe provided. Two drops of the KH-Ind indicator dye was added to the sample after shaking it for a few times. The 1 ml syringe provided was filled with the KH reagent as per the indications. This reagent was added dropwise to the sample while swirling after every drop. This was continued until the sample color changed from green to pink/orange-red. The reading on the syringe was then converted to alkalinity reading using the equation:

$$\text{Alk in meq/l} = (1 - \text{syringe reading}) * 5.71 \qquad \textbf{Equation 3.1}$$

This equation is given in the kits manual.

3.7.2 Total Suspended Solids (TSS)

The TSS of the samples was determined gravimetrically using Whatman filter paper No. 1. The filter papers were dried in an oven at 105 °C to a constant weight and then cooled in a desiccator. Water samples were shaken to homogenize and 100 ml filtered through the pre-weighed filter papers using a Buchner funnel that was fitted to a vacuum pump. The residue on the filter paper was dried to a constant weight in the oven at 105 °C. TSS was determined as the weight of the residue per volume of the water sample filtered. It was expressed in mg/L and was obtained as per equation 3.2.

$$TSS\ (mg/l) = (A-B)\ 1000/v \qquad \textbf{Equation 3.2}$$

Where:

A=weight of dry filter paper plus dry residue, (mg)

B=Weight of dry filter paper, (mg)

v=Sample volume, ml

3.7.3 Coliforms

3M *E.coli* Petrifilm plates were used to determine the feacal coliform load of the samples. The count plate was placed on a flat surface. The top film was then lifted and 1 ml of sample dispensed onto the center of the bottom film. Slowly, the top film was rolled down onto the sample to prevent the entrapment of air bubbles. The plate was then left undisturbed for one minute to permit evenly distribution of the sample and solidification of the gel.

The plates were then incubated in a horizontal position with the clear side up at 37.5°C for 24 ±2 hours. After the incubation, the plates were removed and enumeration of *E. coli* carried out. Blue colonies associated with entrapped gas were counted as *E. coli* while other coliform colonies were red and associated with gas bubbles. Figure 10 shows sample plates under incubation.

Figure 10. Sample 3M *E.coli* kits under incubation.

3.7.4 Lead and Copper ions analyses

Water samples whose initial concentration of lead and copper ions was known were passed through the filters. Plastic bowls were used to collect the filtrate which was later transferred into PET bottles awaiting analysis. An AAS was used to determine residue concentration of the ions under analysis. A calibration curve was obtained by using the calibration standards that had been previously prepared. The concentration of the filtrate was obtained from the calibration curve obtained.

3.7.5 Nitrates and Nitrites

The coagulative effect of *M. oleifera* seeds was determined for nitrates and nitrites ions.

Nitrates:

The USEPA approved Brucine method (USEPA method 352.1) was used to determine the amount of nitrates in the water samples. 5 ml of sample was measured and diluted to 10 mls using distilled water into a 25 ml volumetric flask. 10 mls of 14 M H_2SO_4 solution was added to the solution and the mixture cooled to room temperature in flowing water. 0.5 ml of the Brucine solution was added and the mixture shaken for one minute. This mixture was then

put in a water bath at 100°C for 25 minutes. After the 25 minutes the flasks were removed and put in a cold water bath so as to acquire room temperature. The flasks were then topped up to the mark with distilled water and the absorbance of the solutions at 410 nm read with a UV-Vis spectrophotometer. A calibration curve was obtained from the standards prepared and the concentration of the samples determined from it. Two sets of blanks were run. One set containing distilled water, sulphuric acid and complexing reagent and the other containing the sample and the acid but without the complexing reagent. The absorbance of both blanks was subtracted from the absorbance of the samples.

Nitrites

Determination of nitrites was done using the method proposed by the UoN/UNEP protocol, 2009. A 10 ml sample aliquot was obtained and put in a tube. 0.4 ml of the NEDA color reagent was added to the sample and mixed and the color allowed to form for 15 minutes. The color was read in a spectrophotometer at 540 nm. A blank sample was also treated in a similar manner and the absorbance subtracted from that of samples. A calibration curve was obtained by complexing standards and reading their absorbance.

3.8 Quality Control and Quality Assurance

Quality control was ensured by subjecting blanks to similar treatment to samples and analysing them. Performing the experiments in triplicates and use of thoroughly cleaned apparatus were also observed to offer quality assurance.

3.9 Statistical Analysis

Data analysis was done using Microsoft Excel to compute the mean values and the standard deviations for all the parameters. The data is then presented in tabular forms or graphically.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Filters

4.1.1 Clay composition

The clay to be used in making the filters was found to contain the following oxides as per XRF analysis.

Table 2. Percentage oxide composition of the clay

Oxides	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3
%Composition	57.8	15.37	1.11	1.90	2.34	2.10	0.49	0.10	7.62

The Loss on Ignition (LOI) was 10.75%

The clay was rich in Silicates (57.8%) and Alumina (15.37%) and had low concentration of Titanium (0.49%) and Manganese oxide (0.10%). This is in agreement with chemical characterisation of clays as aluminosilicate minerals [Grimshaw, 1971]. A study done on clay soils from Kirinyaga County indicates that the major components of the raw clays, when expressed as the oxides are: silica (SiO_2), 43.5 to 52%; alumina (Al_2O_3), 17 to 22%; iron (III) oxide (Fe_2O_3), 12 to 16%; titanium (IV) oxide (TiO2), 3.5 to 5.3%; Lime (CaO), 1 to 3%; magnesium oxide (MgO), 0.5 to 1.25%. Elements occurring in very small quantities in the range of 0.1 to 0.9%, again when expressed as oxides are, Na_2O, 0.30 to 0.40%; K_2O, 0.20 to 0.30%; MnO, 0,14 to 0.46% [Muriithi *et. al* ., 2012]. Therefore, the clay could be said to contain typical mineral composition as other clays from other parts of the country.

4.1.2 Sample filters

Frustrum shaped filters were prepared from clay mixed with saw dust with varying amount of the sawdust and the clay. Four ration by volume i.e. 65:35, 60:40, 55:45, 50:50 were selected and filters prepared from each ratio in triplicate. Figure 11 shows some of the sample filters prepared.

Figure 11. Sample filters

Filters fired at 850°C were assigned letters A, B, and C while those fired at 650° C were assigned D, E, and F. All filters made from the same type of sawdust but fired at 850°C and 650°C had a similar physical appearance. The filters prepared from *M. oleifera* dust were lighter in colour compared to the others.

4.1.3 Determination of flow rates

The filters flow rates were found to range between 20ml/h and 104.5 ml/h. These rates were found to be dependent on the ratio of clay to sawdust (C:S) and the thickness of the filters wall. The flow rates increased with increase in the amount of sawdust for the first two filters. This would be attributed to the fact that as the sawdust increased, more pores were available for the passage of water. However, a decrease is observed with an addition of more sawdust to the clay. With addition of sawdust, the elasticity of the clay is lost. For this reason , the 55:45 and 50:50 filters were made from inelastic mould of clay that implied making filters with thicker walls to compensate for the inelasticity. As a result, their flow rates decreased with the 50:50 filter having the lowest flow rate. The flow rates can be enhanced without compromising the efficiency of the filters by reducing the wall thickness of the filters and making larger filters that can accommodate more water. The flow rates are graphically presented in figure 12.

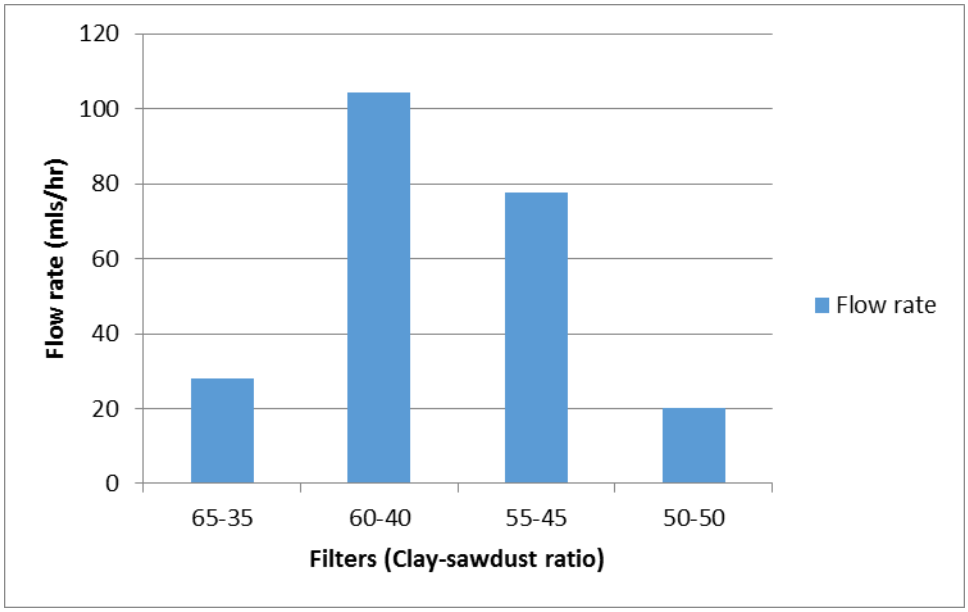


Figure 12. Local sawdust filters flow rates

On examining filters made from the *M .oleifera* powder, the filters were found to have lower flow rates compared to the filters made from local sawdust. On average, the best performing filter could filter an average of 17.75 mls/h. The low flowrates could be attributed to the fact that the *M. oleifera* powder was so fine implying that the pores formed after firing the filter were also tiny and could therefore not allow much water to pass through at a time. The flow rates are plotted in figure 13 alongside with those of the filters made from local sawdust.

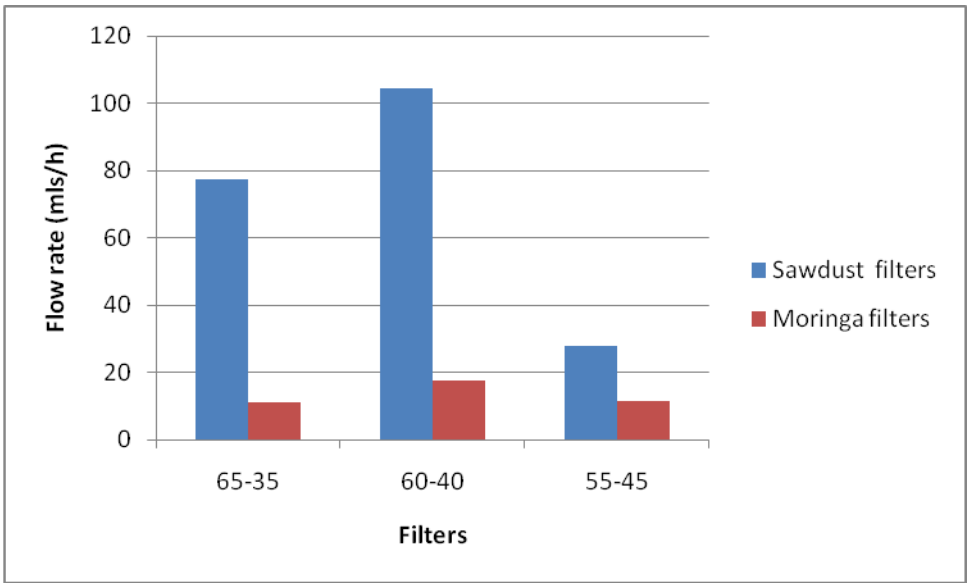


Figure 13. Comparison of flowrates for filters made from different combustible material

Various researchers have prepared filters using different ratio of the clay to sawdust thus resulting in different flow rates for the various filters. By varying the grain size of the sawdust (300, 600 and 900 µm) and using a clay: sawdust ratio 1: 2, Varkey and Dlamini (2012) obtained flow rates ranging between 50- 140 ml/h which compares to flowrates recorded for the some of the filters prepared in this work.

4.1.4 Physico-chemical parameters

Turbidity, Total Dissolved substances (TDS), Total Suspended Solids (TSS), and pH were used to monitor the effectiveness of the filters in the physicochemical parameters removal. The filters were effective in lowering turbidity from 64.1±0.75 NTU to a residue turbidity range of 0.9 to 1.8 NTU corresponding to a reduction efficiency range of 97.2- 98.6%. With TSS, the filters eliminated almost all the TSS reducing it from 248±3.61 mg/l to an average of 0.75±0.75 mg/l. On working out the percentage efficiency for TSS removal it was found to be over 99.5%. Effect on TDS was minimal with an average of 11.5% reduction. pH was not affected by the filters thus resulting in reduction efficiency of less than 1%. The reduction efficiency for the filters are plotted in figure 14.

