JIMMA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

ENVIRONMENTAL ENGINEERING CHAIR

DEVELOPMENT OF POINT OF USE WATER PURIFICATION TECHNOLOGY USING MORINGA SEED COUPLED WITH SCORIA AS AN ALTERNATIVE COAGULANTION-FILTERATION MEDIA.

BY: BERACHA DANDESA

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Development of point of use water purification technology using Moringa seed coupled with Scoria as an alternative coagulantion-filteration media.

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DECLARATION

I, Beracha D. O hereby declare that the work presented in the thesis entitled **"Development of point of use water purification technology using Moringa seed coupled with Scoria as an alternative coagulantion-filteration media."** was based on the original work done by me under the supervision of Professor Esayas Alemayeh and Yalemsew Adela, School of Civil and Environmental Engineering at Jimma Institute of Technology. No part of this thesis has been presented for any other degree award from any other institution.

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Abstract

The coagulation-flocculation, filtration and adsorption behavior of some low-cost adsorbents such as peanut husk, charcoal, fly ash, Volcanic ash soil and natural zeolite materials have been studied as treatment agents to remove undesirable PO_4^{-3}, Fe^{+3} and F^- ions and other heavy metals from water by adding significant alternatives to the water purification technology. Chronic exposure to high fluoride (>1.5) leads to dental and skeletal fluorosis while high concentration of phosphate (i.e. >1 mg/l) in drinking water cause digestive problems and interfere with coagulation in water treatment plants whereas high concentration of iron (>0.3mg/l) has the potential of generating bad taste to the drinking water. This study aimed at developing point of use drinking water purification technology using Moringa Olifera seed (MOs) coupled with Virgin Scoria (VSco) as coagulant and filter media. The physicochemical parameters considered to evaluate the efficiency of the technology were turbidity, TDS, COD, Color and PO_4^{-3}, Fe^{+3} and F^-.

The physicochemical analysis of water sample was done before and after both treatment, using standard methods. The sampling and analytical efforts was focused on two major phases (1) The coagulation flocculation through jar test experiments using MOs and (2) the filtration process through VSco filter media. Jar test experiments was conducted under batch experiment as a function of solution pH, contact time, adsorbent dosage and adsorbate concentration to obtain maximum operation quality and optimal dose range at the standardized agitation speed. Based on this, the physicochemical analysis indicated that turbidity from (150-8NTU), PO_4^{-3}(20-5.95mg/l), Fe^{+3} (7- 2.93mg/l) and F^- (9-2.83mg/l) reduction was achieved at 35mL/L of Optimum Moringa dose within 6.5-7.5pH range. Then VSco filtration was conducted after jar test under small column experiment as a function of contact time (0, 2, 4hrs). The VSco removal capacity showed that the removal of turbidity from (8-2.54NTU), PO_4^{-3}(5.95-1.07mg/l), Fe^{+3} (2.93-0.43mg/l) and F^- (2.83-1.94mg/l) were attained after 4hr detention time.

Generally, the percent removal of turbidity, PO_4^{-3}, Fe^{+3} and F^- increases remarkably with increasing of their initial concentration. At an initial concentration of turbidity (150NTU), PO_4^{-3} (20mg/l), Fe^{+3} (7mg/l) and F^- (9mg/l), the removal efficiency were 98%, 84%, 85% and 60% respectively. However, the removal capacity of VSco decreases with increasing the time of operation unless it was washed from clogging particulate matter or replaced by new scoria. The batches experiment (using positively charged protein of MOs) suggested that the removal behavior was mainly controlled by cation exchange and typically displays characteristics of charge neutralization. Therefore, we recommend VSco -Moringa as an economic, efficient and simple Point of Use drinking water treatment technology.

Keywords: *MOs, VSco, coagulation, flocculation, filtration, turbidity, PoU, physicochemical parameters.*

Acknowledgements

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List of Abbreviations

AWWA   American Water Works Association

BDL   Below Detention Level

COD   Chemical oxygen demand

DOC   Dissolved Organic Carbon

EDTA   Ethylene diamine tetra-acetate

EPA   Environmental protection agency

MCL   Maximum contaminant level

MOs   Moringa Olifera seed

NOM   Natural Organic Matter

NTU   Nephelometric turbidity units

PoU   Point of Use

PVC   Poly Vinyl Chloride

RSF   Rapid sand filters

SSF   Slow sand filters

TDS   Total dissolved solid

VSco   Virgin scoria

WHO   World Health Organization

CHPTER ONE

INTRODUCTION

1.1 Background

The world water crisis was extremely increasing day to day as clean drinking water accessibility decline by far. Treatment of contaminated water remains a topic of global concern to minimizing this remaining complications (Weber *et al.,* 1991). Although 2 billion people have gained access to improved water sources between 1990 and 2010, more than 780 million people were still relying on unimproved sources such as surface water and unprotected wells for drinking water (WHO/UNICEF, 2011).The increase of accessibility of potable water has been lowest in the least developed countries and amongst the poorest people and there are great disparities between the regions of the world.

The situation was worst in sub-Saharan Africa, where 40% still do not have improved water and in this area the population growth exceeds the number of people that have gained access to improved water sources (Bodlund, 2013). In Ethiopia, the shortage of safe quality drinking water supply was predictable, due to rapid population growth and other factors like industrial discharge, agricultural run-off and poor sanitation practices putting long-term pressure and quality problem on the potable water resources. People were still consuming untreated water from rivers, springs, wells, surface impoundments and other open water sources which often contain biological and chemical agents detrimental to health (Teka, 1982). Water from these sources was rarely fit for drinking unless treated first due to excessive chemical and physical constituents (organic or mineral contents) which was the major reason for the poor water quality. The main problems were caused by iron and manganese, fluoride, nitrate, phosphate, turbidity, color and etc.

Among undesirable ions in water which was addressed by this study were phosphate (PO_4^{-3}), fluoride (F^-) and iron (Fe^{+3}) including suspended particulate matter (turbidity) as a major one. Phosphorus (P) was an essential nutrient for all life forms, required for the necessary building block of life to occur. However, when the concentration increases beyond the natural threshold, it was a limiting nutrients in aquatic ecosystems. The U.S. EPA. (1999) reports that excess phosphate

can initiate nuisance algae blooms, leaving dead and living plankton, precipitates of phosphorus as one of the main problems in drinking water management (Kyzas and Kostoglou, 2014).

Fluoride (F^-) is another common ion in waters, which in large amounts in drinking water can cause discoloration of the teeth (Kemira, 2003). Fluoride pollution has been observed not only in various minerals and chemical processes but also in some natural water systems over large areas in Asia, Africa, America, Europe, where the fluoride concentration can range from 0.01 to 3 mg/l in fresh water and 1–35 mg/l in ground water (Gandhi, 1993). Fluoride in drinking water was considered to be beneficial or detrimental depending on its concentration and total amount ingested. It is beneficial in human body for the calcification of dental enamel and maintenance of healthy bones when present within the permissible limit.

On the other hand, iron is one of the most abundant resources comprising 0.5 to 5% of earth's crust (Ityel, 2011; Vance, 1994). High iron concentrations in water give them a reddish color in the presence of oxygen and are responsible for problems like staining, taste issues, stock losses in aquaculture and pipe fouling. This secondary contaminant's maximum contaminant level (MCL) set by EPA for amount of total iron in public water systems is 0.3 mg- Fe/L (EPA, 2013).

To alleviate these prevailing difficulties, approaches are focusing on sustainable water treatment systems (Fufa *et al*, 2014). This study was designed to investigate the sustainable drinking water purification potential of porous Virgin Scoria (VSco) from volcanic rock, which was abundant in many parts of Ethiopia and Moringa Oleifera Seed (MOs) from natural plant origin.

The Moringa Oleifera (MO) tree grows in tropical and subtropical regions around the world and its seeds have been used in drinking water treatment in small scale in Sudan and India for generations. The coagulant in the seeds is believed to be one or several proteins that act as a cationic polyelectrolyte. The soluble particles in the water attaches to the active agent, that binds them together creating large flocs in the water. Previous studies indicate that MO is an efficient coagulant and does not have an effect on most of the properties of the water, but an increase in COD has been noticed. However, the use of MOs together with VSco as a filter media was designed to remove COD and the possibilities of organic matter developed in MOs treated water.

Different ways of extracting the active agents were used and this would have an effect of the treatment efficiency. The optimum dosage of the coagulant was investigated for different levels of turbidity, phosphate, fluoride, iron and monitoring of the properties of the water was performed.

Volcanic rocks are formed from volcanic magma. The most abundant volcanic rocks include Scoria, a rough rock that looks like furnace slag and Pumice, a finely porous rock foamy with air bubbles (Bryan, S.E. 2004). Scoria and pumice deposits originate in areas with young volcanic fields. These rocks are abundant in Europe (Italy, Turkey, Greece and Spain), Central America, Southeast Asia and East Africa (Eritrea, Djibouti, Kenya and Ethiopia) (Moufti *et al*., 2000). The Ethiopian Rift Valley, which covers around 30% of the area of the country, has several of these cinder cones and lava fields (Reimann *et al*., 2003) and (Assefa G. 1984). Volcanic rocks have received considerable interest for heavy metals removal mainly due to their valuable properties: high surface area, low cost and local availability in large quantities. In recent year, the potential of vol canic rocks to remove metals from water and wastewater has been reported (Kwon *et al.,* 200)

1.2 Statement of the problem

In developing countries polluted water undergoes no treatment for most of the less developed community sectors (Homsi, 2000), leaving large volumes of contaminants to the natural streams and surface water sources used for human consumption flowing through urban streams and drains. Serious attention was not given in controlling the point and non-point sources of contaminants due to lack of potentially strong castigation and failure of empowering the society with lesson. This has adversely affected the quality of drinking water in and around the main source (Obiri-Danso *et al.,* 2005). For instance, the presence of turbidity, phosphorous, fluoride and iron in water pose huge mess in drinking water quality (Cloern *et al.*, 2010).

Naturally occurring levels of phosphates in surface and ground water bodies are not harmful to human health, animals or the environment. Conversely, phosphate level (>1.0 mg/l) cause digestive problems and interfere with coagulation in water treatment plants as a result, organic particles that harbor microorganisms may not be completely removed (Sheila, 2005). Besides that, treatment cost of contaminated water was also raised to high level because the costs of advanced equipment were needed.

The deficiency of fluoride (<0.4mg/l) intake leads to dental caries while excessive consumption (>1.5) leads to dental and skeletal fluorosis which was a severe chronic disease manifested by mottling of teeth in mild cases, softening of bones and neurological damage in severe cases (Wang and Reardon, 2001). An urgent need to treat fluoride contaminated drinking water was highly necessary to make it safe for human consumption since it was toxic to mankind. On the other hand, the presence of dissolved Fe^{+3} in drinking water could have an impact on the color, odour, and poor bitter taste to drinking water (Appelo & Postma, 1994 and Kemira, 2003). In order to avoid such grievances, it was recommended that the Fe^{+3} concentrations in potable water should not exceed 0.3 mg/l (WHO, 2006).