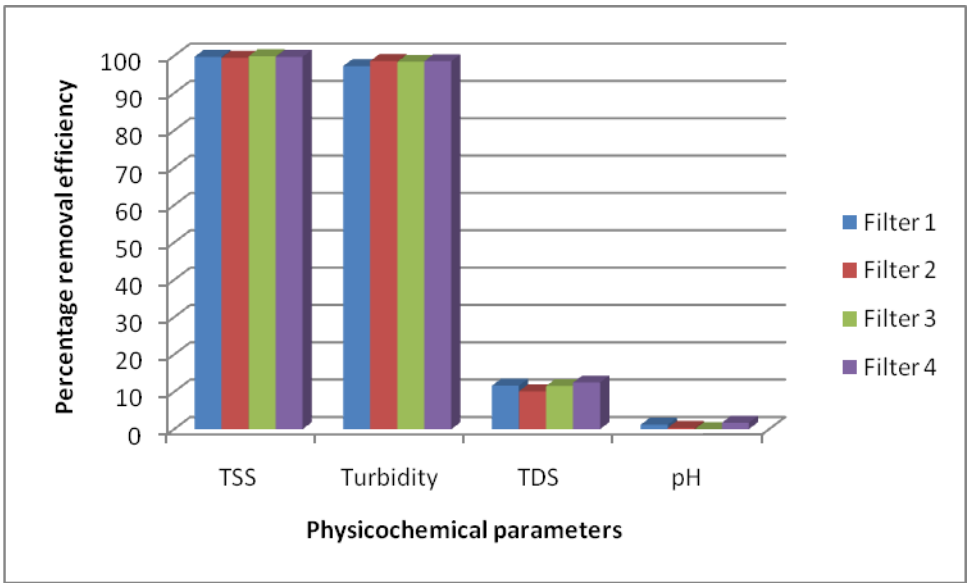


Figure 14. Efficiency of different filters in removal of physicochemical parameters

The other interesting observation was that the various filters (different amount of sawdust) gave similar results in the filtration results. This implies that the different amount of the combustible material used did not affect the filtration efficiency but only affected the pore size thus the difference in flow rates as discussed previously. The ceramic filters are in the

range of microfilters and are therefore able to trap particles that are in the micro range as it is the case with the suspended particles and the particles responsible for turbidity, (Simonis and Basson, 2011). As a result the efficiency of the TSS and Turbidity removal is close to a hundred percent. However, with TDS and pH the dissolved ions are too small and would pass through the filter pores thus the observed low removal efficiency. Various researchers have tested commercial ceramic filters and their efficiency in turbidity removal observed to give similar results. Sagara (2000) observed that for the three types of ceramic filters he tested; Nepalese ceramic candle filter, Indian ceramic candle filter and IPI purifier, the residue turbidity was below 1 NTU.

On varying the turbidity of the raw water, it was observed that the higher the turbidity of the raw water, the lower the turbidity of the treated water as illustrated in table 3.

Table 3. Efficacy of the filters in turbidity removal for water of different initial turbidity

Initial Turbidity (NTU)	Residue turbidity (NTU)	% reduction
5	2.3667±0.059	52.7
10	2.06±0.046	79.4
20	1.4467±0.047	92.8
50	1.213±0.032	97.6
65	0.8967±0.031	98.6

For all the water samples, the residue turbidity was below 3 NTU and thus could be considered safe for consumption. Naturally occurring turbid water obtained from Nairobi River at the Chiromo Bridge was used in the experiment and therefore turbidities higher than 65 NTU could not be achieved. The improved efficiency with an increase in initial turbidity has also been reported by Sagara (2000). In his work he suggested that as the particles in water get filtered, the effective pore size of the filter gets smaller due to the clogging of the pores by the filtered particles. This therefore implies that the highly turbid water would reduce the pore size more and thus the higher efficiency. However, very turbid water would result to total clogging thus preventing any filtration to take place.

Firing at different temperature and using filters made from a different type of clay did not have significant difference in physicochemical parameter removal. Moreover, the filters from *M. oleifera* powder were equally at par with the other filters. However, as it has been indicated previously these filters had much lower flow rates which could probably be attributed to the very fine powder that the plant material produced.

4.1.5 Microbial contaminants

Water from Nairobi River at the Chiromo Bridge was used as the source of the bacteria. Preliminary results indicated that the initial *E. coli* and Coliforms were too numerous to be counted (TNTC). On diluting the sample with distilled water, the Coliforms were enumerated as 390 CFU/ml *E. coli* and 530 CFU/ml other Coliforms. Nairobi River has generally been reported to contain high levels of the indicator organism, *E. coli*. Musyoki *et al.,* (2013) recorded an average of 980 ± 130 CFU/ml for the river before the Dandora Sewage Treatment Plant (DSTP) and an average of 1000 ± 110 CFU/ml after the DSTP point. The high levels of the feacal coliforms contamination could be attributed to the surface runoffs from the city as well as wastewater pollution from the informal settlements located alongside its course in addition to effluent from the sewage treatment plant (UN Habitat, 2007).

Almost all the filters completely eliminated all the *E. coli* and upto 85 % of the other Coliforms. The elimination mechanism is mainly by size exclusion. As it had been discussed previously, the ceramic filters pore sizes are relatively smaller than the bacteria, thus can filter them out and allow water molecules to pass through. Figure 15 is a pictorial representation of the results.

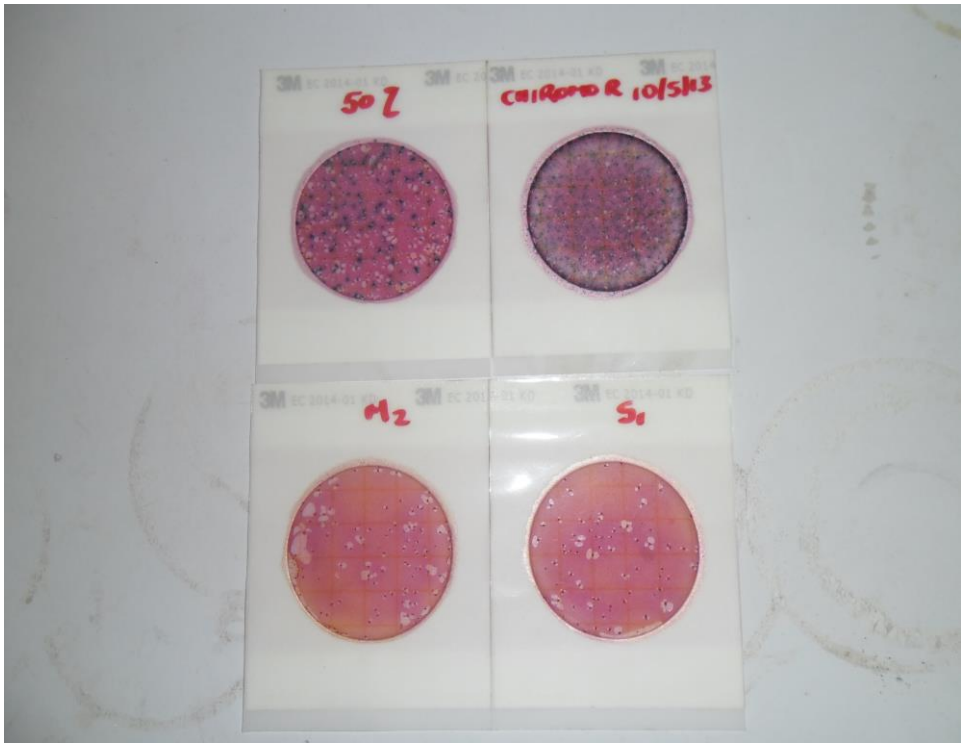


Figure 15. Photograph showing Coliform colonies before and after filtration

The M2 and S1 are plates incubated with water filtrate from filters made using *M. oleifera* stem and husks powder and local sawdust powder respectively. The absence of the blue colonies in plates M2 and S1indicates that all the *E. coli* have been filtered out. As it can be inferred from the picture, the other Coliforms have also been significantly reduced as indicated by the lesser number of red colonies.

Enumeration of the *E. coli* and other Coliforms after the filtration and incubation was done and the results presented in a tabular form in Table 4. The results indicate that three of the four sets of filters prepared eliminated all the *E. coli* and also lowered the other Coliforms load.

Table 4. Residue *E. coli* and other Coliforms after filtration

	E. coli (CFU/ml)	% reduction	Other Coliforms (CFU/ml)	% reduction
Raw water	390±10	0.0	530±10	0.0
Filter 1	0±0	100.0	73.7±13.3	86.1
Filter 2	0±0	100.0	75.7±4.5	85.7
Filter 3	0.33±0.58	99.9	67.7±4.7	87.2
Filter 4	0±0	100.0	83.3±5.0	84.2

On computing the efficiency reduction, the filters recorded an average reduction efficiency of 99.98 % and 85.83 % for *E. coli* and other Coliforms respectively. From literature, ceramic filters have been reported to remove *E. coli* with an efficiency ranging between 98%-100% (Simonis and Basson 2012). By using water spiked with 6.0 * $l0^6$ CFU/ml *E. coli*, Simonis and Basson obtained an average reduction efficiency of 99.999% after filtration through ceramic filters.

The *M. oleifera* filters and the local sawdust filters

There was no significant difference between the two types of filters. However, there was slight increase in efficiency with the filters made from *M. oleifera* powder. This could be as a result of the tiny pores that could be accounted for by the lower flow rates. Both type of filters reduced the total number of Coliforms by over 89 % as illustrated in figure 16.

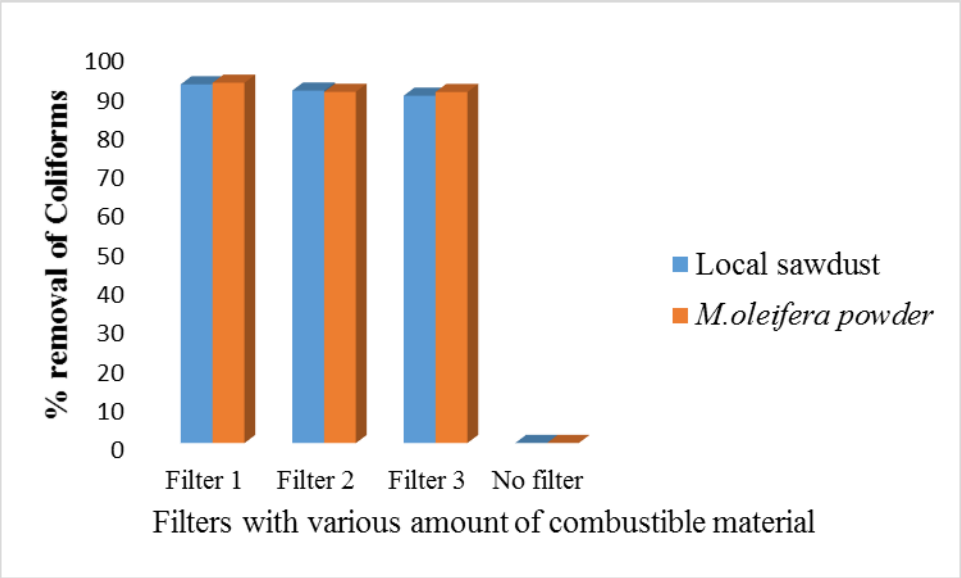


Figure 16. Comparison of the efficiency of removal of Total Coliforms from water using filters made from *M. oleifera* powder and local sawdust

4.1.6 Heavy metals

Lead and copper were used as the indicator ions for the heavy metal analyses. Laboratory samples were prepared by spiking different concentrations of the two metals into distilled water and then passed through the filters. The 60:40 (C:S) filters were used in this experiment since they were found to have the best flowrate.

Copper

The spiked samples had concentration ranging between 5 and 100 mg/l. For all the filtered samples, the residue concentration was below 0.1ppm as illustrated in Table 5. With the 5 and 10 mg/l initial concentration, the resulting concentration was below 0.01 mg/l which was the instruments' lowest detection limit.

Table 5. Residue concentration of copper after filtration

Initial conc (mg/l)	Residue conc (mg/l) (n=3)
5	bdl
10	bdl
20	0.100±0.01
50	0.050±0.02
100	0.015±0.01

On working out the percentage reduction, the filters were found to have a reduction efficiency of over 99.5%.

Lead

Similar test was carried out for Lead ions. The results indicate the residue concentration ranged between 0.02- 0.18 mg/l as illustrated in table 6.

Table 6. Residue concentration of lead ions after filtration

Original conc (mg/l)	Residue conc (mg/l) (n=3)
5	0.193±0.02
10	0.148±0.03
20	0.117±0.03
50	0.113±0.08
100	0.150±0.03

The filters made from *M. oleifera* powder were also equally effective in adsorbing the heavy metal ions and behaved in a similar way like the filters made from the local sawdust. The removal of the heavy metals ions from the water is through adsorption and exchange of ions with the fired clay. Natural and modified clay minerals have been studied as adsorbents for the removal of various toxic and hazardous pollutants of major concern to the environment. Kaolinite and montmorillonite showed good adsorbance for removal of toxic heavy metals as (Cd, Cr, Co, Cu, Fe ,Pb, Mn ,Ni and Zn). The reported results showed that clay could be effectively used as liner in water treatment plants. The maximum attained adsorption was with Cr(III) at an adsorption capacity of 9.2 mg/g, [Talaat *et al*., 2011]. Much work done on the filters has concentrated on their efficiency in removing turbidity and microbial contaminants. Very few research findings have been documented on the efficiency of the filters in heavy metal and other chemical contaminants removal. However, a study done by Mahlangu and coworkers on Silver Impregnated Porous Pots (SIPP) filters indicated that the filters removed contaminants from environmental water samples as follows: 70% to 92% iron, 36% to 68% calcium, 42% to 82% arsenic, 39% to 98% magnesium, 39% to 95% fluorides, 12% to 35% TOC and 45% to 82% turbidity [Mahlangu *et al*., 2012].

4.1.7 Effect of firing temperature

To investigate the effect of firing temperatures, one set of the filters was fired at 650° C while the other one was fired at 850° C. Comparison studies using physico-chemical parameters and microbial contaminants were then done. Both set of filters were similar in appearance after the firing. Results on their effectiveness on contaminants removal from water also indicated that the filters were similar. Both set of filters were equally effective in Feacal Coliforms, turbidity and TSS removal. The filters had some significant effect on TDS while their effect on pH was negligible. This is graphically represented in figure 17.

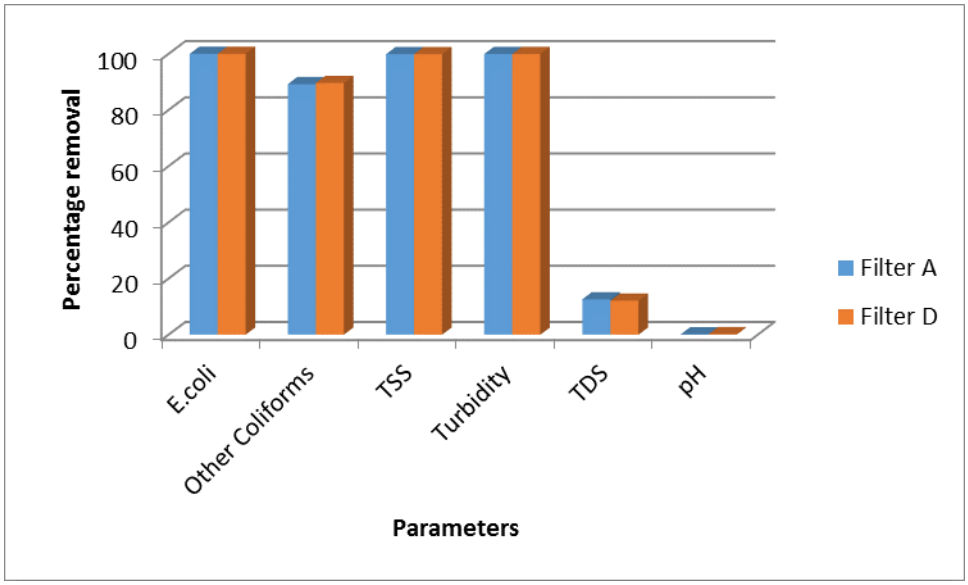


Figure 17. Efficiency of two filters: Filter A fired at 850° C and Filter D fired at 650° C

Since firing at 650° C was equally as effective as firing at 850° C,firing for this type of clay used should be done at the lower temperature to save energy. The temperature should be high enough to vitrify clay and make it hard and resistant to stress. This ensures that it does not change shape when water is added to it and neither will it contaminate the water filtered through.

In this research, the powder obtained from the stem back and seed husks was also used in making filters. As with different firing temperatures utilised, different combustible materials also produced similar results. This implies that the choice of the combustible material should be governed by availability and ability to be ground to fine powder. The results also supports the findings that the ceramic filters operate on the principle of size exclusion where they allow water molecules to pass through but retain any other thing larger than a water molecule. After firing, it is also believed that all the combustible material is converted to ash which is removed from the filter during the initial soaking. Therefore, the combustible material could be any organic material in form of powder capable of being converted into ash at the high firing temperatures.

4.2 Coagulation and disinfection using *Moringa oleifera* seeds

The dry ground *M. oleifera* seeds powder was tested for its disinfection and coagulation properties. From literature the *M. oleifera* seeds have been found to contain charged low molecular water soluble proteins that are responsible for coagulation. The protein(s) act as a

cationic polyelectrolyte, which attaches to the soluble particles and creates bindings between them, leading to large flocs in the water [Arnoldsson *et al*., 2008]. The large flocs settle under gravity and can eventually be filtered or decanted out.

4.2.1 Physico-chemical parameters

Among the physico-chemical parameters identified to test the coagulation properties of the seeds were pH, turbidity, TSS, TDS, conductivity and alkalinity. The seeds lowered turbidity by upto 97 % reduction while TSS was the second most physico-chemical parameter affected by the seeds with a reduction efficiency of upto 50 %. The seeds had a reduction of around 2 % on conductivity, pH, and TDS while the effect on alkalinity was negligible. This is graphically illustrated in figure 18.

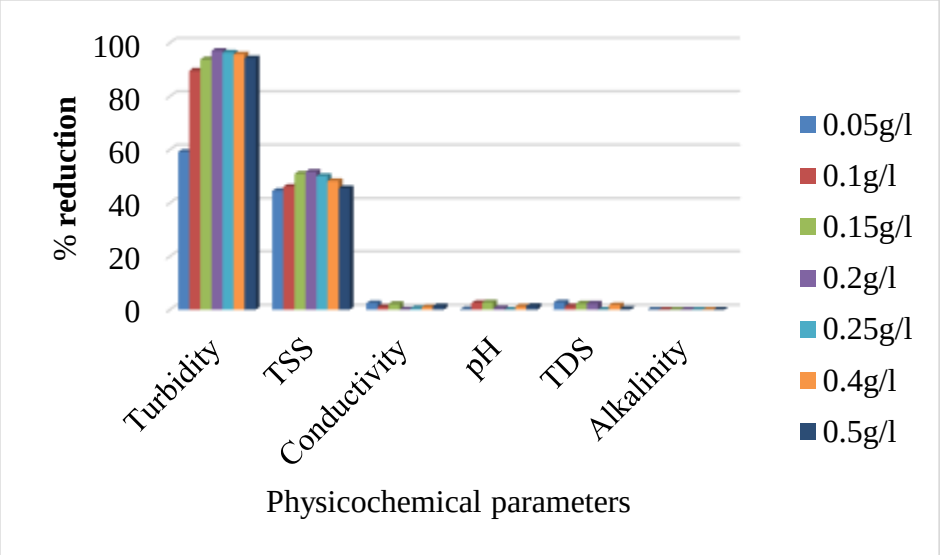


Figure 18. Effect of *M. oleifera* seeds on physicochemical parameters

Turbidity which is a measure of a sample cloudiness is mainly caused by suspended particles which also contributes to TSS. These particles attach to the cationic polyelectrolyte protein of the *M.oleifera* seeds to form large flocs that can settle at the bottom of the container. Flocculation by cationic polyelectrolyte is believed to be achieved in two ways:

- charge neutralization and
- bridging

Charge neutralization involves adsorption of a positively charged coagulant on the surface of the colloid. This charged surface coating neutralizes the negative charge of the colloid, resulting in a near zero net charge. The neutralised colloids form micro flocs that are not

visible to the naked eyes. These micro flocs are then bridged to macro flocs that settle at the bottom of a container through bridging. Bridging occurs when a coagulant forms threads or fibers which attach to several colloids or micro flocs, capturing and binding them together [Louis R., 1993]. From microscopic studies of the flocs formed with *M. oleifera,* it was found that the flocs formed with this seed protein are more tightly packed than those formed with conventional coagulants. This implies better purification results since such packs are easier to separate, [Hellsing *et al*., 2013].

Total Dissolved Substances, Conductivity, Alkalinity and pH are as a result of dissolved chemical ions in the water samples. As a result the cationic polyelectrolyte in the seeds did not affect these parameters. An interesting point to note is that in contrast to many coagulant of chemical nature such as alum ($Al_2(SO_4)_3$) and ferric ($Fe_2(SO_4)_3$), *M. oleifera* seeds did not change the initial pH of the water by any significant value. For this reason, treating water with this biocoagulant would not require any adjustment of the pH after coagulation thus reducing over reliance on chemicals that are not available locally but must be imported into our country.

4.2.2 Optimal dosages for Turbidity removal

The *M. oleifera* seeds have been reported to show excellent turbidity removal from water and waste waters. Nkurunziza *et al*., (2009) had previously reported reductions of 95%, 99%, and 99.8% for turbidities of 50, 250 and 450 NTU respectively on using *M. oleifera* on river water in Butare, Rwanda. For this reason, turbidity measures were used to identify the optimal dosage for coagulation. Both artificial and natural occuring turbid waters were used in the experiments. Various initial turbidity values were used to test whether the optimal dosage was dependent on the turbidity of the raw water.The artificial turbid water was prepared by adding a small amount of clay into distilled water and allowing it to stand for 24 hrs followed by decantation. Serial dilutions were done to obtain water of the required turbidity. With water of various turbidities employed in the experiment the seeds were effective in lowering the turbidities to below 5 NTU which is the WHO recommended guideline for drinking water.

Synthetic turbid water at 100 NTU

The optimal dosage for synthetic turbid water at an initial turbidity of 100 NTU was determined. The turbidity for each dosage was recorded at 1, 4 and 18 hrs and a line graph

plotted as illustrated in figure 19. For all the dosage amounts, the turbidity decreased with time due to gravity. Leaving the water to stand without any amount of the seed powder added to it resulted in a final turbidity of 54 NTU after 18 hours. However, with the least amount of the biocoagulant of 50mg/l, the final turbidity after 18 hours was below 20 NTU.

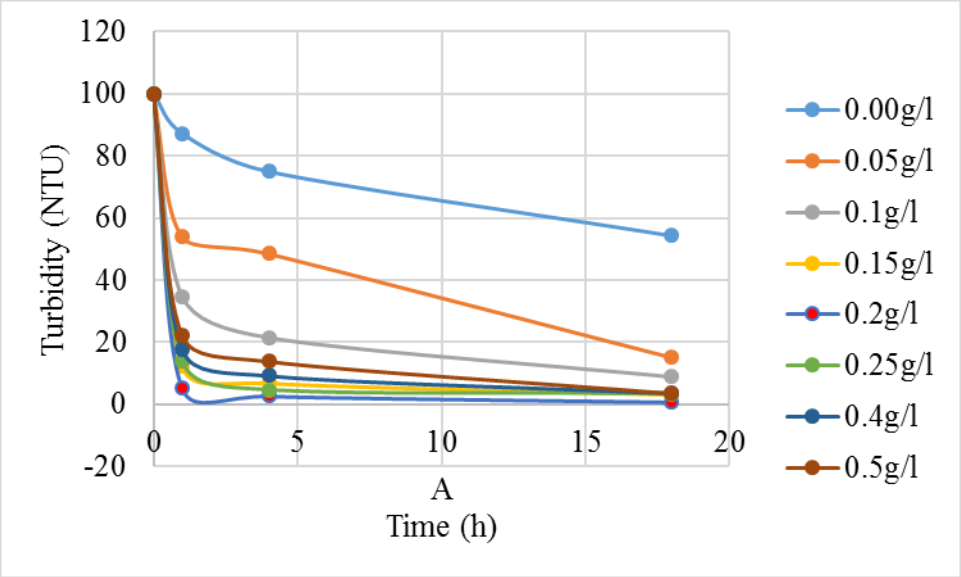


Figure 19. Turbidity removal with time using various dosage of *M. oleifera* seed powder for synthetic turbid water at 100 NTU

The optimal dosage was found to be 0.2 g/l for water at this initial turbidity. With this amount of the seeds, the turbidity reduced from 100 to around 5 NTU after one hour. After 4 and 18 hours, the residue turbidities are 2.74 and 0.83 NTU respectively. Optimal dosage as low as 0.1g/l have also been reported initially. Yongabi, (2011) in his findings reported that 2 grams of crushed *M. oleifera* seeds was used to treat 20 litres of water in Malawi resulting in residue turbidity below 5 NTU.

An interesting observation was that as the concentration of *M. oleifera* was increased from 0.2 to 0.5 g/l dosage, there was a slight increase in turbidity as can be inferred from figure 19. The 0.5 g/l resulted in a final turbidity of 5.16 NTU compared to the 0.82 NTU that was recorded for the optimal dosage of 0.2 g/l. Sutherland *et al*., (1990) and Sutherland *et al*., (1994) in their work have mentioned that once the optimal dosage is achieved, the excess polyelectrolyte proteins repel each other due to their charged nature leading to the flocs floating or suspending in the water. Such floating flocs could be filtered to achieve lower turbidity [Arama *et al*., 2011].

Synthetic turbid water at 16.3 NTU

Synthetic turbid water at an initial turbidity of 16.3 NTU was used in this experiment. Results indicated that lesser amount of the seeds would be required for this water as indicated in figure 20.