So far little has been done in alternative measures which was helpful in improving such drinking water quality problems for the community sectors relying on untreated water sources. In Ethiopia, it has been observed that drinking waters were directly tapped from their sources and used without any purification or pre-treatment (Alemayehu, 2001). According to this report the local people were more concerned on the color and odor of the water sources. Particularly, the overall inorganic

as well as organic constituents of these waters were not concerned before using the water for drinking.

Different Existing technologies have been established for many years in order to make the water suitable for human consumption (Gupta and chaudhuri, 1995). Most of them were convectional and expensive. Conventional methods for removal of phosphate, fluoride and excessive iron involves the use of inorganic chemicals (Srimurali *et al*., 1998), biological treatment, ion-exchange, aeration, sand filtration, adsorption, etc.(kartinen and Martin, 1995). These available methods have several disadvantages which make them not sustainable and unaffordable for non-developed areas around the globe since the processes request high energy, infrastructure, maintenance and highly skilled labor (Peter, 1999) and also associated with human health and environmental problems (Kaggwa *et al*., 2001).

All of them were less attractive for low-income countries (Carr and Strauss, 2001) and this situation persists and it will continue to cause substantial loss of human lives unless it was seriously dealt with at all levels. Therefore, numerous efforts have been oriented to obtain low-cost but efficient removal technology that may be used in poorly developed areas for drinking water purification purposes.

1.3 Significance of the study

The primary purpose of water treatment was to provide drinking water to consumers that was free of undesirable health factors using different form of technology based on the required quantity and quality of the water. The study was designed to look for alternative water purifying media where Virgin Scoria (VSco) from volcanic rock and Moringa Oleifera Seed (MOs) from natural plant origin found abundantly and were chosen for experimentation. VSco's potential to remove contaminants mainly depends on their valuable properties porous, high surface area and local availability in large quantities (Alemayehu and Lennartz, 2010, Kwon, *et al*, 2005).

Using Moringa seed as a coagulant gives many advantages, such as cheap substitute and safe for human health (Hsu et al., 2006) less and biodegradable sludge production (Ghebremichael, 2004) doesn't required pH adjustment (Ndbigengesere and Narasiah, 1998). On the other case, as it was already addressed by many researchers, there was the probability of the increments of nutrient and COD in the water treated with Moringa Olifera seed (MOs) (Bengtsson, 2003). However, based on the design of this study, in addition to its filtration capacity of other ions, VSco filtration was designed to resolve this suspected problems expected to be remained in the treated water.

Therefore, this study was attempted not only to improve the gap of moringa seed water filtration and purification quality problems but also that VSco-Moringa drinking water purification was safe for human health and the environment, efficient, highly economical and sustainable alternative technology in removing suspended clay particles, anions and cations from water for those communities directly relying on untreated water source for their drinking water consumption. Hence, the following were research questions that was attempted.

1.4 Research Question:

☛ What is the drinking water purification capacity of Moringa Olifera seed (MOs) from undesirable concentration of turbidity, PO_4^{-3}, F^-, and Fe^{+3}?

☛ What is the turbidity, $PO4^{-3}$, F^-, and Fe^{+3} removal capacity of Virgin Scoria (VSco) after Moringa Olifera seed (MOs) coagulation?

☛ What is the maximum removal capacity and optimum operating parameters of VSco together with Moringa Olifera seed (MOs) of $PO4^{-3}$, F^-, and Fe^{+3} and suspended matters for point of use drinking water purification?

☛ How much the optimized design parameters of the media is effective in purifying the real water for point of use drinking purpose?

CHPTER TWO

LITRATURE REVIEW

2.1 The Global Need for Clean Water

A common definition of clean water was water that should be free of pathogenic organisms, toxic substances, turbidity, color, taste, odor, and an acceptable level of minerals and organic material (Thanh and Hettiaratchi, 1982). Every human on our planet has a fundamental right to a reliable supply of clean water. Yet according to the World Health Organization, there were still 1.1 billion people in the world without access to an improved water supply (WHO and UNICEF, 2000). This translates to 6% of the total global population lacking access in urban areas, and 29% lacking access in rural areas. This was not only a critical problem in developing countries, but also a challenge faced by many municipalities in both rural and remote areas of the developed world.

With the increasing demand of clean drinking water, the use of untreated surface and groundwater have to be increase. The major challenge was to optimize the benefits of untreated water as a resource from pollutants and nutrients it contains, and to minimize the negative impacts on human health. Because of high treatment costs, most cities in low-income developing countries may not have treatment facilities in the foreseeable future. However, while the use of untreated water has become a routine for public consumption, it was very important to look for economically viable interventions that could be adopted for contaminated water purification.

2.2 Conventional Water Treatment Methods

Drinking water treatment involves a number of combined processes based on the quality of the water source such as nutrient, turbidity, amount toxic chemical load present in water and the others include cost and availability of technologies in achieving desired level of treatment. Until now, conventional technologies including key steps of coagulation, flocculation, sedimentation, filtration and disinfection have greatly contributed to water quality improvement. These were well proven technologies for the removal of suspended matter, heavy metals, bacteria, and other microorganism. Iron, manganese, tastes and odors also be removed from the water by these processes. No single process can, however, solve every water quality problem rather, a utility must

choose from a wide range of processes that were used for different purposes (Mpagi, 2007). Coagulation and filtration were the most critical unit processes determining success or failure of the whole system and they were the bottlenecks for upgrading treatment plants (Ghebremichael, 2004). The two units were so closely linked that the design of one affects the other. Therefore much emphasis was put on the proper design and operation of these units.
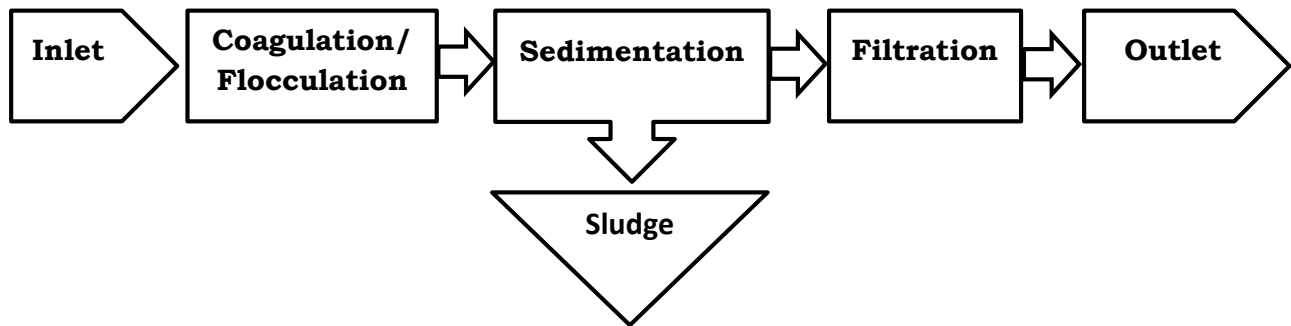
Fig. 2.1. Schematics flow of treatment process

2.3 Coagulation and flocculation method

The particles existing in water would settle down on their own if enough time was given. But settling may take time of days/months due to small particle size and to electrostatic repulsion between the particles. Most of the particles existing in water have negative charges, so they tend to repel each other. In order to remove them effectively, coagulation/flocculation process was recommended to apply (Gao, et al., 2002). Coagulation was a treatment process that includes chemical addition, rapid mixing, and flocculation, intended to form particles large enough to be easily separated. Larger aggregated particles then settle out of the liquid quickly.

When coagulants are added into water, destabilization of colloids, clay particles, Dissolved Organic Carbon (DOC) or Natural Organic Matter (NOM) including metal ions which together were responsible for the manifestation of undesirable water odor, taste, color and the presence of microorganisms (Raghuwanshi et al., 2002) occurs due to adsorption, charge neutralization or particle entrapment (Duan, and Gregory, 2003). Previous studies show that coagulation can remove them by adsorption and charge neutralization, adsorption and inter-particle bridging, and precipitation (Yin, 2010).

The most common mechanism in coagulation/flocculation processes was the inter-particle bridging and charge neutralization (Okuda et al., 2001). Because trace contaminant elements, ions, organic matters, viruses and bacteria were often associated with particulate matter (turbidity), increasing removal of particulates also increases the removal of these pollutants (Jiménez, 2003).

Although the chemicals were very effective and widely used, they have certain drawbacks. Performance of metal salts was significantly influence the pH and alkalinity value of the water, increase the soluble residues, volume and metal content of the sludge. On the other hand, with aluminum salts, there was a concern of associated human health and environmental disaster (Crapper, *et al.*, 1973; Miller, *et al.*, 1984). The suggested mechanism of coagulation property of Moringa Olifera seed (MOs) was supposed to be that positively charged proteins bind to part of the surface of negatively charged particles through electrostatic interactions.

The addition of positively charged coagulants destabilizes the negative charges of the suspended and dissolved particles in the water (Diaz et al., 1999). This leads to the formation of negatively and positively charged areas of the particle surface. Due to particle collision and neutralization, formation of flocs with a net-like structure take place (Figure 1) (Ndabigengesere et al., 1995; Gassenschmidt et al., 1994). When this reaction occurs, the particles bind together (coagulation); this process was also referred to as flocculation. The large particles (flocs) formed were denser and quickly settle to the bottom of the vessel (Ghebremichael,et al., 2009).

2.4 The use of natural Coagulants

A number of effective coagulants have been identified of plant origin. Some of the common ones include okra studied by (AL-Samawi and Shokrala, 1996), Cactus latifaira and Prosopis juliflora (Diaz, *et al.*, 1999), M. oleifera (Olsen, 1987, Ndabigengesere, 1995), peach kernel and beans (Jahn, 2001), and maize (Raghuwanshi, *et al.*, 2002). The finding of Bhole, who comparing the ten natural coagulants from plant seeds would be estimated. The study indicated that maize and rice had good coagulation effects when used as primary coagulants or coagulant aid (Bhole, 1995).

Chitosan, a natural coagulant from animal origin was also an effective coagulant (Pan, *et al.*, 1999; Divakaran and Pillai, 2001). It has also been reported that chitosan possesses antimicrobial

properties (Liu, *et al*., 2000; Chung, *et al*., 2003). By using natural coagulants, considerable savings in chemicals and sludge handling cost would be achieved. Al-Samawi and Shokral, (1996) reported that 50 – 90% of alum requirement could be saved when okra was used as a primary coagulant or coagulant aid. Apart from being less expensive, natural coagulants produce readily biodegradable and produce significantly less sludge volume. For example, sludge produced from M. Oleifera coagulated turbid water was 20 – 30% of that of alum treated water (Ndabigengesere, *et al*., 1995; Narasiah, et al., 2002).

Moringa Olifeira seed coagulant have been a multipurpose tree with most of its parts being useful for a number of applications and it was therefore referred as a "miracle tree" (Fuglie, 1999). It was a small, fast growing, drought resistant and evergreen deciduous tree that ranges in height from 5-12 m with an umbrella shaped crown, straight trunk, 10 – 30 cm thick (Arnoldsson, *et al*., 2008). The pods, leaves and flowers were important source of food, medicines, vitamins etc. in some areas of India and Africa.

Of all the plant materials that have been investigated over the years, Moringa Olifera seed (MOs) have been shown to be one of the most effective as a primary coagulant for water treatment. Moringa Olifera seed (MOs) has been used for generations in countries like India and Sudan. Since the early 1970's a number of studies have been carried out to determine the effectiveness of the seeds for the treatment of surface water (Ghebremichael, 2004; Ndbigengesere and Narasiah, 1998). Utilizing artificially prepared turbid water and naturally turbid raw waters, laboratory investigations have confirmed the seeds to be highly effective in the removal of suspended solids from waters containing medium to high initial turbidities (Sutherland, et al., 1994).

Fig. 1.2. Standing tree, pen fruit with seeds of *M. Oleifera*

Pilot plant trials and full-scale plant trials carried out in Malawi at Thyolo Water Treatment Works demonstrated that the seeds could be used effectively on continuous flow systems producing treated water quality similar to that of aluminium sulphate (Folkard, *et al*., 20001995). In his research, Jahn, (2001) investigated the potential of plant seeds and roots on removal of turbidity and compered it with alum. Compared to the commonly used coagulant chemicals, MO has a number of advantages:

- o It was of low cost
- o Produces biodegradable sludge
- o Produces lower sludge volume
- o It does not affect the PH of the water

However, apart from several advantages of the Moringa Olifera seed (MOs) over chemical coagulants, the main drawback in using Moringa Olifera seed (MOs) in water treatment was the release of organic matter and nutrients to the water. Previous studies showed that Moringa Olifera seed (MOs) increase the organic matter and nutrient contents in treated water, while the purified form does not (Ghebremichael *et al*., 2006, Okuda *et al*., 2001).

The presence of these organic loads was a source of odor, color and taste in water; they also facilitate the regrowth of microorganisms upon storage, thus limiting the use of crude Moringa Olifera seed (MOs) in general as a coagulant for water treatment (Ndabigengesere & Narasiah 1998).

In order to overcome these limitations (based on the raw water turbidity level, the required quality of water and availability of the resource), different alternatives needs to be applied. Some were: mixing the powder with tap or distilled water and filtering to prepare in the form of past, using extraction mediums such as alcohols, salt solution or chemical solvents which have been successfully applied by Okuda et al. (2001) etc. However it was assumed these materials may not be readily available to a user in the field of local community at each point of use for those who directly rely on untreated water source for drinking consumption.

The coagulation and flocculation ability of the seeds has been investigated in several different projects around the world (Ndabigengesere and Narasiah 1998, Bengtsson 2003, Muyibi and Alfugara 2003). These previous studies have shown that neither pH nor alkalinity or conductivity was affected during the treatment, but slight increase in COD and small nitrate has been observed (Bengtsson, 2003, Ndabigengesere and Narasiah 1998). The treatment efficiency was dependent on the turbidity of the raw water, as revealed in previous studies from Katayon report. It was shown that Moringa was more efficient if the water has high initial turbidity (Katayon, *et al*, 2006).

2.5 Filtration

Filtration is a physical process that act as a consistent and effective barrier against suspended particulate matter, trace metal ions, organic matter including pathogens and other form of pollutants. In filtration contaminants were removed by passing the contaminated water through sand or other porous media. Sequentially arrenged sieve size of various sand including coarse aggrigate was carfully compacted in order to retain Moringa Olifera seed (MOs)t of the flocs, undesireable metalic ions and other particles that escape Moringa Olifera seed (MOs) coagulation and sedementation. Such arrengment (that obtained from seive analysis) was required to block the particle size that can be removed in deep-bed filtration which was much smaller than the pore size of the filter (Hall, 1998). This is due to electrostatic adhesion (sticking together) causing adsorption of particles that are in close proximity to the filter medium.

There were several types of filtration including high rate granular filtration, slow sand filtration, and dual media filtration. Dual media filtration uses two types of media with different properties to maximize the removal of particles with different properties. The effectiveness of filtration techniques for removing contaminants depends upon the operating conditions. For example, fast rate and dual media filtration were usually preceded by coagulation. Substances which normally produce turbidity consist largely of trace element, clay minerals and microscopic organisms and occur in widely varying sizes, ranging from those large enough to settle readily to those small enough to remain suspended for very long times.

Table 2.1. Effect of decreasing of particle size on time of settling

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

Source: (Powell S. T., 1954)

The long-term ability to remain suspended in water was basically illustrated above which shows the relative settling times of different particle sizes. These substances, can be removed by coagulation, which serves to agglomerate the very small particles into sizes, which were settleable or can be removed by filters. When flow becomes excessively restricted due to clogging or when turbidity counts of the filtrate become unacceptably high cleaning the bed is necessary.

2.6 Virgin Scoria (VSco)

A number of researchers have focused on the development of cost effective materials and have examined the effectiveness of various natural inorganic and organic materials for the clay suspended, dissolved maters and metal ions attachments. Sand is a common filter materials, but anthracite, granular activated carbon (GAC), zeolite, bentonite, red mud, fly ash, cocoa, shells etc. (Gupta, *et al*, 2000) are also common filter materials.

It has been reported that Virgin Scoria (VSco), has a higher adsorption capacity and affinity for metals than commercial activated powder (Kwon, *et al.* 2005). VSco, for example, has shown to retain larger amounts of zinc (about 1.5 times) compared to that of commercial activated carbon in batch-type sorption tests (Kwon, *et al.,* 2005). The uptake and removal of heavy metals by scoria increased rapidly during the first phase and then became slower and finally approached an equilibrium state within the duration of the experimental period, and this confirmed that the sorption is quite rapid. The result indicates that the sorption mainly took place at the surface of the sorbent during the initial stage. VSco was a vesicular pyroclastic rock with basaltic composition, which was reddish brown to black in color and was light in weight (Bates and Jackson, 1987).

VSco has been used in several industrial applications, such as the manufacturing of a lightweight concrete mixture, a heating-insulating material, low-cost fillers in paints, and sorbents (Alemayehu and Lennartz, 2009; Moufti, *et al*., 2000). VSco was abundant in many places worldwide including Central America, Southeast Asia (Vietnam, etc.), East Africa (Ethiopia, Kenya, etc.), and Europe (Greece, Italy, Spain, Turkey, etc.) (Alemayehu, Lennartz, 2009; Moufti, *et al*., 2000). SiO_2 and Al_2O_3 contents make up about 63% of the scoria, and FeO and CaO compose about 21%. The chemical composition of the Scoria, mean percentage by weight determine d by XRF, was as follows:

Silicon Dioxide (SiO_2) Wt %........................47.4
Iron Oxide (Fe_2O_3) Wt %...........................8.9
Aluminium Oxide (Al_2O_3) Wt %................21.6
Calcium Oxide (CaO) Wt %.......................12.4
Potassium Oxide (K_2O) Wt%......................0.5
Sodium Oxide (Na_2O) Wt%........................3.0
Magnesium Oxide (MgO) Wt%..................3.3
Titanium Oxide (TiO_2) Wt%.......................1.7
Others (Wt %)……………………………1.2

Source: E. Alemayehu and B. Lennartz, 2009

Fig. 2.3.The Red variety of scoria

Despite its use in various industrial applications, the sorption mode of metals onto VSco was still not clearly understood. To understand the sorption mechanism(s) for the removal of heavy metals by scoria, analyze of a number of cations in addition to target heavy metals in the solutions is necessary. Through the leaching experiments of scoria using deionized water under condition equivalent to kinetic sorption tests, it was confirmed that the metal ions Ca(II), Mg(II), Na(I), and K(I) were released at only very low levels of 0.3, 0.1, 1.0, and 0.5 mg/l, respectively, after a reaction time of 24hrs (Jang, *et al.* 2010). The results indicate that the release of these cations from scoria is very slow under the experimental condition.

On the other hand, considering the potential use of VSco as a sorbent or filtration, knowledge of metal interactions with the rock nature was essential. The rough surface and porous structure provide a large number of possible attachment sites for pollutants (Alemayehu, Lennartz, 2009). The large proportion of free silica sites at the grain surface results in a negative charged surface. The removal efficiencies of Pb, Cu, Zn, and Cd by the scoria were 94, 70, 63, and 59%, respectively, after a reaction time of 24hrs (Jang, *et.al*. 2010). In the present study, we attempt to evaluate the usefulness of VSco as a filtration for the removal of inorganic contaminants, in particular phosphate, fluoride and iron.

2.7 Phosphorus pollution

Phosphorus is one of the key elements necessary for growth of plants and animals. Phosphorus in elemental form is very toxic and is subject to bioaccumulation. Phosphate PO_4^{3-} is formed from this element. Load of nutrients has a large effect on the taste and smell of the water and can sometimes be a large problem in both surface and river waters. Among a variety of removing techniques, chemical precipitation advanced biological treatment adsorption is known to be more useful and economical (Yin and Cui, 2006). Pumice and Scoria from volcanic rocks have been used as a natural adsorbents having better features to be used as low-cost adsorbents of pollutants for the removal of phosphate, heavy metals and organic pollutants for water pollution control (Fetene *et al*. 2015).

Today by far, the predominant source of phosphate in many fresh waters which remaining water pollution were runoff from urban, agricultural site, facilities such as animal feeding operations and detergents account for more than half of the phosphates discharged (Farmer, 2001). The presence of excessive phosphate in drinking water (>1mg/l) stimulate bacterial development to consume organic matter and dead plants by using up high amount of dissolved oxygen causing poor drinking water quality and pose burden on the treatment systems.

2.8 Fluoride pollution

High fluoride levels in drinking water has become a critical health hazard of this century as it induces intense impact on human health including skeletal and dental fluorosis (Ayoob and Gupta. **2006**). Though fluoride is an essential constituent for both humans and animals, it can be either beneficial or detrimental to human health depending on the level of fluoride in drinking water (WHO, **2008**).

The most commonly used methods for the defluoridation of water are adsorption (Srimurali *et al*. 1998 and Reardon and Wang, 2001), ion exchange (Vaaramaa and,Lehto, 2003), precipitation (Singh *et al*. 1999), electro dialysis (Amor *et al*. 2001). Among these methods, adsorption is the most widely used method for the removal of fluoride from water. Therefore, an economically viable and easy method for defluoridation of drinking water is highly desirable. Different materials, which have been used for defluoridation such as activated alumina (Ghorai and Pant, 2004), amorphous alumina (Wang *et al*. 2001), activated carbon (Ramos *et al*. 1999), low-cost adsorbents such as calcite, clay charcoal, tree bark, saw dust, rice husk, ground nut husk (Fan *et al*. 2003) and etc.