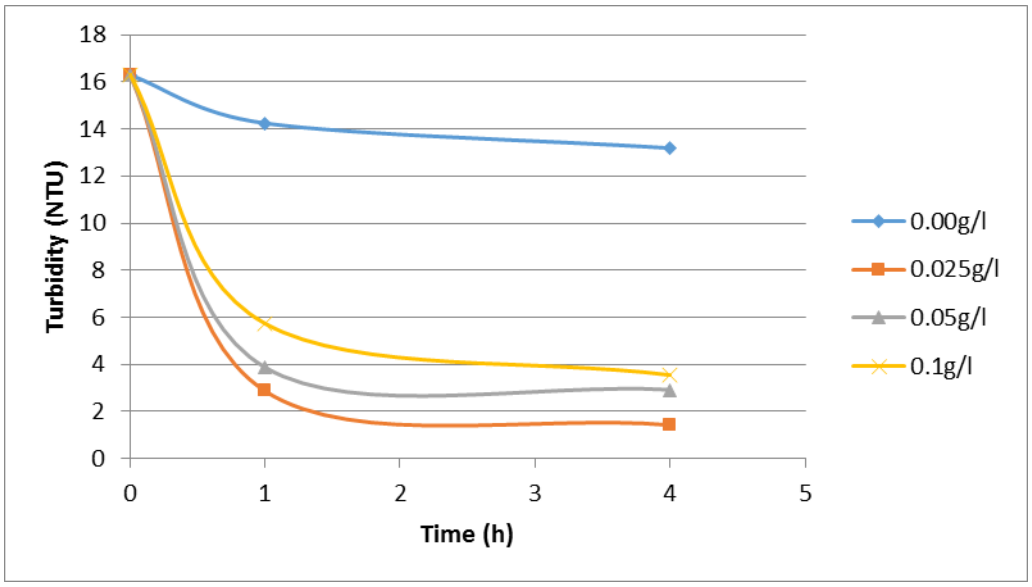


Figure 20. Optimal *M.oleifera* dosage for synthetic turbid water at 16.3 NTU initial turbidity

The optimal dosage for water with an initial turbidity of 16.3 NTU was around 0.025 g/l. This dose reduced the turbidity to 2.88 NTU and 1.44 NTU after one and four hours respectively. Leaving the water to stand on the bench also lowered the turbidity from 16.3 NTU to 13.2 NTU which corresponds to a 19.2 % reduction after the four hours. With a dosage of 0.025 g/l, the reduction was at 91.2 % which is significantly high as compared to leaving the turbid matter to settle under gravity. As with the previous case, increasing the amount of *M. oleifera* seeds powder beyond the optimal dosage, led to an increase in the turbidity of the water. A dosage of 0.1 g/l which is four times higher than the optimal dosage resulted in residue turbidity of 5.7 and 3.6 NTU after one and four hours respectively. This as explained above is as a result of repelling flocs caused by the excess charged particles in water (Sutherland et al., 1990; Sutherland et al., 1994). From personal communication with people who use the seeds for water treatment, a stinging taste is experienced when too much of the seeds are added to drinking water. For this reason, the amount of seed's powder added should not be be more than the optimal dose to achieve maximum turbidity reduction and

avoid the stinging taste in water. The lowest turbidity value achieved for this water sample with an initial turbidity of 16.3 NTU was 1.44 NTU which is high compared to 0.82 NTU value achieved by using water at initial turbidity of 100 NTU. The behaviour has been reported by other scholars and could be attributed to the fact that low turbidity waters contain limited colloidal matter; hence, a very limited inter-particle contact system for the polyectrolyte [Weber, 1972., Pritchard *et al*., 2010-a].

Naturally turbid water

Naturally turbid water obtained from Nairobi River and at an initial turbidity of 22.5 NTU was used in this test. The residue turbidity after treatment with various amount of *M. oleifera* seeds powder were recorded after one and four hours and a line graph plotted in figure 21 to indicate the trend.

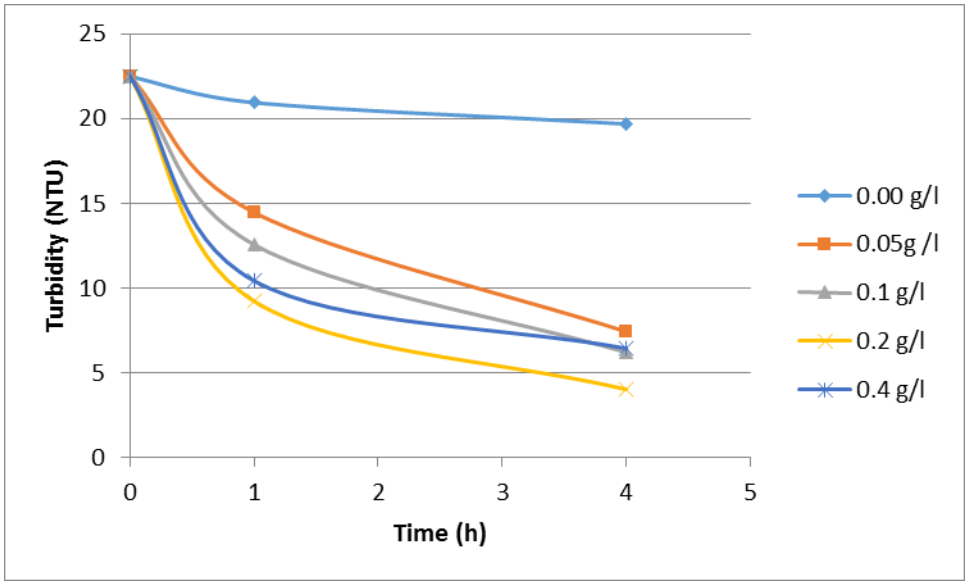


Figure 21. *M. oleifera* optimal dosage for naturally turbid water

The blank sample turbidty reduced to 19.7 NTU from 22.5 NTU after the four hours corresponding to a reduction efficiency of 6.8%. In contrast, for all the samples treated with *M. oleifera* seeds, the residue turbidity ranged between 4.0 and 7.4 NTU which translates to 59.0 to 35.75 % reduction. The optimal dose was found to be 0.2 g/l which is higher than that of synthetic turbid water. Mathematically, the optimal dosage for this natural water is around 10 times greater than that of synthetically turbid water of the same initial turbidity range. This dosage resulted in a residue turbidty of 4.02 NTU after four hours which is within WHO recommended turbidity maximum limit for drinking water. However, this lowest residue turbidity achieved is higher than that of the synthetic turbid water which gave a

residue turbidity of 1.44 NTU. Increasing the dosage after attaining the optimum dose resulted in an increase in residue turbidty as it had observed previously. A 0.4 g/l dosage increased the residue turbidity from 4.02 NTU to 6.44 NTU hence lowering the reduction efficiency from 59 % to 53.6 %.

Pritchard *et al* (2010-a) had previously reported that the seeds were not as effective with the natural turbid water as they were with artificial turbid water. They reported that natural water require far higher doses (x15) of *M. oleifera* seeds than the model turbid water to successfully produce coagulation. It has been proposed that the reduced efficiency with water of lower and natural turbidity could be as a result of formation of small and less dense flocs that could not settle effectively, [Arnoldsson *et al*., 2008]. This could be the reason more of the seed powder is required for natural turbid water so as to ensure a heavy floc that can settle by gravity is achieved.

For all the cases studied, the optimum dosage that reduced turbidity to acceptable limits for drinking water was found to be equal or less than 0.2 g/l. Studies conducted previously indicate that the single seeds have been shown to vary in weight between 0.15 g and 0.3 g (Jahn, 1989). This then indicates that the number of seeds can be used as the measure of quantity at household level. Practically, only one seed or less would be required for every litre of water that is to be purified.

Effect of deoiling the seeds on turbidity removal

The *M. oleifera* seeds were deoiled and the hexane soluble oil content found to be 26.40±1.04 % of the total mass of the seeds. From literature, the seeds have been reported to contain over 40% edible oil [Lalas and Tsaknis, 2000]. The lower yield obtained in this work could be as a result of the method employed for the extraction. Filtration was used to separate the oil containing hexane from the seeds powder thus the possibility of inneffective extraction.

The effect of deoiling the seeds on their coagulant potential was tested against synthentic turbid water at an initial turbidity of 110 NTU. The water was treated with various dosages of the deoiled seeds and the turbidity recorded after 1, 4 and 18 hours. The results are presented in Table 7.

Table 7. Optimal dose for the *M. oleifera* deoiled seeds

	Turbidity at different time intervals (NTU)		
Amount of deoiled seeds powder (g/l)	1 hr	4 hrs	18 hrs
0.00	97.33±1.63	61.90±2.82	33.60±0.40
0.05	76.00±2.63	32.50±1.51	2.93±0.21
0.1	37.27±1.20	6.47±2.02	1.94±0.13
0.15	12.33±0.45	5.46±0.40	1.71±0.34
0.2	17.10±0.86	6.53±0.32	2.04±0.08
0.4	16.83±0.45	6.60±0.46	3.76±0.82

Turbidiy was observed to reduce with time as would be expected. By leaving the water to stand without adding any biocoagulant, the turbidity of the water fell from 110 NTU to 97.3 NTU, 61.9 NTU and 33.6 NTU after 1, 4, and 18 hours respectivelly. The residue turbidity attained after 18 hours without any treatment was still much higher than the recommended maximum limit of 5 NTU. On adding 0.05 g/l of the deoiled seed powder, turbidity reduced from 110. NTU to 76.0, 32.5, and 2.93 NTU after 1, 4, and 18 hrs. The optimal dose was found to be 0.15 g/l. At this dose, turbidity reduced to 12.3 NTU after the first one hour with a further reduction to 1.71 NTU after 18 hours. Increasing the dose above the optimal dose lead to an increase in the residue turbidity obtained. This as has been explained earlier is as a result of the excess polyelectrolyte proteins repeling each other due to their charged nature leading to the flocs floating or suspending in the water. For all the dosages ranging between 0.05 and 0.4 g/l, the residue turbidity after 18 hours was below 3.8 NTU thus meeting the WHO and KEBS guidelines on turbidity in drinking water. The results indicate that deoiling did not affect the coagulation ability of the seeds. This clearly indicates that the edible oil can be extracted first before the seed cake is used in water treatment. Mechanical extraction of the oil should be the best approach in the villages since organic solvents cannot be used in extracting oil intended for consumption.

Comparison of the deoiled and non-deoiled seeds

To get a better picture of the effect of deoiling the seeds, the jar test were carried out with both the oiled and deoiled seeds at the same time. The results obtained were averaged and are

as illustrated in Table 8. It was confirmed that deoiling the seeds did not have any significant effect on their coagulation strength.

Table 8. Comparison of the oiled and deoiled seed powder in turbidity removal

Amt of *M. oleifera* seeds (g/l)	Residue turbidity (NTU)	
	Deoiled seed powder	Oiled seed powder
0.05	4.925±0.078	4.85±0.071
0.1	3.725±0.078	3.66±0.057
0.2	2.45±0.212	2.45±0.106
0.3	3.665±0.078	4.83±0.028
0.5	5.44±0.042	6.62±0.056

After the optimal dosage is attained for both the seeds powder and the seeds cake, residue turbity of the oiled seeds is higher than that of the deoiled ones for any given dosage. This could be as a result of the excess oil associated with the oiled seeds leading to cloudiness and thus translates to increased turbidity.

Effect of pH on turbidity removal

Since the coagulation property of *M. oleifera* seeds have been attributed to cationic polyelectroyte proteins, [Arnoldsson *et al.*, 2008], the effect of altering the pH was investigated in this experiment. pH 5, 7 and 9 were chosen as the working conditions and the results illustrated graphically in figure 22. The turbidity was monitored after 1, 4, and 24 hours.

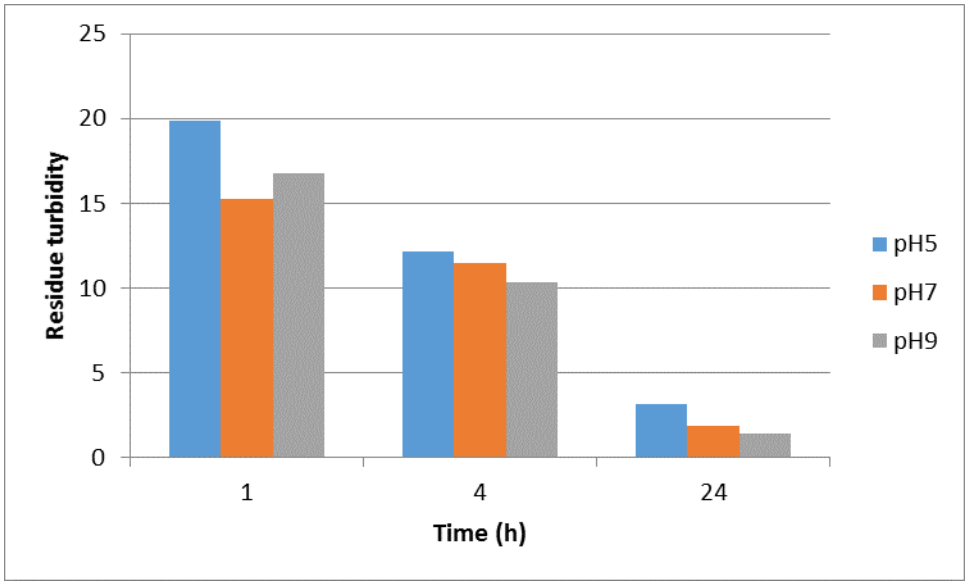


Figure 22. Effect of pH on turbidity removal

From the graph, it can be observed that the seeds were more effective in coagulation with increase in pH. The slightly basic media produced the best results followed by the neutral media. Acidic conditions led to reduced efficiency of the seeds.

4.2.3. Microbial contaminants

The 3M petrifilm *E.coli* kits were used for the enumeration of *E. coli* and total Coliforms to test for the disinfectant ability of the *M. oleifera* seeds. Figure 23 shows the cultured plate of the raw water. The blue dots associated with gas bubbles indicate the *E.coli* Colony Forming Units (CFUs) while the red dots indicate the other Coliforms CFUs.