However, the lowest limit for fluoride reduction by most of the adsorbents is greater than 2 mg/l, therefore, they are not suitable for the drinking water treatment purpose especially as some of them can only work at an extreme pH value, such as activated carbon which is only effective for fluoride removal at pH less than 3.0 (McKee and Jhonston, 1984). Activated alumina has a great capacity for fluoride adsorption, which is dependent upon the crystalline form, the activation process and the solution pH and alkalinity (Ramos *et al*. 1992). Thus, it is important to develop or find cheaper adsorbents for fluoride removal from water that have greater fluoride adsorption capacities like the

above said adsorbents. This paper concentrates on investigate low cost material for fluoride sorption which can effectively remove fluoride from aqueous solutions at a relatively low level.

2.9 Iron pollution

The extensive use of groundwater can be explained by the ease of access, better protection from pollution sources, higher water quality as compared to surface water (Hallberg and Martinell,1988) less subject to seasonal and perennial changes, uniformly spreading overlarge areas (UNESCO, 2004). However, groundwater contamination has major complications on the environment and can pose serious threat to human health. Iron is necessary to sustain the vital body function in trace amounts (Salem *et al.*, 2000). Higher dissolved concentrations of iron cause aesthetic problems to drinking water (Tredoux *et al.*, 2004).Adverse effects of higher iron concentrations in drinking water can be summarized as follows:

o Iron (II) ions are oxidized to higher forms in a water distribution system and this results in the formation of hydroxide suspensions causing undesirable turbidity and colour of water,

o The presence of iron bacteria in water supply system causes change in water quality (smell) and bacterial growth.

o In the case of the occurrence of iron (II) ions at the consumer's point, iron is oxidized and precipitated under suitable conditions affecting storage instruments.

o If water is not treated then there cause metallic taste in water, staining of different products like clothes, paper and plastics (Homoncik et al., 2010).

The World Health Organization (WHO) has approved the removal of iron when concentrations higher than 0.3 mg/L (World Health Organization, 1996) while Environmental Protection Agency (EPA) also has established secondary standards of 0.30 mg/l for iron (U.S.EPA, 2001). So if concentrations are higher than these standards, then water must be treated before using it for drinking purposes.

The principle of most methods used for iron removal is that originally dissolved (F^{+2}) iron is transformed into undissolved (F^{+3}) compounds that can be removed through precipitation. In this method groundwater is purified on the surface by different processes like chemical oxidation followed by filtration, aeration followed by filtration, iron exchange method (Wilson *et al.*, 1999).

CHPTER THREE
OBJECTIVE

3.1 General Objectives

To develop point of use drinking water purifying technology using Moringa Olifera seed (MOs) as a coagulant and Virgin Scoria (VSco) as filtration media in combination.

3.2 Specific Objective

The goal can be achieved with the following objectives:

1. To investigate PO_4^{-3}, F^-, and Fe^{+3} and suspended matters removal capacity of Moringa Olifera seed (MOs) in different design parameters using jar test.

2. To determine PO_4^{-3}, F^-, and Fe^{+3} and suspended matters removing capacity of VSco as a filtration media after MOs optimization under different contact time.

3. To optimize design parameters of VSco coupled with MOs for point of use drinking water purification.

4. To assess the effectiveness of the optimized design parameters of the media with real water and groundwater in actual field conditions.

CHAPTER FOUR

MATERIALS AND METHODS

4.1 General description of the study Area

The study was conducted in Jimma University, Institute of technology at Environmental Engineering laboratory, Jimma college of agricultural soli lab, Environmental health science and technology. It is located in Oromia Regional State, South West Ethiopia which was located at 346 km from Addis Ababa.

4.2 Study Design and Period

The study was seen in two separate works (Fig.4.1). The first one was the batch experiment with Moringa Olifera seed (MOs) coagulant under jar test experimentation. This experiment was conducted to obtain the optimized dose of MOs by evaluating various Moringa Olifera seed dose, turbidity and solution pH.

The second phase was the filtration process using VSco after coagulation was completed using Moringa Olifera seed (MOs).VSco filtration was conducted under small column experiment at different time in order to proof its water purification quality at PoU. Generally this experimental based study was conducted from June - August, 2016 study period at Environmental Engineering laboratory Jimma Institute of Technology University.
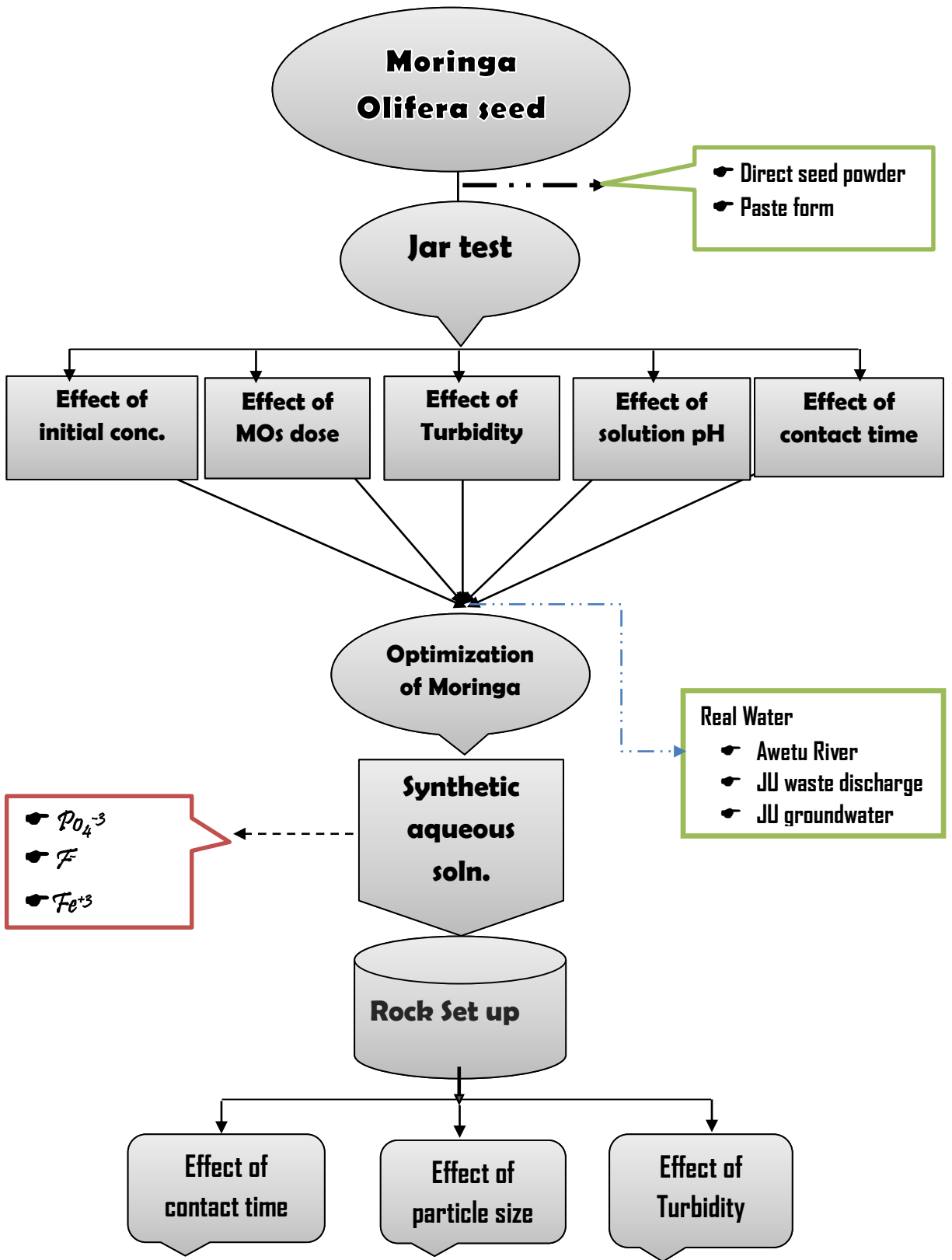
Fig. 4.1. The study design

4.3 Collection of samples

Starting from June - August, 2016, gathering of both MOs and VSco samples was done. The sampling campaign includes (1) Purchasing of Moringa Olifera seed (MOs) (20g) from Southern part of Ethiopia around Arbaminch city, (2) Gathering of VSco (5g) from the Main Rift Valley of Ethiopia (Alemayehu and Lennartz, 2009), (3) Gathering of deionized water from Jimma University Agricultural campus and 4) collection of chemical salts (KH_2PO_4, NaF and $FeCl_2$) from Jimma town water distribution organization and Jimma University of Environmental health and technology to the Environmental Engineering laboratory where the study would be conducted.

4.4 Study variables
4.4.1 Independent variables

- pH
- Contact time
- Initial concentration of PO_4^{-3}, F^-, and Fe^{+3}
- Adsorbent dose
- Turbidity

4.4.2 Dependent variable

- Removal capacity of Moringa-VSco

4.5 Sample preparation
4.5.1 Preparation of Virgin Scoria and gravel

VSco was a naturally occurring material consists different mineralogical and chemical composition (fig.2.3). Initially VSco was washed several times with distilled water to remove any impurities, and dried in an oven at 105ºc for 12 hours to remove the moisture. The dried VSco sample was crushed and separated in to different sieve size (0.212-20mm) size as indicated in (Fig.4.2).

Fig. 4.2. Virgin Scoria after sieve analysis

4.5.2 Preparation of Moringa Olifera seed (MOs) Coagulant

Mature seeds showing no signs of discoloration, softening or extreme desiccation were collected. The collected seeds with its husk was air-dried for several days. The shells surrounding the seed kernels was removed from the pods using knife and the kernels was crushed using laboratory mortar and pestle into a fine powder and sieved using a sieve with a pore size of 200μm to obtain a fine powder as proposed by (Amagloh & Benang, 2009). Coagulation- flocculation experiment by using MOs as a coagulant were prepared in different practice.

1. Application of MOs press cake (solids residue remaining after oil extraction of active components)
2. In the form of direct use of seed powder
3. In the form of paste (by mixing the powder with clean water and filtered by clean cloth etc. are the most common ways based on different factors like the required water quality.

The second and third methods were specifically applied for this study, i.e. MOs in paste form and in direct use of seed power. The seed powder was mixed with some amount of clean water to form a paste. Dosing solutions of paste was prepared from 0.5 to 5% concentration, e.g. 0.5 to 5 g/l dose which was identified as effective MOs range (Osman & Mohammed, 2009) which was applied for different sources of raw waters. The milky white suspension was added to the turbid water for water purification. Figures a, b, c and d shows the MO pods, MO seed, de-husked seed kernel and seed powder.
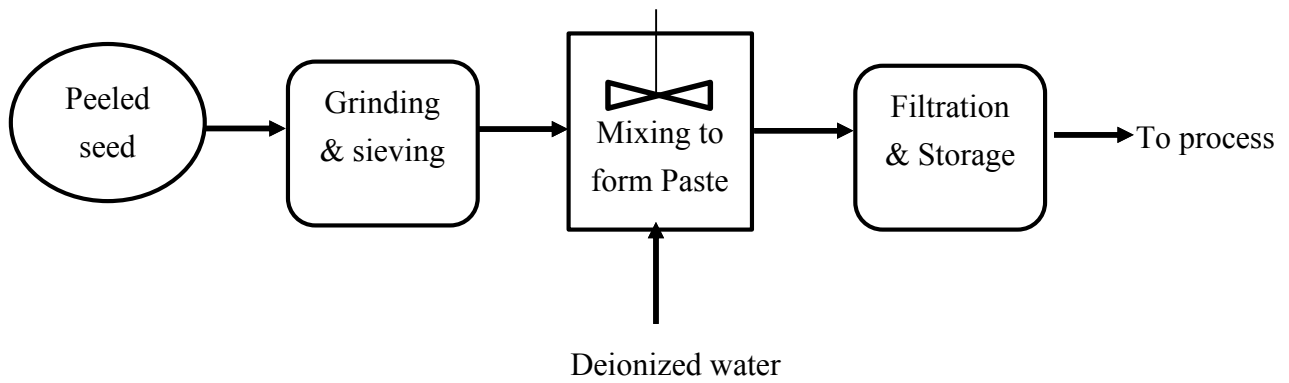
Fig. 4.3. Schematic illustration of the Moringa preparation steps

(c)

(d)

Fig. 4.4. Moringa (a) pods, (b) Seeds, (c) de-husked seed kernels and (d) seed powder

4.5.3 Adsorbate

Deionized water was used throughout this study for the preparation of synthetic aqueous solution of PO_4^{-3}, F^- and Fe^{+3} including turbidity. The three salt used for the three analyst were Anhydrous Potassium dihydrogen phosphate KH_2PO_4 (**0.7165g**) for phosphorus (1ml KH_2PO_4 represents 0.5mg PO_4^{-3}), anhydrous Sodium Fluoride NaF (**0.2210g**) for fluoride (1mg NaF represents 0.1mg F^-) and iron chloride $FeCl_3$ (**0.5g**) for iron (1mg $FeCl_3$ represents 0.2mg Fe^{+3}) including various turbidity levels from clay. Stalk solution of synthetic PO_4^{-3}, F^- and $Fe^{+3}$was prepared from those salt (analytical reagent) and different initial concentrations of each were taken from the stalk (6, 12, 20mg/L PO_4^{-3}), (3, 6, 9mg/L F^-) and (2, 5, 7mg/L Fe^{+3}), respectively. This wide range was necessary, because in extreme conditions (especially the phosphate and fluoride) content in Ethiopia reach about 30mg/l and 17mg/l, respectively.

Three actual raw water sources were collected from JU wastewater discharge, JU groundwater and Awetu Surface water for the conformation of this design.

4.6 Chemicals and Instrument used

Phosphate content after each treatment was determined by using kit method (LCK350) having the capacity of measuring from 2-20mg/l and iron was measured using Phenanthroline method after calibration curve. Detection of phosphate and iron were analyzed (detected) by spectrophotometry (DR5000). Fluoride was determined by direct electrode method while COD was determined by the dichromate closed reflux method and measured using a spectrophotometer, Alkalinity by means of titration, pH with pH meter (pH 3310), and conductivity with (conductivity meter).These were done according to standard methods for the examination of water and wastewater analyses methods (Stephenson et al., 1985).

4.7 Jar test and Filtration setup

The purpose of this experiment was to estimate the contribution of MOs and VSco filtration in combination for the removal of turbidity, TDS, COD, PO_4^{-3}, F^- and Fe^{+3} from drinking water for point of use daily demand spatially for the community sector directly rely on untreated water sources.
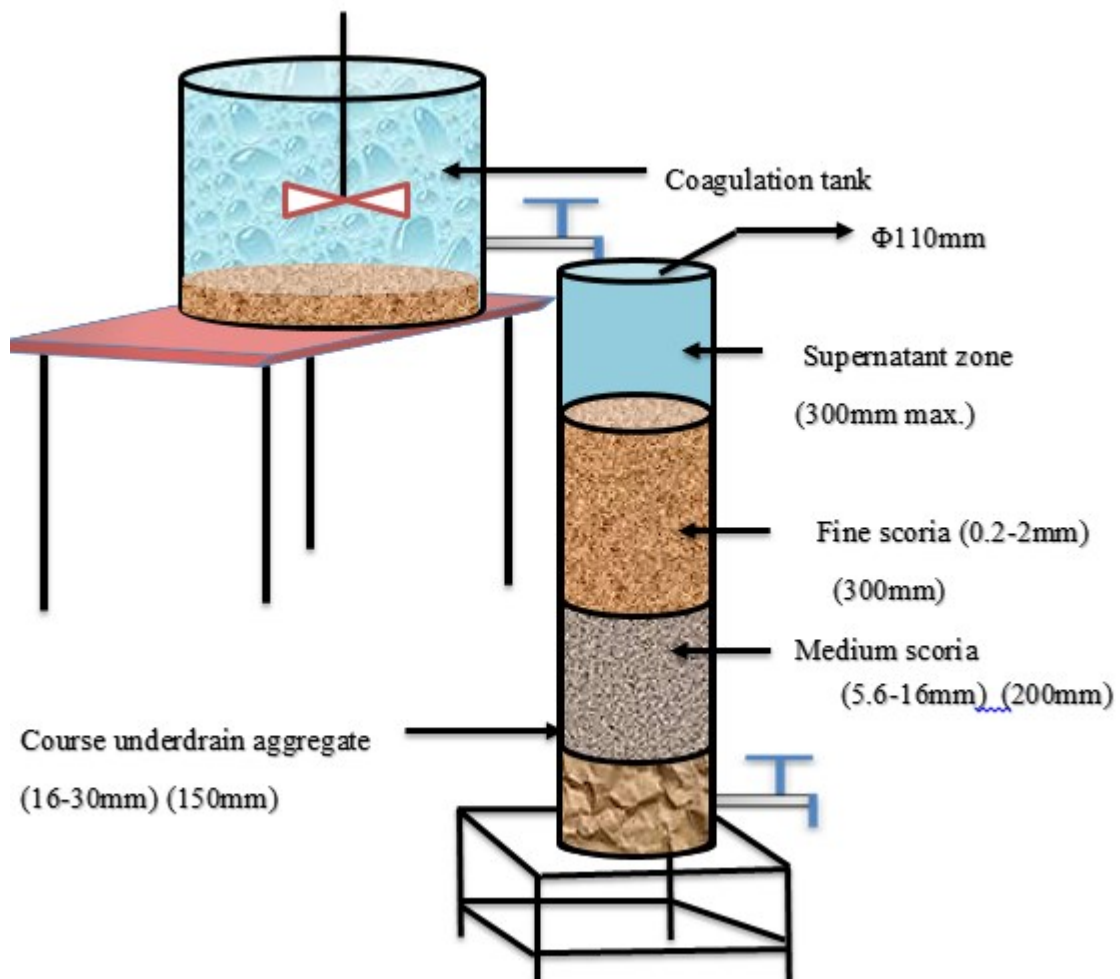
Fig. 4.4. Moringa-VSco Drinking water purification experimental setup

Filtration tube was fabricated from PVC pipe with 110mm in diameter and 1000mm height fitted with an outlet pipe as indicated in **fig.4.4**. The bed of the set-up would be made up of a well graded uniformly arranged layers of bottom gravel to upper layer of Scoria. The water to be purified was filtered through the compartments filled with fine scoria (0.212-2mm) for 300mm, medium scoria (5.6-16mm) for 200mm and course aggregate (16-30mm) for 150mm based on the study design. The column was then packed carefully, by pouring the scoria in increasing size from top to bottom based on sieve size analysis result and shaking with a metal rod to compact and remove any free space.

VSco filtration was conducted directly after the completion of coagulation flocculation processes with MOs. Vertical down-flow filtration was adjusted at 0.022 m^3/h filtration rates after the filtration tube was full. Typically, a slow sand filtration has a depth of about 0.7m and operated at rate of 0.08 to 0.25m^3/h compared to 5-15m^3/h in rapid filters (Borchardt *et al*., 2012). The optimum removing steps from coagulation set-up would be allowed to pass through filtration set up.

Fig. 4.5. Moringa-VSco PoU drinking water purification setup

The evaluation of any remains of turbidity, TDS, color, taste, pH, odor, alkalinity, PO_4^{-3}, F^- and Fe^{+3} after coagulation flocculation using MOs under jar test including organic matter of MOs possibly pass was evaluated at 60, 120 & 240min time interval onto VSco filtration media. Evaluation was based on various design parameters, i.e. contact time, initial concentration, adsorbent particle size. However, the challenge in conducting the experiment was feeding the water in and out of the VSco filtration tube continuously at a constant rate using a fitting outlet. The flow rate was kept constant by keeping the head from up and below at a constant level.

4.8 Jar Test Experiments

Jar test was conducted to determine the effective dosage of coagulant to reduce the turbidity, TDS, color, taste, pH, odor, alkalinity and PO_4^{-3}, F^- and Fe^{+3} of the synthetic aqueous solution of the prepared water samples and the actual real surface and groundwater respectively. The jar testing apparatus contains six jars, one jar used as control, while five of them was adjusted depending on what conditions were being tested.

Primarily synthetically prepared water sample consisting of 100NTU (related to actual war water condition) turbidity level was used for evaluating effective coagulant dose from various MOs mass for both paste and powder. The standard time for jar test application using MOs coagulant was used for this study (rapid mix at 120 rpm for 1 min, slow mix at 30 rpm for 15 min and 30 min for sedimentation) (Ravikumar and Prof.Sheeja, 2013). The Jar test activities was as follows.

1. Identical turbidity level (100 NTU) was tested under various MOs dose (30, 50, 70, 100, 150, 200mg/L) in direct use of powder and (15, 25, 35, 50, 75, 100Ml/l) in paste using 1g/l and 2g/l MOs dose.
2. Various turbidity levels (20, 50,100,150,250,300NTU) simulated with clay causing potential increase in turbidity were adjusted and tested under effective MOs coagulant dose obtained typically from 100NTU.
3. For effective MOs and Turbidity identified from (№ 1-2), the better pH removing range was tested at (6.0, 6.5, 7.0, 7.5, 8.0, 8.5pH).

4. Therefore, from various coagulant dosages, optimum operating MOs dose, effective turbidity level and better pH range were identified by "Jar test method"

The active agent is believed to be a protein, but the exact form of the protein which act as cationic polyelectrolytes is not yet known (Sutherland et al 1994), which attach themselves to the soluble particles and create bindings between them, leading to large flocs in the water. Stirring and mixing accelerates the electrostatic flocculation.

5. Jar tests were performed again for synthetic aqueous solution of PO_4^{-3}, F^- and Fe^{+3} with different initial concentrations of (6, 12, 20mg/LPO$_4^{-3}$), (3, 6, 9mg/L F$^-$) and (3, 5, 7mg/LFe^{+3}) were tested under effective MOs dose and pH range identified.