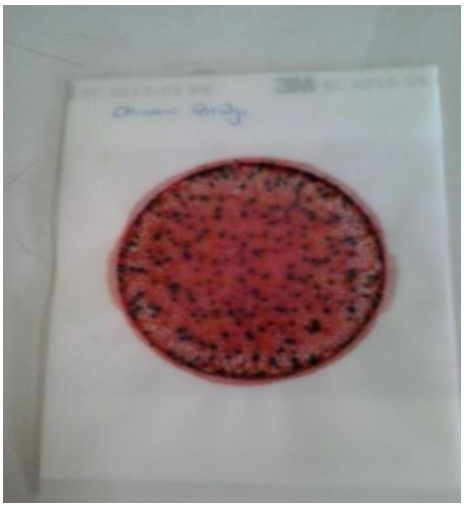
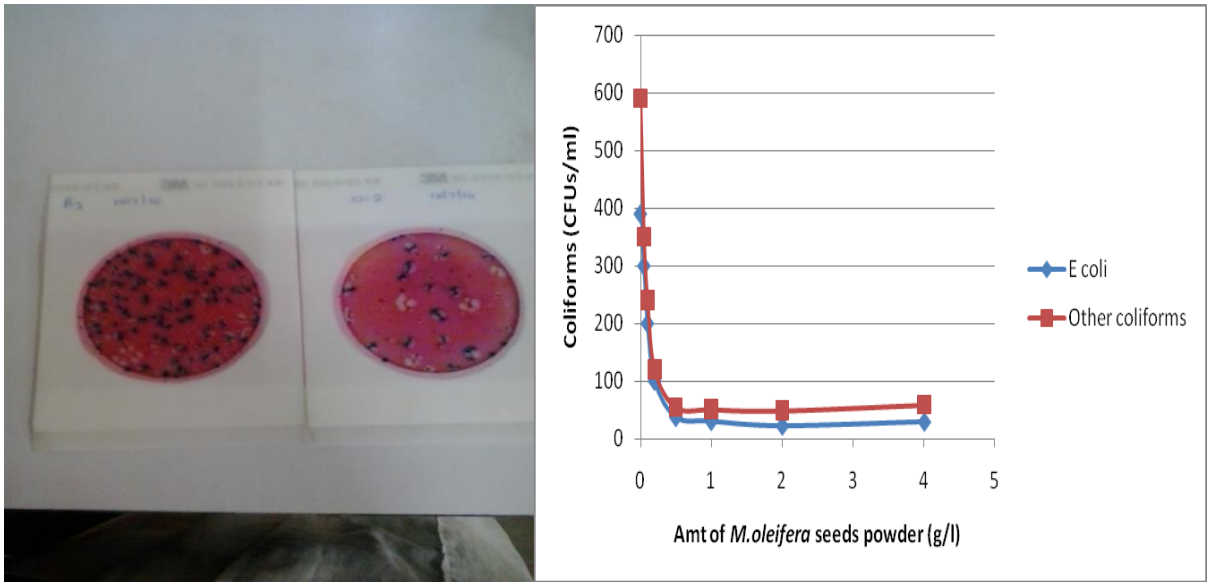


Figure 23. A 3M petrifilm *E. coli* plate cultured with raw water

The raw water was found to contain 390CFUs/ ml *E. coli* and 590 CFUs/ml total Coliforms. The 3M petrifilm *E. coli* kit is circular with an area of 20 square centimeters. The kit is subdivided into square boxes of one square centimeter. Enumeration of the colonies for the overly populated kits was done by averaging the colonies of three square boxes and multiplying the figure by 20. For kits with lesser colonies, enumeration of all the colonies was possible and was therefore carried out.

Preliminary disinfection results

Preliminary tests were carried out by adding various amounts of the *M. oleifera* seeds onto the raw water in various jars. After the inoculation, enumeration of the Coliforms was carried out. Figure 24 shows (a) pictorial results of the blank sample and the sample treated with 1g/l of the *M. oleifera* seeds and (b) the line graph for the preliminary results. The pictorial representation shows a reduction in the number of both blue and red dots thus indicating the reduction in the number of coliforms.



a) b)

Figure 24. Preliminary disinfection results; a) photograph of kits cultured with blank sample (left) and treated water (right), b) disinfection trend

The disinfection increases with increase in the dosage load for the low dosage values below 1g/l. After this dosage is achieved, an increase in the dosage does not lead to an increase in disinfection. On working out the disinfection efficiency, the seeds reduced the *E. coli* and total coliform loads by over 90% for a 1 g/l dosage. The mechanisms of the disinfection

process have not been fully understood. Some scholars propose that the cationic polyelectrolyte coagulate the bacteria which are attached to clay particles [Bukar *et al*., 2010] while others are of the school of thought that the seeds contain water soluble proteins which are antimicrobial in nature [Eilert *et al*., 1981]. In either case, the seeds reduce the faecal bacterial load of a sample and can therefore be employed in treating water in communities where potable water is not available.

Optimal disinfection dosage

To determine the optimal disinfection dosage, an experiment with raw water at an initial concentration of 260 CFU/ml and 300 CFU/ml *E. coli* and other Coliforms respectively was used. This was a lower figure compared to 390 CFU/ml *E. coli* and 590 CFU/ml other Coliforms that had been recorded previously. The disparity was as a result of different seasons in sampling which was brought about by unavailability of the *E. coli* kits. The raw water was treated with varying amounts of the *M. oleifera* seeds and the residue number of *E. coli* and other Coliforms computed. Figure 25 is a plot of the residue number of the faecal Coliforms after one hour against the various amounts of the seed powder used.

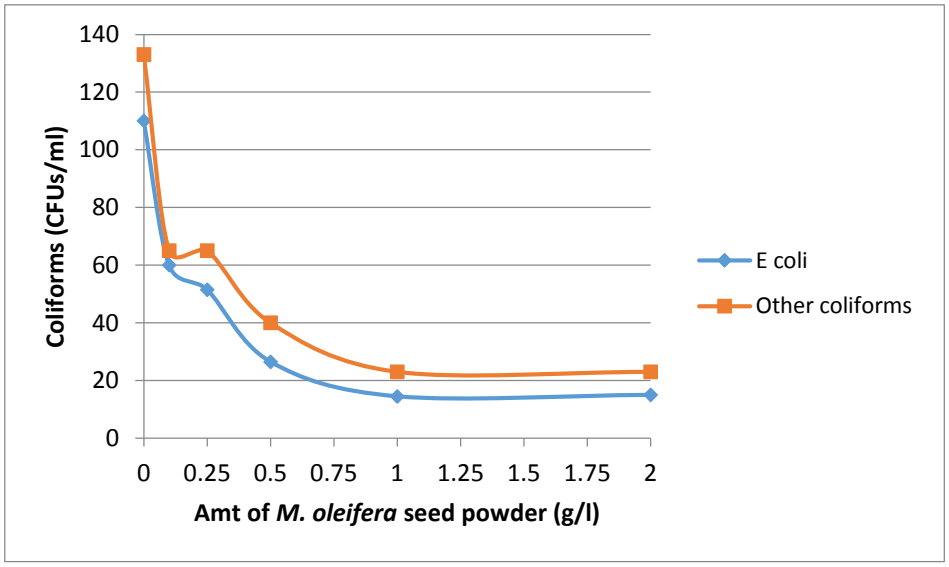


Figure 25. Optimal dose disinfection results

The blank sample which was not treated with *M. oleifera* seeds powder had the residue number of *E. coli* and other Coliforms at 110 CFU/ml and 133 CFU/ml respectively. This corresponds to a 48.6% of the original number of the total Coliforms. With addition of the seeds powder in the dosage of 0.1, 0.25, 0.5, 1.0, and 2.0 g/l, the residue number of the total

Coliforms reduced to 125, 116.5, 56.5, 37.5, and 38.5 CFU/ml respectively. By computing the percentage value of the residue coliforms from the original level of 560 CFU/ml, the various dosages were found to lower the Coliforms to a range of 33.75 – 6.78% of the original number of Coliforms. The optimum dosage was found to be 1g/l corresponding to a residue value of 14.5 CFU/ml *E. coli* and 23.0 CFU/ml other Coliforms which is equivalent to 6.70 % of the initial number of the Total Coliforms.

Both KEBS and WHO indicate that drinking water should contain no *E. coli* for every 100 ml of water sampled. Hence, water treated with *M. oleifera* seeds alone is not fit for consumption since even the optimal dosage does not eliminate all the faecal coliforms and so does not comply with WHO and KEBS standards for drinking water . However, in areas where no other alternative is available, the seeds can be used to reduce the microbial load to a lower less significant level.

As it has been reported above, shaking a blank sample and leaving it to stand on the bench led to a significant reduction of the Coliforms. For this reason, to compute the disinfection efficieny, the blank sample residue number was used as the initial level of the Coliforms and the efficieny in percentage worked out. A bar graph of the disinfection efficiency of *M. oleifera* seeds powder against the various amount of the seeds powder was plotted and is shown in figure 26. The blank sample had 110 CFU/ml *E.coli* and 133 CFU/ml other Coliforms.

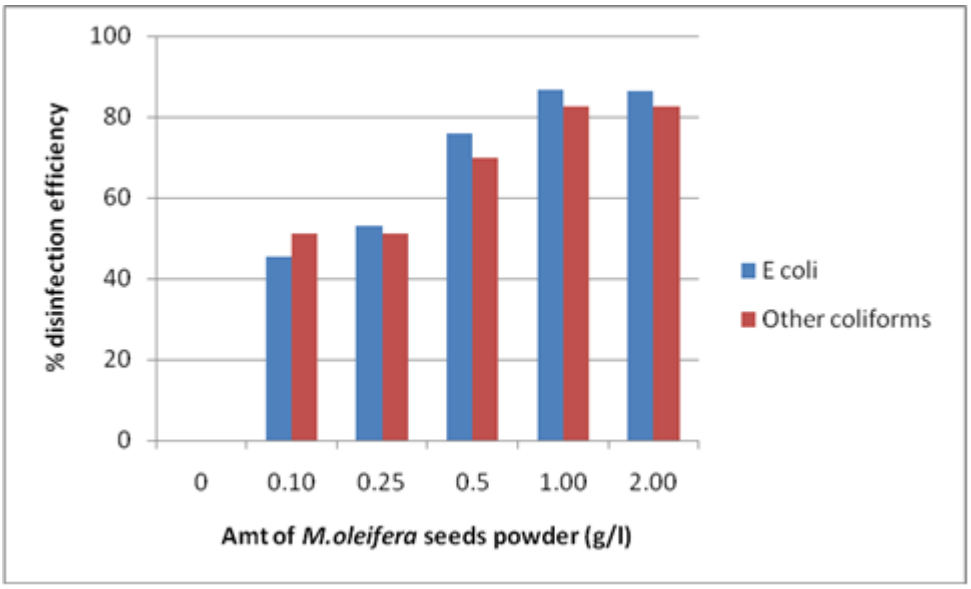


Figure 26. Disinfection efficiency against various amounts of the seeds powder

The percentage efficiency increased with an increase in the dosage of the *M.oleifera* seeds. A dose as low as 0.1 g/l resulted in a disinfection efficiency of 45.45% and 51.13 % for *E.coli* and other Coliforms respectively. This efficiency increases upto the 1 g/l dose which is the optimal dose with an efficiency of 86.82% and 82.71% for *E. coli* and other Coliforms respectively. Increasing the dose beyond this dose does not lead to an increase in the percentage efficiency. The 2 g/l which is twice the amount of the optimal dose results in an efficiency of 86.36% for *E. coli* and 82.71% for other Coliforms which is slightly lower than the value obtained with the lower dose of 1 g/l. Different scholars have reported different efficiencies either in terms of percentage reduction or logarithimic reduction of the microbial load. Yongabi *et al*., (2011) reported a 95% efficiency reduction of the total aerobic mesophilic bacterial counts, *E. coli* counts as well as coliforms counts. They reported an optimal dosage of between 4 and 5 g/l. Amagloh and Benang (2009) reported an efficiency of between 90-99% for total coliforms. Pritchard *et al*., (2010-b) reported different efficiency at different working conditions. By changing the initial microbial load, and initial turbidity of the test water, they observed efficiency that ranged between 84 and 88% for articificial model water and 77 and 88% for natural water. Their model water was spiked with 100-300 CFU/ml *E. coli* while their river was reported to contain an average of 26.5 CFU/ml. For their work, they reported an optimal dose ranging between 0.75 and 1.25 g/l. The slightly lower figure reported in this work could be as a result of using natural water. Natural water contains many chemical, physical and microbial particles and the coaguation and disinfection of such water would require complex action as compared to coagulating and disinfecting artificial water that only contain specific pollutants. This would therefore result in lower efficiency in treatment for natural waters compared with synthetic water.

Effect of time on Feacal Coliforms disinfection

The minimum amount of *M. oleifera* seeds that could result in maximum disinfection when the treated water samples were left to stand for upto six hours were investigated in this experiment. The jar tests were carried out as previously outline with the sampling of water for inoculation conducted after 1, 3 and 6 hrs. Figure 27 is a pictorial presentation of the effect of time on the disinfection properties of the *M. oleifera* seeds.

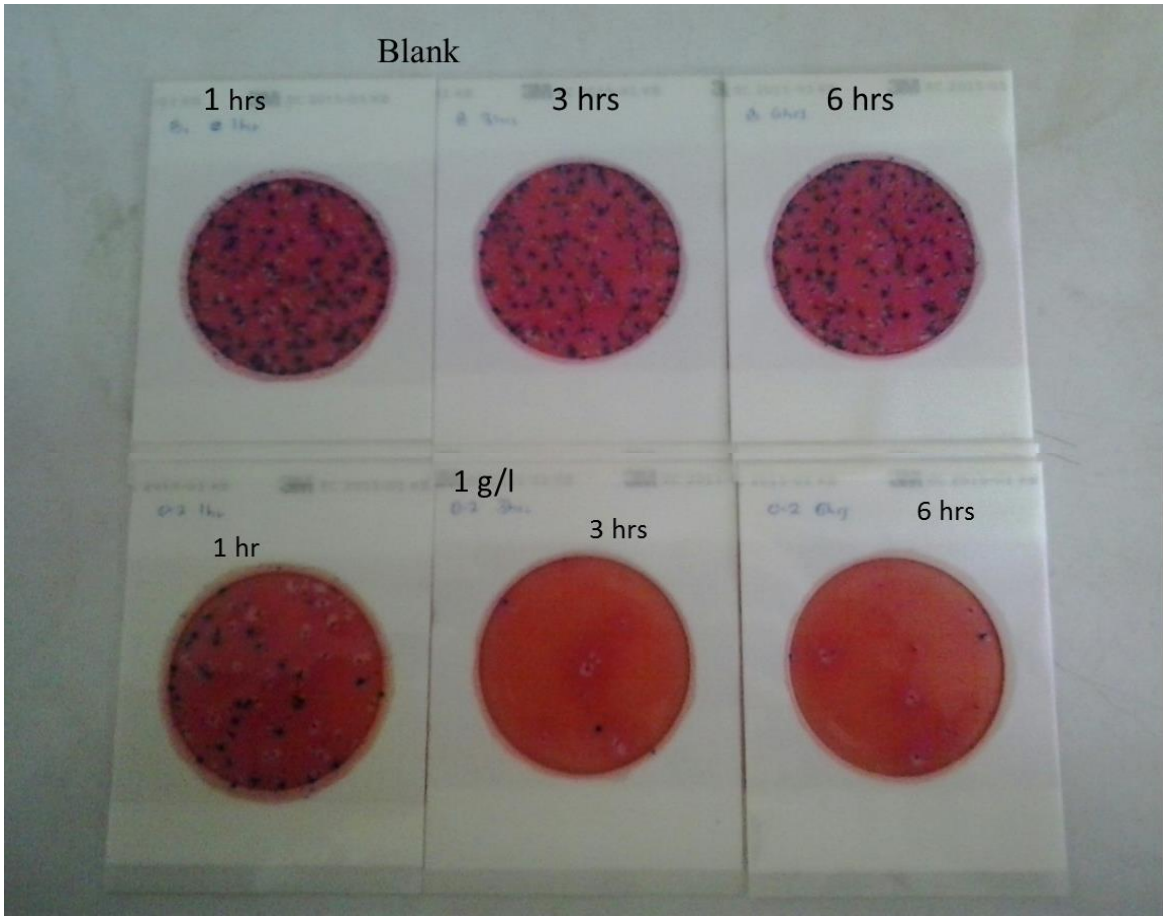


Figure 27. Pictorial illustration of the effect of time for the 0.0 and 1g/l dosages after 1, 3 and 6 hours.

The blank sample had a high residue number of Coliforms as evidenced from the blue and red dots even after leaving the waters to stand for six hours. With a dose of 1 g/l, the residue coliforms considerably reduced after one hour with an almost 100 % reduction after 3 and 6 hours. Enumeration of residue Coliforms was carried out and the results presented in Table 9.

Table 9. Effect of time on Coliforms disinfection

Amount of *M. oleifera* seeds (g/l)	Residue coliforms count (CFU/ml) with time (n=3)							
	0 hr		1hr		3 hrs		6hrs	
	E. coli	Other Coliforms	*E. coli*	Other Coliforms	*E. coli*	Other Coliforms	*E. coli*	Other Coliforms
0	260±10	300±10	125±5.0	153.3±6.5	92.3±4.2	107±3.6	96.5±7.8	104±3
0.1	260±10	300±10	115.3±4.7	127.7±9.3	76.3±4.9	79.3±18.5	92.3±2.6	85±2.8
0.2	260±10	300±10	86.7±2.5	109±7.5	67.3±5.9	75.6±16.6	69±2.8	90.3±2.5
0.25	260±10	300±10	69±2.6	87.7±5.0	36±3.6	74.7±4.5	59.7±1.5	38±3.0
0.5	260±10	300±10	43.3±3.8	77.7±3.1	26±5.3	47±1.4	39.7±8.5	22.5±2.1
1	260±10	300±10	28±2.6	56.3±1.5	3.7±2.5	14.7±4.4	3.0±1.0	13.7±5.3
2	260±10	300±10	28.7±4.2	57.3±5.5	2.0±1.0	9.0±2.0	2.7±1.5	11±3.0

The *E.coli* were found to reduce for the first 3 hours for all the dosages. At 6 hours, the *E. coli* residue is increasing for the lower doses. For instance at the lowest dose of 0.1 g/l, the residue count after 3 hours is 76.3±4.9 CFU/ml. After six hours, the same sample recorded a residue *E. coli* count of 92.3±2.6 CFU/ml. The increase would be as a result of the residue *E.coli* feeding on the nutrients present in the water and multiplying thus resulting in the increase. At a dose of 1 and 2 g/l the residue number of *E. coli* was 3.7±2.5 and 2.0±1.0 CFU/ml respectively after three hours. After 6 hours, the average residue counts were 3.0±1.0 for the 1 g/l dosage and 2.7±1.5 CFU/ml for the 2 g/l dosage. Since almost all the *E. coli* were eliminated after the first 3 hours, there was no significance increase in the number of Coliforms after leaving the samples to stand for an extra 3 hours.

A similar behaviour was observed for the other Coliforms. There was a major decrease after the first one hour with a slight decrease after the third hour and a slight increase after the sixth hour for the lower dosages. With the 1g/l dosage, the other Coliforms reduced from 300±10 CFU/ml to 56.3±1.5, 14.7±4.4 and 13.7±5.3 CFU/ml after 1, 3 and 6 hours respectively. The other Coliforms were more resistant to the phytodisinfectant activity of the *M. oleifera* seeds with the residue counts much higher than those obtained for the *E. coli*. These findings are in agreement with earlier findings reported by Yongabi *et al*., (2011). In their findings they found out that *E. coli* recorded the highest zone of inhibition (15 mm) compared to other mesophilic bacteria (1mm).

The above data is presented in figure 28 in form of a bar chart for clear visualization. The total Coliforms count decreases with increase in time and in the amount of *M. oleifera* used.

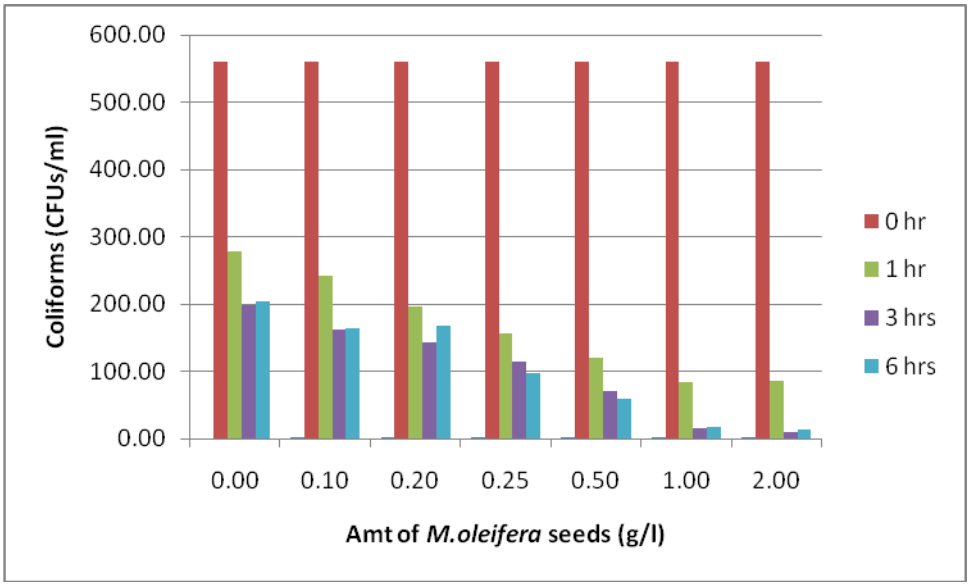


Figure 28 Effect of time on Total Coliforms disinfection

The 1 and 2 g/l dosage recorded the least number of residue Coliforms for all the sampling time intervals. However, after the third hour, the change in the Coliforms count is not significant for all the dosages. This implies that the three or six hours wait is not necessary. For the water to be safe for consumption, maybe a secondary water treatment such as filtration should follow the biocoagulation and phytodisinfection of the seeds.

Effect of pH

The effect of pH on the phytodisinfectant ability of the *M. oleifera* seeds was also investigated. A dosage of 1g/l was chosen and the samples pH adjusted to 5, 7 and 9. The disinfectant tests were carried out and the enumeration of *E.coli* and other Coliforms recorded after 1, 3 and 6 hours. Residue fraction was calculated using equation 4.1 below

$$\text{Residue fraction} = N/N° \qquad \textbf{Equation 4.1}$$

Where N is the number of coliforms after phytodisinfection

N° is the initial number of Coliforms before disinfection.

Figure 29 gives the results for the effect of pH on *E. coli* disinfection. For all the pH values chosen, the residue fraction after one hour was between 0.02 and 0.06 with the highest residue figure recorded at pH 5 and the lowest figure at pH 9. The same trend is observed after the third and fourth hour but with reduced discrepancy between the residue fractions values.

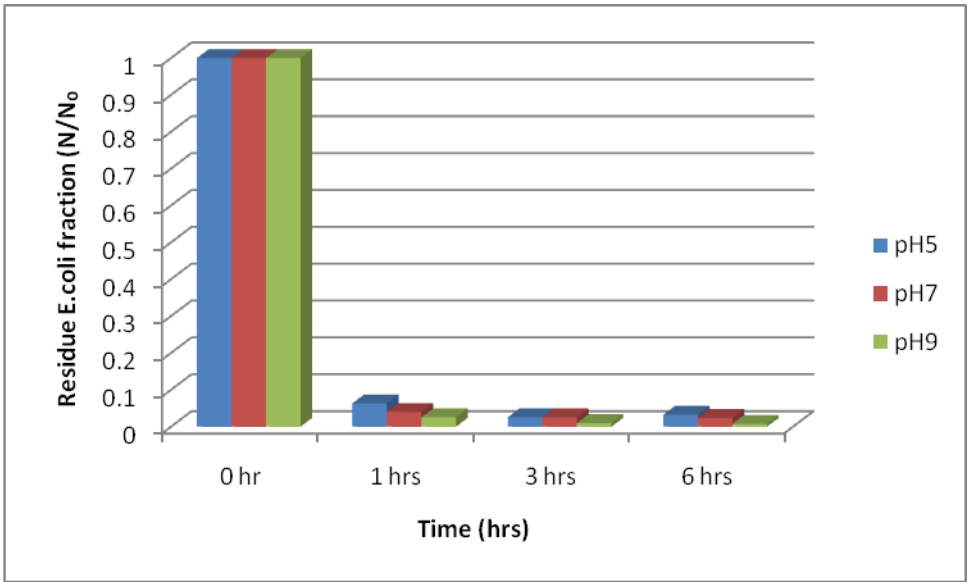


Figure 29. Effect of pH on *E. coli* disinfection

A basic media of pH 9 was found to be a better working pH for the *M. oleifera* seeds while acidic conditions were found to lower the efficiency of the seeds. Since natural water is generally slightly basic, then the seeds would be effective in disinfecting water. A similar behaviour was observed for the Total coliforms. pH 9 was the best working pH while pH 5 gave higher residue fraction value.

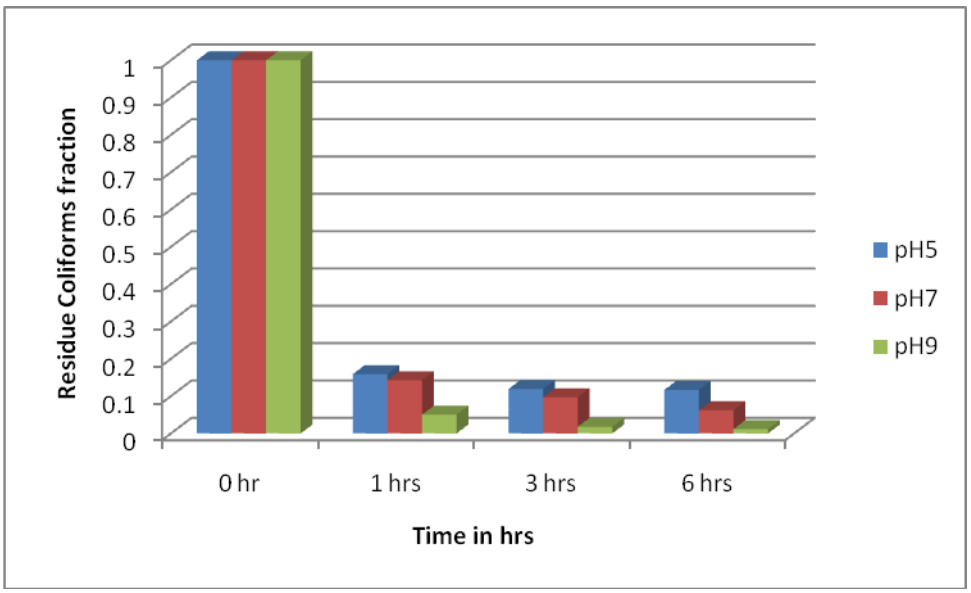


Figure 30. Effect of pH on Total Coliforms disinfection

The other Coliforms were more resistant to the disinfections thus leading to higher residue fractions for total coliforms. pH 5 recorded a residue fraction of 0.15 after one hour compared

to the 0.06 recorded for the *E. coli*. pH 9 recorded a residue fraction of 0.05, 0.02 and 0.01 after 1, 3 and 6 hours respectively. At neutral pH, the residue fraction ranged between 0.14 and 0.06. For this reason the alkaline media was again found to give better working conditions for the *M. oleifera* seeds. Previous work by Pritchard and coworkers had reported that the seeds were more effective in neutral pH but also observed that alkaline conditions were overall more favourable than acidic conditions [Pritchard *et al*., 2010-b] .