6. Finally the maximum removed results of PO_4^{-3}, F^-, Fe^{+3} and turbidity after MOs treatment were applied separately for further purification on VSco filtration and measurements of the remaining final concentration.

7. Then lastly the actual surface and groundwater was treated based on this optimized set up for the final recommendation.
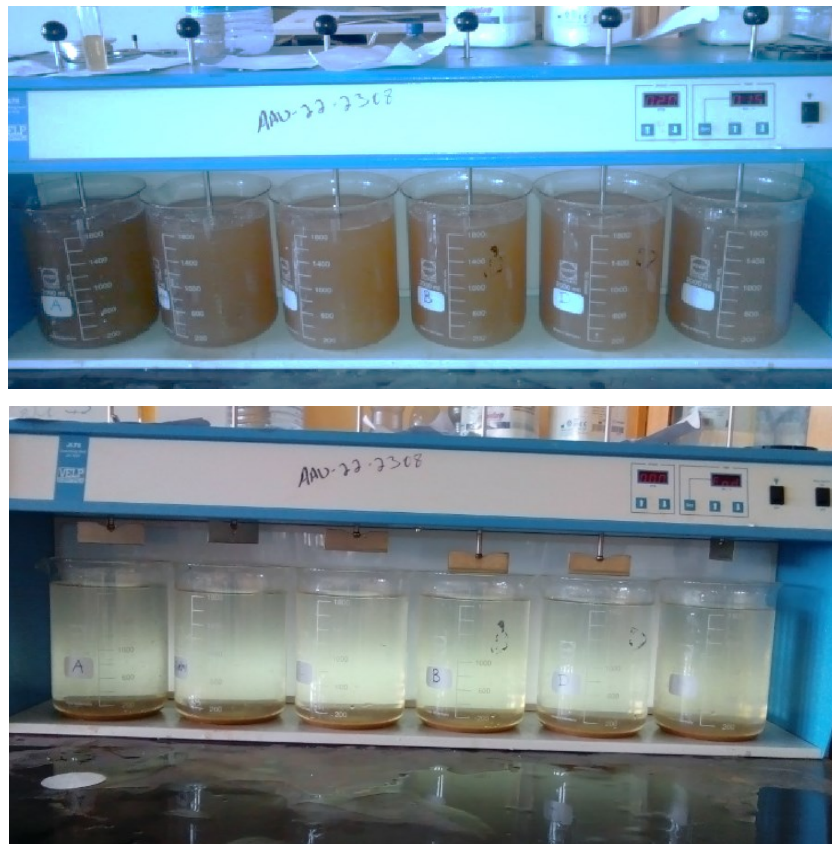
Fig.4.6. Jar test treatment process with Moringa Olifera seed (MOs) coagulant

4.9 Data Analysis

Data stored and analyzed using Microsoft Excel Version 2013, scientific calculators and Minitab 16. Multiple comparison and calculation was done by using Sigma plot 12.0 software and presented using graphs, tables and others (annex). All result of the finding of the experimental study was collected, analyzed and compared with other finding.

4.10 Data Quality Control

The quality of the data duplicate experiments was carried out during each set of experiments and average of the duplicate measurements was reported (Refer to APPENDIX B). At each set of experiments calibration (standardization) was conducted for analysis.

4.11 Ethical consideration

Ethical consideration was taken in to account for the study to be sound and ideal. Each and every of data collection, processing, and analysis was followed scientific methods and procedures. Furthermore all concerned bodies was informed prior to the study get started. Finally, the result of laboratory analysis honestly recorded and interpreted based on scientific procedures.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Sieve Analysis

During the process of filtration, raw water could be percolated through the porous VSco medium, stopping and trapping organic material, chemical ions, even bacteria and viruses. The easiest way to determine effective particle size was to pass a dried VSco sample through a stack of decreasing sieve sizes as described below. The VSco was arranged in size ranging from 0.212 to 20mm. Optimum water purification performance of VSco was dependent on a well-established sieve analysis. This provides an effective surface filtration of such a very small particles.

Table 5.1. Sieve Analysis of VSco.

IS Sieve (1)	Mass Retained (2)	Percentage Retained (2) x 100 / 15000.7 (3)	Cumulative Percentage Retained (4)	Percent finer 100-(4) (5)
20mm	684	4.56	4.56	95.44
16	976.4	6.51	11.07	88.93
11.2	1600.6	10.67	21.74	78.26
5.6	2763	18.42	40.16	59.84
2	3765.5	25.10	65.26	34.74
0.85	2568.8	17.12	82.38	17.62
425μm	1295	8.63	91.02	8.98
212	1273.4	8.49	99.51	0.49
pan	74	0.49	100.00	0.00
Σ	15,000.7gm			
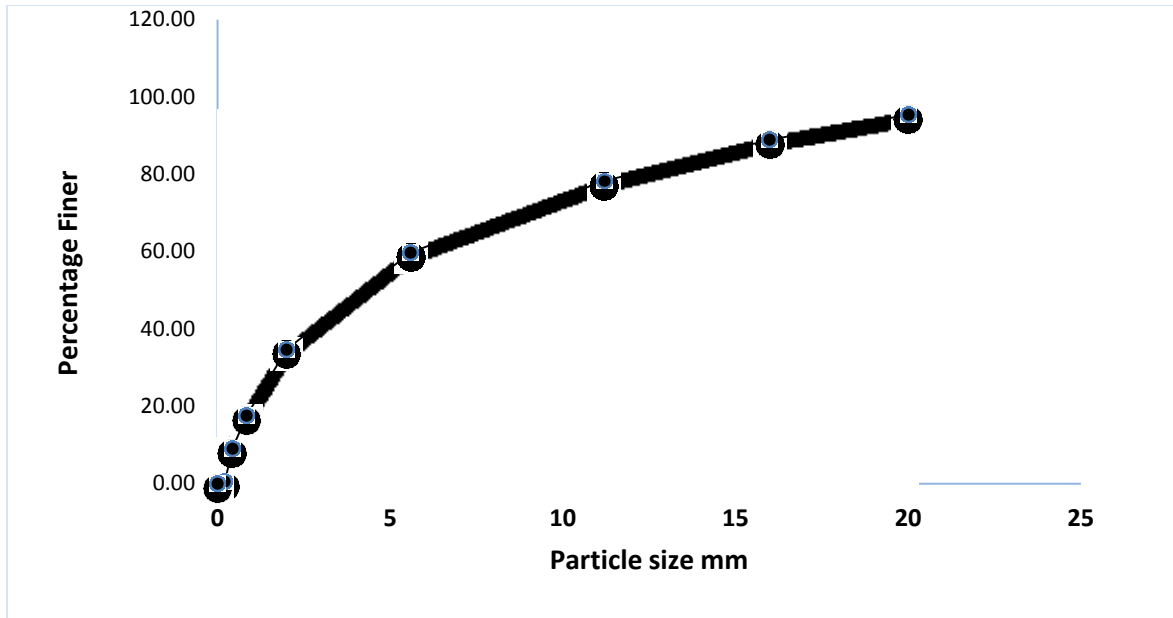
Fig. 5.1. Particle size distribution curve

D_{10} = 0.45mm D_{30} =1.68mm D_{60} = 5.6mm

i.   **Uniformity coefficient**

$$C_u = \frac{D_{60}}{D_{10}} = \frac{5.6}{0.45} = \underline{\mathbf{12.40}}.......\text{well-graded (because greater than 6)}$$

ii.   **Coefficient of curvature**

$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}} = \frac{(1.68)^2}{5.6 \times 0.45} = \underline{\mathbf{1.12}}.......\text{well-graded (between 1\&3)}$$

⊙   Effective particle size (D_{10}) – the particle diameter such that 10% (by weight) of the grains in the sample are smaller than it and 90% of grains are larger than it. It's also referred to as D_{10}.

⊙   Uniformity coefficient (C_u) – is a method of expressing the size difference between the largest and smallest grains in the sample (also known as the particle size distribution).it's the ratio of D_{60}/D_{10}.

⊙ D_{60} is the particle size whereby 60% of the samples grains are smaller and 40% are larger.

The sieve analyses of VSco indicated that the effective size was 0.45mm and the uniformity coefficient was 12.40. VSco was sieved to obtain sand grains larger than the sand grains used as filter media. This sand was used above the gravel which was used as an underdrain to prevent fine Scoria sand from escaping the filter. The recommended size of sand used for filtration purpose and that of the VSco was stated below for the comparison.

Table 5.2. Recommended Characteristics of sand filters

Characteristics	Rapid sand filters (RSF)	Slow sand filters (SSF)
Filtration rate (m^3/h)	5 – 15	0.08 – 0.25
Media effective size (mm)	0.5 – 1.2	0.15 – 0.30
Bed depth (m)	0.6 – 1.8	0.9 – 1.5
Run length	1 – 4days	1 – 6months
Ripening method	15min – 2h	Several days
Regeneration method	Backwashing	Scrapping
Maximum raw-water turbidity	Unlimited	10NTU

Source: Borchardt,*et al.* 2012.

Characteristics   **Virgin Scoria filters (VSco)**

- o Filtration rate…………………………0.022 – 0.1m^3/h
- o Media effective size…………………..0.45mm
- o Bed depth……………………………..1m
- o Run length……………………………1month
- o Ripening method……………………...10min – 4h
- o Regeneration method…………………Washing, Replacing
- o Maximum raw-water turbidity………..12-8NTU