The mechanism of the disinfection process is still a subject under debate. Some sholars advocate for a coagulation mechanism with the consideration that the bacteria are attached to charged clay and silt particles that are readily coagulated by the cationic polyelectrolyte coaggulant that is present in the *M. oleifera* seeds [Bukar *et al*., 2010]. Other researchers have reported that the *M. oleifera* seeds contain proteins that act as disinfectants. The seed contain number of benzyl isothiocyanate and benzyl glucosinolate which act as antibiotic [Eilert 1981].This has been proved by extracting the proteins using methanol and testing it against *E. coli.* 100 mg/ml of this extract of *M. oleifera* seeds demonstrated a marked inhibition of 15mm as opposed to an inhibition of 1mm and 17 mm for alum and chlorine respectively [Yongabi *et al*.,2011]. Bichi and co-workers have reported that the mode of attack of the Moringa seeds extract on the *E. coli* cell is by rupturing the cell and damaging the intercellular components, allowing water to dip in to cell which causes it to swell more and burst leading to death [Bichi *et al*., 2012].

4.2.4 Nitrates and nitrites

Nitrates

Water samples were treated with *M.oleifera* seeds and the concentrations of nitrates ions analysed in the treated samples and the blank. Prior to running the samples, standards were run and the calibration curve obtained used to compute the concentration of the samples. The calibration curve is attached as appendix 12. Raw water at an initial concentration of 0.5710±0.004 mg/l nitrates ions was used. After the coagulation pocess with various amount of the seeds, and computational of the residue concentration of the ions, Table 10 was computed to illustrate the results.

Table 10. Effect of the *M. oleifera* seeds on nitrates concentration

Amount of *M. oleifera* seeds (g/l)	NO_3^- Concentration (mg/l)
0	0.5710±0.004
0.05	0.5659±0.007
0.1	0.5827±0.002
0.2	0.5710±0.009
0.5	0.5743±0.004

The blank sample had a concentration of 0.5710±0.004mg/l while the treated samples concentration ranged between 0.56 and 0.58 mg/l for the various dosages employed. This indicates that the seeds did not have any significant effect on the NO_3^- ions.

Nitrites

Water contaminated with nitrites ions was also subjected to the *M. oleifera* seeds treatment. Various dosages were employed and the residue concentration determined from the calibration curve that was prepared beforehand. The calibration curve is attached as appendix 13. Table 11 indicates the results of this test.

Table 11. Effect of *M. oleifera* seeds on NO_2^- ions.

Amount of *M. oleifera* seeds (g/l)	NO_2^- Concentration (mg/l)
0	0.2588±0.002
0.05	0.2545±0.001
0.1	0.2520±0.103
0.2	0.2588±0.004
0.5	0.2527±0.003

A similar behaviour was observed for the nitrites ions. The *M. oleifera* seeds did not have any effect on the nitrites. The blank samples had a concentration of 0.2588±0.002 mg/l while the samples treated with various amount of the seeds had concentration ranging between 0.252 and 0.258 mg/l.

The nitrates and nitrites ions had been chosen as the indicator ions for other nutrients commonly found in surface water. The seeds have been found not to have any effect on their concentration which implies a different method should be employed for drinking water that is contaminated with these nutrients. The use of *M. oleifera* seeds as a coagulant has mainly focused on its ability to lower turbidity and microbial contaminants in water and therefore not much is available on its effects on nutrients. However, its effects on nitrates and nitrites concentration in water had been reported earlier on. The seeds were reported to slightly increase these ions concentration after treatment, [Ndabigengesere and Narasiah 1998]. Some recent work on the effect of the seeds on nutrients reports that the seeds slightly increased the amount of nitrates, nitrites and phosphates after treatment [Subramanium *et al*., 2011]. These scholars attributed the increase in the level of the nutrients to the fact that the treatment of water samples by the addition of seeds would inevitably add the seeds' natural phosphates and nitrates/nitrites to the water samples as leachates. These researchers suggest that instead of using the seed powder for water clarification, one could use only the purified proteins extracted from the *M. oleifera* seeds. These proteins have indeed been shown to be effective in the removal of phosphates and nitrates in water samples, [Ndabigengesere and Narasiah 1995].

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The work explored the development of a POU water purification system. Ceramic filters were prepared and their efficacy in removing some physical, chemical and biological contaminants in water evaluated while also testing the coagulation and disinfectant properties of *M. oleifera* seeds. The clay used in preparing the filters was first characterized and the results indicated that the clay was rich in silicates and Alumina and could therefore be classified as an aluminosilicate. It contained 57.8%, 15.37% and 7.62% of SiO_2, Al_2O_3 and Fe_2O_3 respectively while the other major elements oxides were all below 2.4%. The least of them were the Titanium and Manganese oxides at a composition of 0.49% and 0.10% respectively.

Filters were prepared using clay and sawdust on a volume ratio. Four ration by volume i.e. 65:35, 60:40, 55:45, 50:50 (clay-sawdust) ratio were selected and filters prepared from each ratio in triplicate. The 60:40 ratio was identified to have the best flow rate of 104.5 ml/h. The filters were very efficient in removing the feacal Coliforms, turbidity, Total suspended solids (TSS), and lead and copper ions. For all the filters, the efficiency of TSS removal ranged between 99.4 and 99.8% while for turbidity the efficiency was above 97.2 %. The filters efficiency in removing *E. coli* and other Coliforms ranged between 99.91 to 100% and 84.3 to 87.2 %. For the heavy metals, the filters were able to adsorb upto 99.5 % of the copper ions and above 96.5 % of lead ions from water.

The ceramic filters are therefore a cost effective method of improving the quality of drinking water especially water that is turbid and contaminated with Microbial contaminants. However, filtering turbid water clogs the filters and may block the filters completely. For this reason, highly turbid water needs a pretreatment process before it can be passed through the filters.

Studies on the *M. oleifera* seeds for their coagulation and disinfection properties indicated that the seeds were effective in lowering turbidity and the feacal Coliform loads of water samples. The seeds at a dosage of 0.2 g/l could lower turbidity from 100 NTU to 2.74 NTU corresponding to a reduction efficacy of over 97%. With feacal Coliforms, a dosage of 1g/l could lower the *E. coli* count from 260 CFU/ml to 14.5 CFU/ml and other Coliforms from

300 CFU/ml to 23 CFU/ml. The seeds effect on pH, nitrates/nitrites, TDS, conductivity and alkalinity were negligible. Slightly basic conditions improved the efficiency of the seeds as compared to acidic conditions. Deoiling the seeds did not lower the effectiveness of the seeds in coagulation thus the edible soil can be extracted first before the seeds cakes are used for the water treatment purpose.

Sequential use of the two POU would produce quality water and also prevent clogging of filters. The seeds could be used in the pretreatment step to lower the turbidity of the water and also lower the Microbial contaminants. On passing this water through the filters, the *E. coli* would be completely eliminated and turbidity lowered to below 2 NTU.

5.2 RECOMMENDATIONS

i. Since the tested POU were found to be effective in improving the quality of water, communities without access to potable water should be encouraged to use them in treating their drinking water.
ii. The prototypes prepared should be upscaled to the market level and field studies carried out. A cost analysis should then be undertaken to help in curbing unnecessary cost and in determining the most efficient and economical way of preparing the filters.
iii. Relevant certification from the Kenyan authorities should be sort for compliance of the filtered water.
iv. A hydraulic press should be obtained and used in making filters to ensure filters of specific dimensions are prepared thus aid in comparison studies.
v. Local communities should also be trained on how to make the filters so that they can be in charge of their water quality and also generate some income.
vi. More studies should be done on the ceramic filters to test their efficiency in removing agricultural and industrial wastes such as Persistent Organic Compounds. Determination of the size and structure of the pores should also be done to aid in understanding the purification mechanism.
vii. Extraction and application of the active coagulant protein in the *M. oleifera* seeds should be carried out to prevent the proliferation of bacteria caused by the seeds nutrients.
viii. Lastly, farmers should be sensitized on the benefits of the *M. oleifera* plant and encouraged to plant it in their homesteads to serve as a source of a water coagulant and also as a source of food.

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APPENDIX

Appendix 1. The mean and standard deviation for the local sawdust filters flowrates (ml/hr).

	Mean	Std dev
65-35(Filter 4)	28.0	1.6
60-40(Filter 3)	104.5	5.8
55-45(Filter 2)	77.5	1.9
50-50 (Filter 1)	20.0	1.3

Appendix 2. Mean TSS, Turbidity, TDS and pH and standard deviation after filtration.

	TSS(mg/l)		Turbidity(NTU)		TDS(mg/l)		pH	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
Filter1	0.6667	0.5774	1.7700	0.3923	313.6667	14.3643	7.6533	0.0586
Filter2	1.3333	0.5774	0.8500	0.0917	319.0000	5.1962	7.6733	0.0950
Filter3	0.3333	0.5774	1.0300	0.0400	314.0000	21.5174	7.7267	0.0751
Filter4	0.6667	1.1547	0.9233	0.0379	310.6667	7.7675	7.5700	0.1058
Blank	248.00	3.6056	64.1333	0.7506	345.3333	27.5923	7.7000	0.0265

N=3

Appendix 3. Percentage filtration efficiency [$(N_i-N_f)/N_i*100$] removal of the various physicochemical parameters.

	TSS	Turbidity	TDS	pH
Filter 1	99.7312	97.2401	11.6432	1.1688
Filter 2	99.4624	98.5967	10.1408	0.3463
Filter 3	99.8656	98.3940	11.5492	-0.3463
Filter 4	99.7312	98.5603	12.4883	1.6883

Note: N_i- Value before filtration

N_f- Value after filtration

Appendix 4. E. coli count, mean and standard deviation (CFU/ml) after filtration

	Sample1	**Sample 2**	**Sample 3**	**Mean**	**Std Dev**
Filter1	0	0	0	0	0
Filter2	0	0	0	0	0
Filter3	0	0	0	0	0
Filter4	0	0	1	0.3333	0.5774
Blank	390	380	400	390	10

Appendix 5. Other Coliforms count, mean and standard deviation (CFU/ml) after filtration.

	Sample1	Sample 2	Sample 3	Mean	Std Dev
Filter1	65	67	89	73.6667	13.3167
Filter2	71	80	76	75.6667	4.5093
Filter3	73	66	64	67.6667	4.7258
Filter4	78	88	84	83.3333	5.0332
Blank	520	540	530	530	10

Appendix 6. Percentage efficiency in removal of *E.coli* and other Coliforms after filtration

	E. coli	**Other Coliforms**
Filter 1	100.0000	86.1006
Filter 2	100.0000	85.7233
Filter 3	100.0000	87.2327
Filter 4	99.9146	84.2767

Appendix 7. Mean and standard deviation of *E. coli* (CFU/ml) after filtration using filters made from two type of combustible materials.

	Local sawdust		***M. oleifera* powder**	
	Mean	**Std Dev**	**Mean**	**Std Dev**

Filter 1	0.0000	0.0000	0.3333	0.5774
Filter 2	0.3333	0.5774	0.0000	0.0000
Filter 3	0.0000	0.00000	0.0000	0.0000
Blank	385.0000	5.0000	385.0000	5.0000

Appendix 8. Residue mean and standard deviation of Total Coliforms (CFU/ml) after filtration using filters made from two type of combustible materials.

	Local sawdust		***M. oleifera* powder**	
	Mean	**Std Dev**	**Mean**	**Std Dev**
Filter 1	70.6667	2.5166	67.0000	1.7320
Filter 2	85.3333	4.5093	88.33333	2.3094
Filter 3	97.3333	9.4516	88.66667	2.5166
Blank	910.0000	8.660254	910.0000	8.6603

Appendix 9. Percentage efficiency, %, of the two types of filters in total coliforms removal.

	Local sawdust filter	***M. oleifera* powder filter**
Filter 1	92.2344	92.6374
Filter 2	90.6227	90.2930
Filter 3	89.3040	90.2564
No filter	0.0000	0.0000

Appendix 10.Effect of firing temperature on various parameters; residue mean and standard deviations.

	Filter A		**Filter D**		**Raw water**	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
E.coli	0.0000	0.0000	0.0000	0.0000	390.0000	10.0000
Other	57.3333	4.5092	55.0000	3.6056	530.0000	10.0000

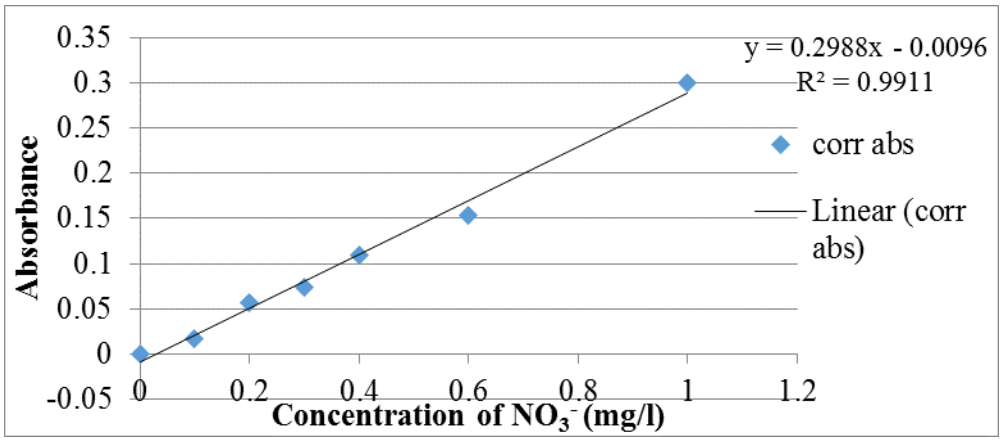
Coliforms						
TSS	0.3333	0.5774	0.3333	0.5774	248.66667	1.5258
Turbidity	0.9733	0.0352	0.9833	0.0473	69.9333	0.6806
TDS	310.3333	8.6217	312.0000	9.0000	354.6667	4.5092
pH	7.8883	0.0252	7.8767	0.0301	7.8800	0.0458

Note: Filter A was fired at 850ºC while filter D was fired at 650ºC

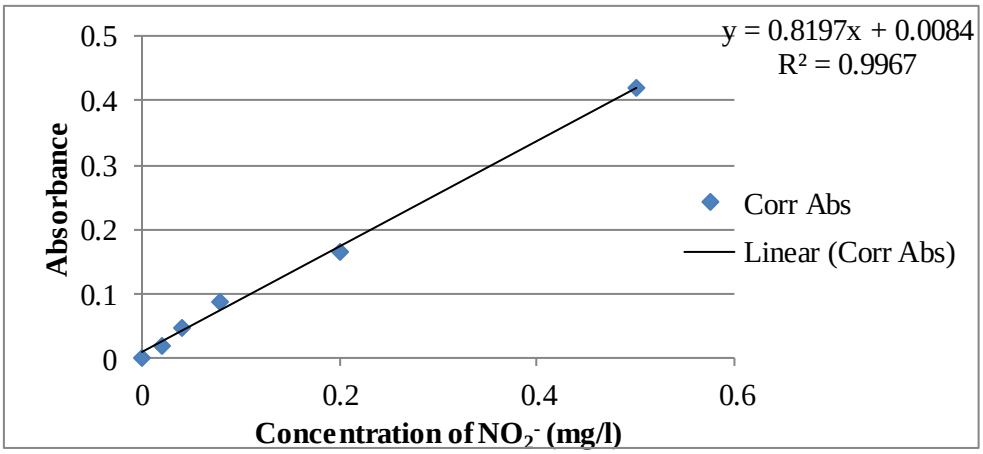
Appendix 11. Comparison of the percentage reduction efficacy of the filters fired at two different temperature.

	Filter A	**Filter D**
E.coli	100.0000	100.0000
Other Coliforms	89.1824	89.6226
TSS	99.8656	99.8656
Turbidity	99.9498	99.9325
TDS	12.5822	12.1127
pH	0.0845	0.1690

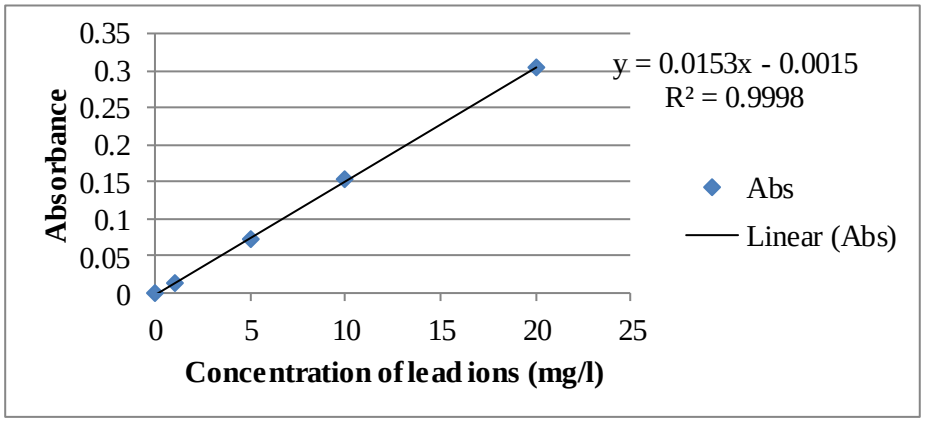
Appendix 12. Calibration curve for determination of nitrates concentration



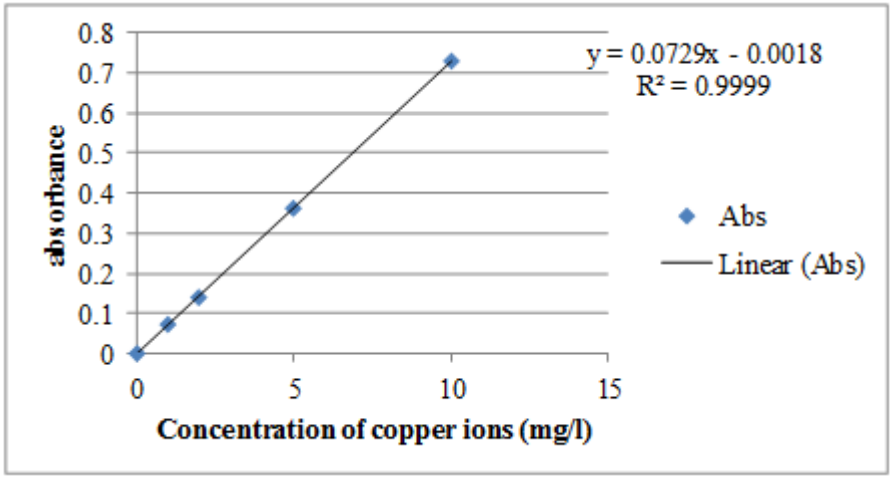
Appendix 13. Calibration curve for the determination of nitrites concentration.



Appendix 14. Calibration curve for lead ions determination.



Appendix 15. Calibration curve for copper ions determination.



Appendix 16. Wavelengths, detection limits and optimal analysis range of copper and lead metals using AAS.

Element	Wavelength(nm)	Detection limits	Lamp current (mA)	Analysis range
Lead	217	0.02	3	0-20
Copper	324.8	0.01	8	0-10

Note: Air/Acetylene flame was used in the analysis

Appendix 17. Mean and standard deviation for various physicochemical parameters after treatment with various amount of *M. oleifera* seeds.

***M. oleifera* amount (ø/l)**	**Turbidity**		**TS**		**Conductivity**		**pH**		**TDS**		**Alkalinity**	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
0.00	85.10	1.13	418.00	7.07	475.00	5.66	8.52	0.04	238.50	2.12	14.50	0.71
0.05	34.80	1.56	232.00	4.24	463.50	2.12	8.51	0.03	232.00	1.41	14.50	0.71
0.10	8.91	0.62	225.50	7.78	470.00	1.41	8.31	0.09	235.50	0.71	14.50	0.71
0.15	5.29	0.04	205.00	9.90	465.00	2.83	8.29	0.03	233.00	2.83	14.50	0.71
0.20	2.54	0.01	202.00	2.83	474.50	2.12	8.48	0.04	233.00	2.83	14.50	0.71
0.25	3.08	0.01	208.50	3.54	472.50	2.12	8.52	0.03	238.50	2.12	14.50	0.71

0.40	3.65	0.35	216.50	4.95	470.50	3.54	8.42	0.01	234.50	2.12	14.50	0.71
0.50	4.94	1.07	228.00	8.49	469.00	2.83	8.41	0.02	238.00	4.24	14.50	0.71

Appendix 18. Percentage reduction of some physicochemical parameters by *M. oleifera* seeds.

Dosage	**Turbidity**	**TSS**	**Conductivity**	**pH**	**TDS**	**Alkalinity**
0.05g/l	59.1069	44.4976	2.4210	0.1174	2.7254	0.0000
0.1g/l	89.5358	46.0526	1.0526	2.5234	1.2578	0.0000
0.15g/l	93.7897	50.9569	2.1052	2.6995	2.3061	0.0000
0.2g/l	97.0153	51.6746	0.1052	0.5282	2.3061	0.0000
0.25g/l	96.3807	50.1196	0.5263	0.0000	0.0000	0.0000
0.4g/l	95.7168	48.2057	0.9474	1.1737	1.6771	0.0000
0.5g/l	94.1951	45.4545	1.2632	1.3498	0.2096	0.0000

Appendix 19. Optimal *M. oleifera* seeds dosage for synthetic turbid water at 100±0.56 NTU.

	1 hr		4 hrs		18 hrs	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std dev**
0.00g/l	87.2000	3.3451	74.9333	1.4572	54.3000	1.6000
0.05g/l	53.8667	3.9627	48.5333	6.9759	15.2000	0.3000
0.1g/l	34.7333	0.4041	21.5667	0.8737	8.9267	0.4366
0.15g/l	12.2000	0.7937	6.9400	0.7937	3.2233	0.1097
0.2g/l	5.2500	0.3051	2.7400	0.3051	0.8300	0.0755
0.25g/l	13.8000	1.9975	4.6450	1.9975	3.3867	0.5313
0.4g/l	17.6667	0.6807	9.3333	0.6807	3.6533	0.2454
0.5g/l	22.2000	0.7550	13.9333	0.7550	5.1600	0.8502

Appendix 20. Optimal dosage for synthetic turbid water at 16.3 ±0.26 NTU initial turbidity.

	0 hr		**1 hr**		**4 hrs**	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
0.00g/l	16.3000	0.2646	14.2333	0.3055	12.9000	0.3000
0.025g/l	16.3000	0.2646	2.8800	0.2651	1.4400	0.0794
0.05g/l	16.3000	0.2646	3.8500	0.0624	2.9000	0.3988
0.1g/l	16.3000	0.2646	5.7433	0.0586	3.5550	0.7464

Appendix 21. Optimal dosage for naturally turbid (22.5±0.3 NTU) water.

	0 hr		**1hr**		**4 hrs**	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
0.00 g/l	22.5000	0.3000	20.9667	0.2517	19.7000	0.5568
0.05g /l	22.5000	0.3000	14.4667	0.2082	7.4133	0.2421
0.1 g/l	22.5000	0.3000	12.5667	0.1114	6.2100	0.1114
0.2 g/l	22.5000	0.3000	9.2333	0.1250	4.0233	0.1250
0.4 g/l	22.5000	0.3000	10.4333	0.5095	6.4433	0.5095

Appendix 22. Effect of pH on turbidity removal using *M. oleifera* seeds.

	1 hr		**4 hrs**		**24 hrs**	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
pH5	19.83	0.67	12.19	0.28	3.15	0.06
pH7	15.23	0.31	11.43	0.31	1.87	0.10
pH9	16.43	0.51	10.30	0.14	1.43	0.04

Appendix 23. Preliminary disinfection results

Amt of *M. oleifera*	***E. coli* (CFU/ml)**	**Other Coliforms**

seeds (g/l)		(CFU/ml)
0	390	590
0.05	300	350
0.1	200	240
0.2	100	120
0.5	37	55
1	30	51
2	22	49
4	29	59

Appendix 24. Optimal disinfection dosage

Moringa dosage (g/l)	*E. coli*		Other Coliforms	
	Mean	Std Dev	Mean	Std Dev
0.00	110.00	14.14	133.00	9.90
0.03	84.50	6.36	104.50	6.36
0.05	72.50	2.12	62.50	3.54
0.10	60.00	7.07	65.00	7.07
0.20	52.00	5.3	70.00	6.93
0.25	51.50	7.78	65.00	2.83
0.40	34.00	7.07	49.00	14.14
0.50	26.50	0.71	40.00	19.80
1.00	14.50	0.71	23.00	2.83
2.00	15.00	1.41	23.00	1.41

Appendix 25. Percentage disinfection efficiency.

Dosage (g/l)	*E. coli* (CFU/ml)	Other Coliforms (CFU/ml)
0	0	0
0.10	45.4546	51.1278
0.25	53.1818	51.1278

0.5	75.9091	69.9248
1.00	86.8182	82.7068
2.00	86.3636	82.7068

Appendix 26. Residue *E. coli* fraction after treatment with *M. oleifera* seeds.

	Residue fraction			
	0 hr	**1 hr**	**3 hrs**	**6 hrs**
pH5	1	0.0633	0.0257	0.0323
pH7	1	0.04	0.0253	0.0243
pH9	1	0.0257	0.01	0.0077

Appendix 27. Residue fraction for other Coliforms after *M. oleifera* seeds disinfection.

	Residue fraction			
	0 hr	**1 hr**	**3 hrs**	**6 hrs**
pH5	1	0.1586	0.1190	0.1164
pH7	1	0.1426	0.0971	0.0621
pH9	1	0.05	0.0178	0.0116

Appendix 28. KEBS, WHO and USEPA maximum permissible level on some drinking water parameters.

Substance/ Characteristic	**KEBS**	**WHO**	**USEPA**
pH	6.5-8.5	6.5-8.5	6.5-8.5
Turbidity (NTU)	5	5	1
TDS (mg/l)	1,500	500	500
TSS (mg/l)	nil		30
Conductivity (µS/cm)	50-500	50-500	50-500
Copper (mg/l)	0.1	1.3	1.3
Lead (mg/l)	0.05	0.015	0.015

NO_3^-(mg/l)	10	10	10
NO_2^-(mg/l)	1	1	1
E. coli (CFU/100ml)	nil	nil	nil

Source: KEBS, WHO, USEPA