5.2 Analysis on Physicochemical Parameters

5.2.1 Effect of MOs dose on turbidity removal

Direct seed powder and the paste prepared from (1, 2g/L) mas stock solution of MOs was tested based on effective range of MOs paste (0.5-5g/l) identified (Osman, 2009). By using constant turbidity level (100NTU) comparison of direct powder and paste form was conducted at different dose. Based on this comparison, 2g/l paste were highly effective from other paste and direct powder **(fig. 5.2).**
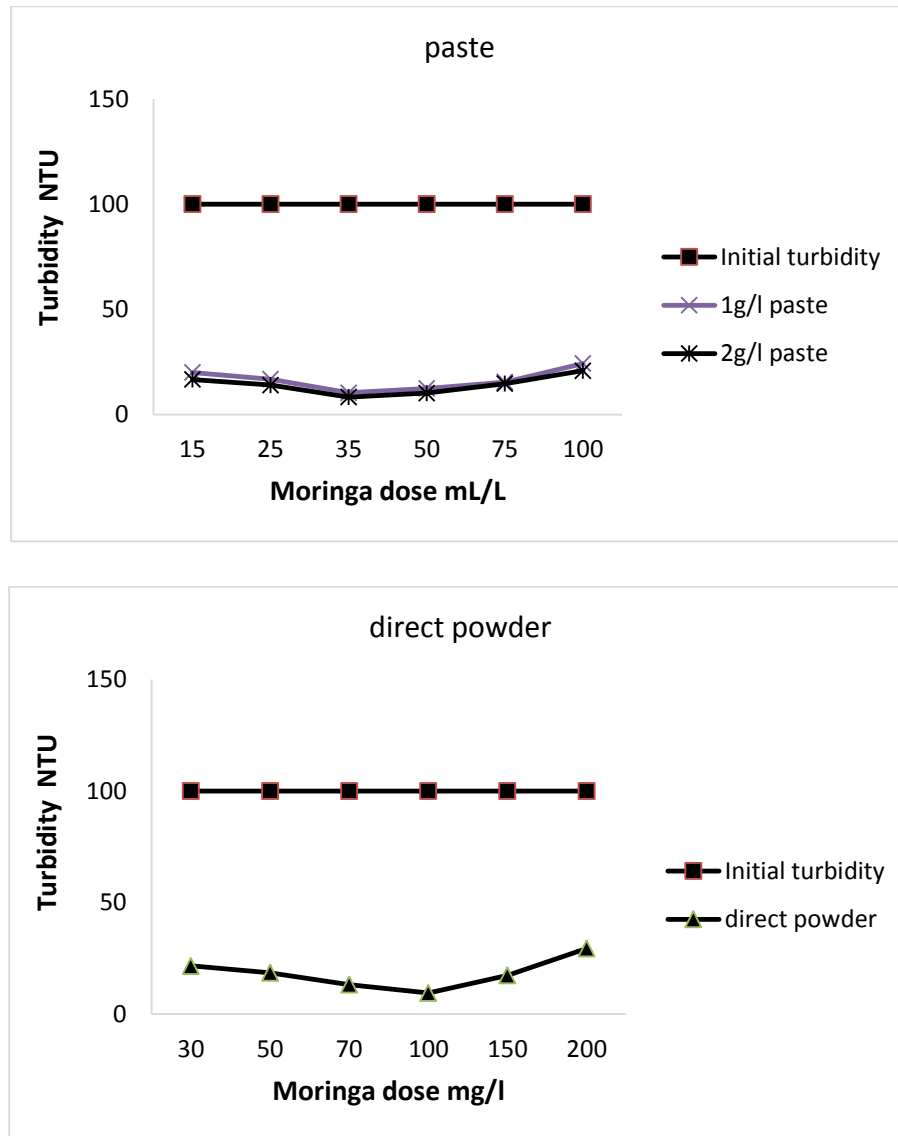
Fig. 5.2. Effect of Moringa Olifera seed (MOs) coagulant on turbidity

As indicated in the above figure, turbidity reduction from 100-9.5NTU in direct powder form and 100-8.3NTU in paste form were achieved at 100mg/l and 35ml/l (70mg/l) effective MOs dose respectively. With the same turbidity an increase or decrease in dosage from 35ml/l (paste form) and 100mg/l (direct use powder), showed less reduction in turbidities specifically at 100 NTU. This was due to the attainment of residual turbidities above 10NTU due to excessive MOs from below and insufficient from above per liter of untreated water. The finding of others also indicated that optimum dosage of Moringa treated water was found between 17 mg/l and 67 mg/l for both low (15 NTU) and medium (100 NTU) turbidity levels (Arnoldson and Bergman, 2007).

The increase in turbidity of treated water when the MOs dose increase typically for specifically turbid untreated water (i.e.100NTU) was due to the suspensions in solution since these samples were not filtered. This conformation was previously supported by a recent scholar Osman in 2009. That is why dosage beyond the optimum point would, apart from obvious disadvantages such as increased poor bitter taste, COD content in the water, also lead to an increase in turbidity (Mpagi, 2007). In comparison of both optimum doses **i.e., 35ml/l from 2g/L paste was more effective than 100mg/L** of direct use of powder in rapid reduction of the turbidities**.**

However, as indicated in **fig. 5.3**, turbidity versus various MOs dose indicated that MOs have direct relationship with turbidity, i.e. as turbidity increase MOs dose also increase to significantly reduce the respective turbidity properly. Specifically but, for Constant turbidity level the amount of MO required was also definite.
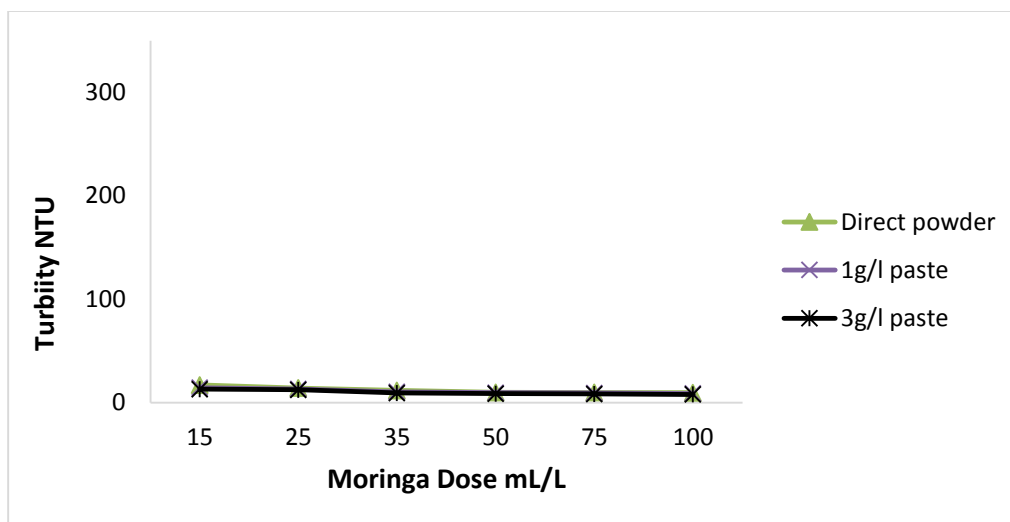
Fig. 5.3. Effect of various Moringa Olifera seed (MOs) coagulant on turbidity

5.1.1 Effect of Turbidity on Effective MOs dose

According to this studies, achievement of rapid reduction of turbidity (**50-200NTU)** was observed at 35m/l (70mg/l) MOs dose. This optimum dosage was the minimum dosage of coagulant corresponding to the removal of different physicochemical parameters such as various turbidity level, TDS, COD within the standard limits. Folkard studied in 1993 by obtaining the optimum dosage for Moringa which lies between 50 and 150 mg/l depending on the turbidity of the raw water. The figure also depicts that MOs dose range from 50-100mg/l was responsible in rapidly reducing various turbidity levels of water samples showing the best potential coagulating agent.

Though most studies have focused on treatment of drinking water which has low turbidity, the seeds have also shown high coagulation for high-turbid water. Based on **fig. 5.4**, low-turbid water of 30-50NTU to 13-12NTU, water of medium turbidity of 50-150NTU to 10-8.7NTU and that of high turbidity of 150-300NTU to 8.7-8NTU was achieved. Some variation was occurred with the previous studies stated that MOs can reduce turbidity in low-turbid water of 21.5-49.3 NTU to 2.7 NTU, water of medium turbidity of 51.8-114 NTU to 2.9 NTU and that of high turbidity of 163-494 NTU to 1.4 NTU (Muyibi and Alfugara, 2003). This was due to that the seed paste used was neither extracted nor filtered but, as it is.
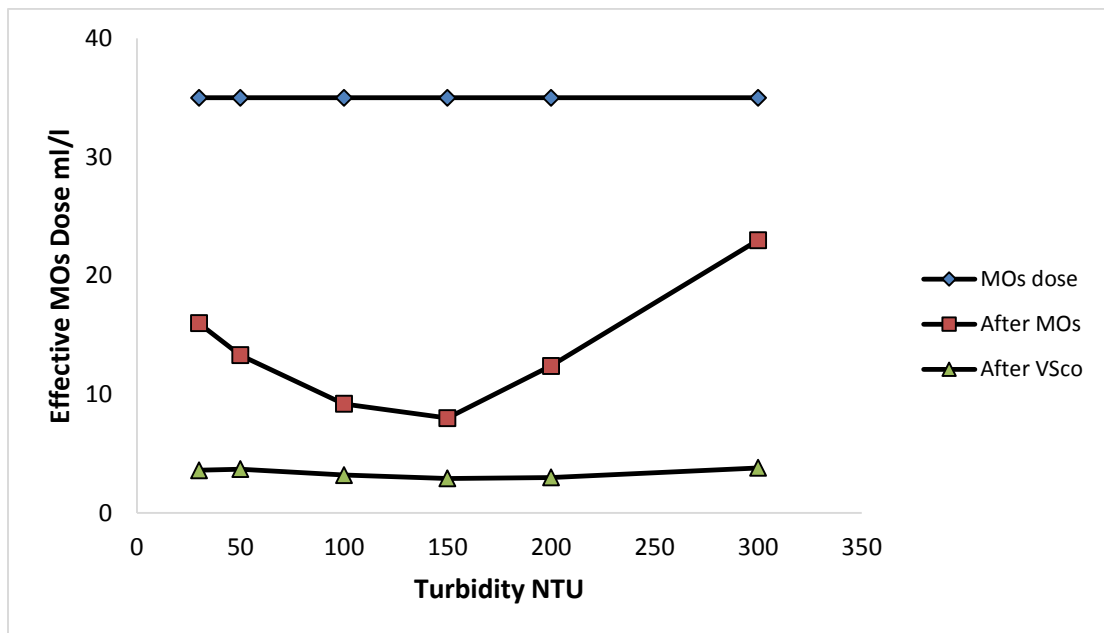
Fig. 5.4. Effect of various turbidity on effective Moringa (MOs) dose.

Therefore, **35ml/l** optimum dose was used thorough out the whole study as effective coagulants for chemical parameters also with different initial concentrations (6, 12, 24mg/LPO$_4^{-3}$), (6, 9, 12mg/L F$^-$) and (3, 5, 7mg/LFe^{+3}).

The process of trapping impurities and undesirable ions and suspended particulate matters from drinking water by using MOs natural coagulant was indicated in **fig.5.5**. The positively charged protein of MOs was highly effective in disintegrating such a color forming substances and binding to itself increasing its mass to settle immediately to the bottom of the beaker.

| Coagulant | Trapping of | Precipitate |
| Added raw water | Impurities | settle to bottom |

Fig. 5.5. Mechanisms of Moringa Olifera seed (MOs) coagulation activities.

5.1.2   Effect of VSco on turbidity

One of the fingered argument when treating drinking water with MOs was the possible development of organic matter in the treated water increased considerably with the dosage of MOs. This leads to changes in color, odor and taste of the treated water if it was stored for a long time. To reduce such complain different options would be adopted. 1) Optimization of the dose for the right consumption without excessive use, 2) Supporting the coagulation with sand filtration as designed by this studies and 3) Purifying the coagulant seed by extraction before use (Ndabigengesere, 1998 and Ghebremichael et al., 2005) and other alternatives were also designed as a better solution to reduce such retained organic matter in treated water.
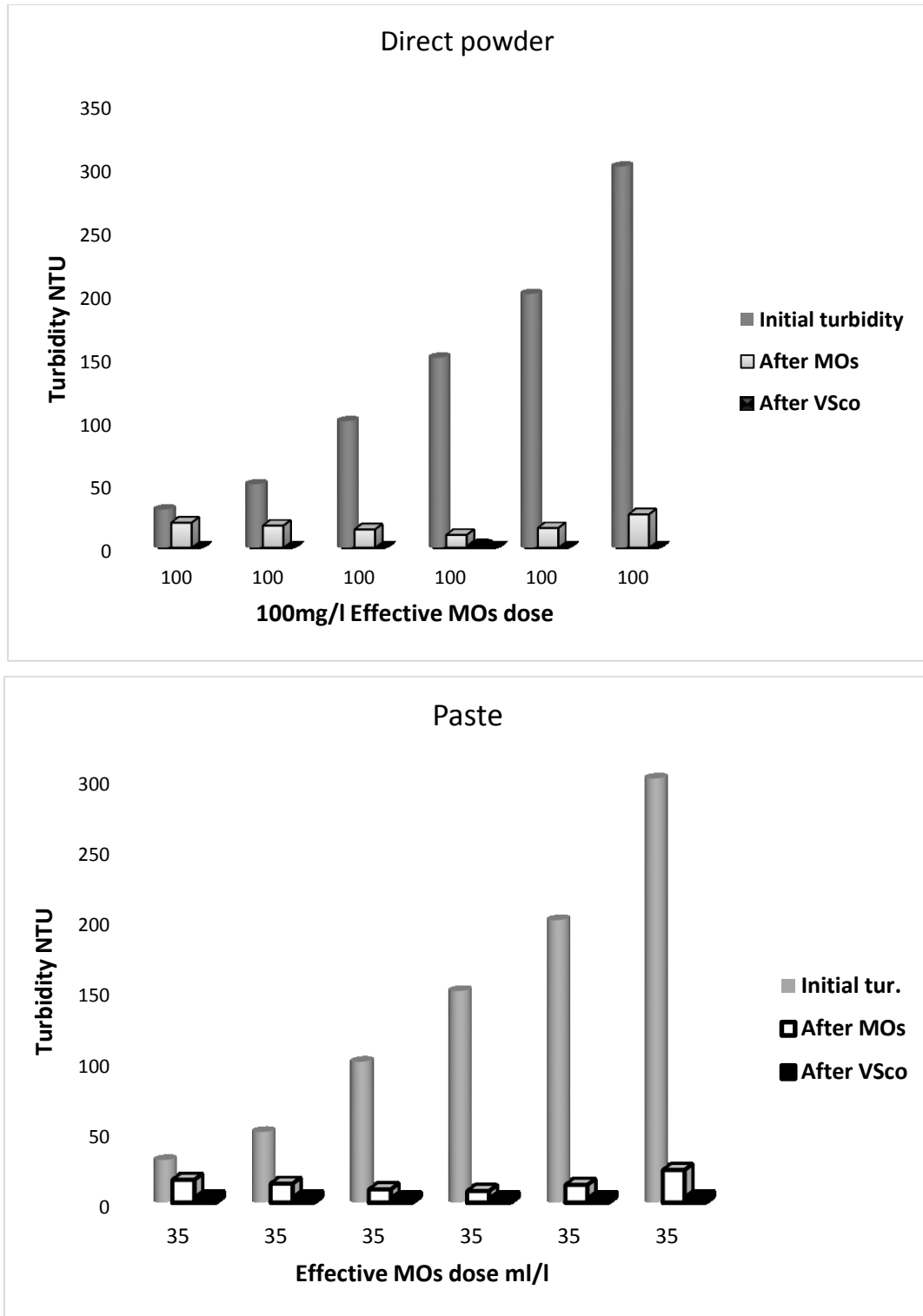
Fig. 5.6. Effect of turbidity on effective Moringa Olifera seed (MOs) dose

According to this study, Optimization of MOs dose supported with VSco filtration was designed and based on this possibility, the setup bring better treatment result in order to

decrease the amount of organic matter added. For example by using the optimum dose of **MOs (35ml/l),** reduction of turbidity from **150 NTU to 2.92** NTU which was the best result of this finding was achieved. Therefore, treatment with MOs and VSco filter led to a more successful outcome.

5.1.3   Effect of pH on turbidity removal

The coagulation flocculation process took place on MOs were believed to be dominated by formation of complexion (precipitation) between the ions in the water and protein molecules. However, as it was concluded by many researchers, MOs coagulant which was a positively charged surface causing charge interaction with the surrounding aqueous phase without affecting the natural setup of the treated water like pH, alkalinity, etc. (Ndabigengesere and Narasiah 1998).

However, for the assurance of these facts synthetically prepared water sample of pH range (6.0, 6.5, 7.0, 7.5, 8.0 and 8.5) was evaluated at effective moringa dose (35ml/l) and turbidity (150NTU) **fig. 5.7**. Based on this evaluation the best site of MOs removing site was registered around 6.5-7.5 pH range, but almost small variation. One advantages obtained from this range was that the pH of deionized water lies between this rang and hence, pH adjustment did not required. Within this range MOs removing capacity remains at maximum level.
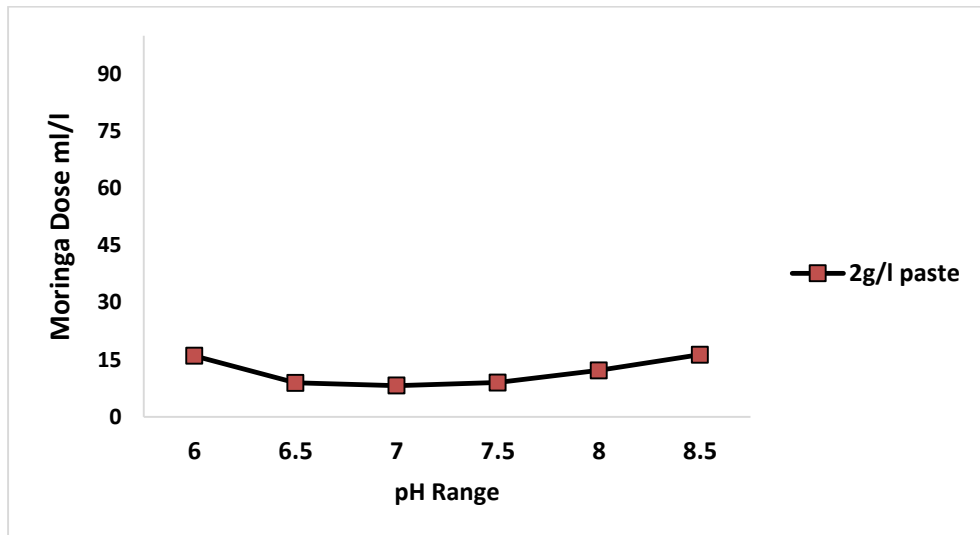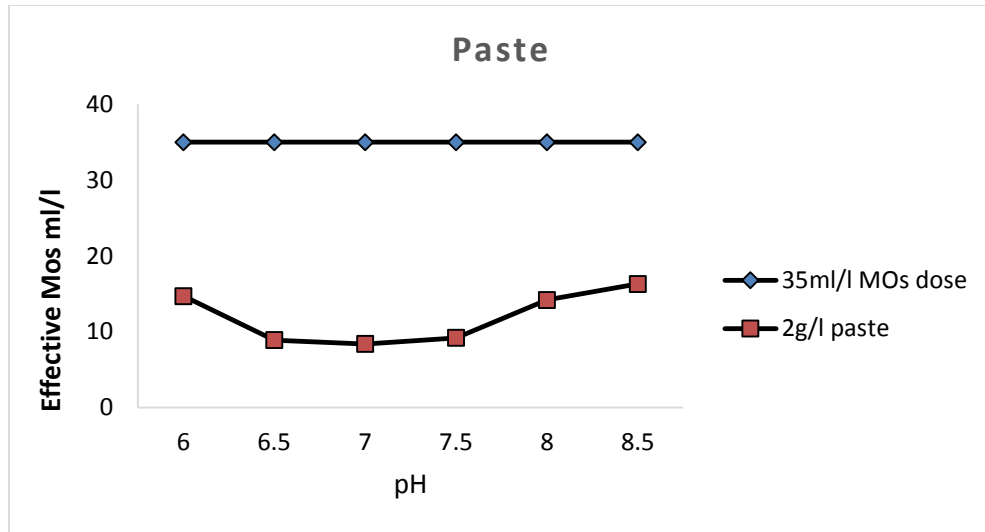
Fig. 5.7. Effect of pH on effective Moringa Olifera seed (MOs) dose

The observed result shows that pH increase with increasing concentrations of the Moringa as coagulant. It was reported that the action of Moringa as a coagulant lies in the presence of water soluble cationic proteins in the seeds. This suggests that in water, the basic amino acids present in the protein of Moringa would accept a proton from water resulting in the release of a hydroxyl group making the solution basic (Ndabigengesere et al., 1995). During the analysis, it was observed that after the water treatment with Moringa seed; pH was slightly increase but not show remarkable change when the dose increase. The recommended acceptable range of pH for drinking water specified by (WHO, 2006) is between 6.0 and 8.0.

5.1.4 Phosphate, Fluoride and Iron removal efficiency on VSco - Moringa

Jar tests were performed in aqueous synthetic PO_4^{-3}, F^- and Fe^{+3} solution of water with different initial concentrations (6, 12, 20mg/l PO_4^{-3}), (3, 6, 9mg/l F^-) and (3, 5, 7 mg/l Fe^{+3}). The treatment was performed at optimum MOs seed coagulant dosage of 35ml/l for all analysis. VSco filtration was conducted directly after coagulation with Moringa Olifera seed (MOs) and separates the last remaining flocs that failed to disappear during coagulation, flocculation process. VSco treatment was performed at different time interval (0, 2, 4hrs). Table 5.2, shows the effect of contact time versus initial concentration of phosphate, fluoride and iron on Moringa coagulant supported with VSco filtration media. Accordingly, the removal capacity of MOs coagulant was increased as the initial concentration increase while VSco treatment indicated that when the time of treatment increase, its removing capacity also increase till its efficiency reduced due to clogging.

Table 5.2. Phosphate, Fluoride and Iron of removal efficiency of VSco -Moringa

Coagulant Moringa Dose = 35mL/L					
Initial Concentration (mg/L)	Residual Concentration (mg/L)				Removal efficiency %
	(MOs) cog. 46min	VSco Filt. treatment 60min	120min	240min	
A. Phosphate					PO_4^{-3}
6	2.34	1.52	1.23	0.69	61-88.5
12	2.94	1.64	1.35	1.13	75-91
20	5.95	1.79	1.43	1.07	70-95
B. Fluoride					F^-
3	2.33	1.83	1.65	1.57	22-48
6	2.6	2.24	1.98	1.85	57-69
9	2.83	2.45	2.07	1.94	69-78
C. Iron					Fe^{+3}
3	1.96	0.98	0.63	0.45	35-85
5	2.7	0.86	0.72	0.53	46-89
7	2.93	0.75	0.64	0.43	58-94
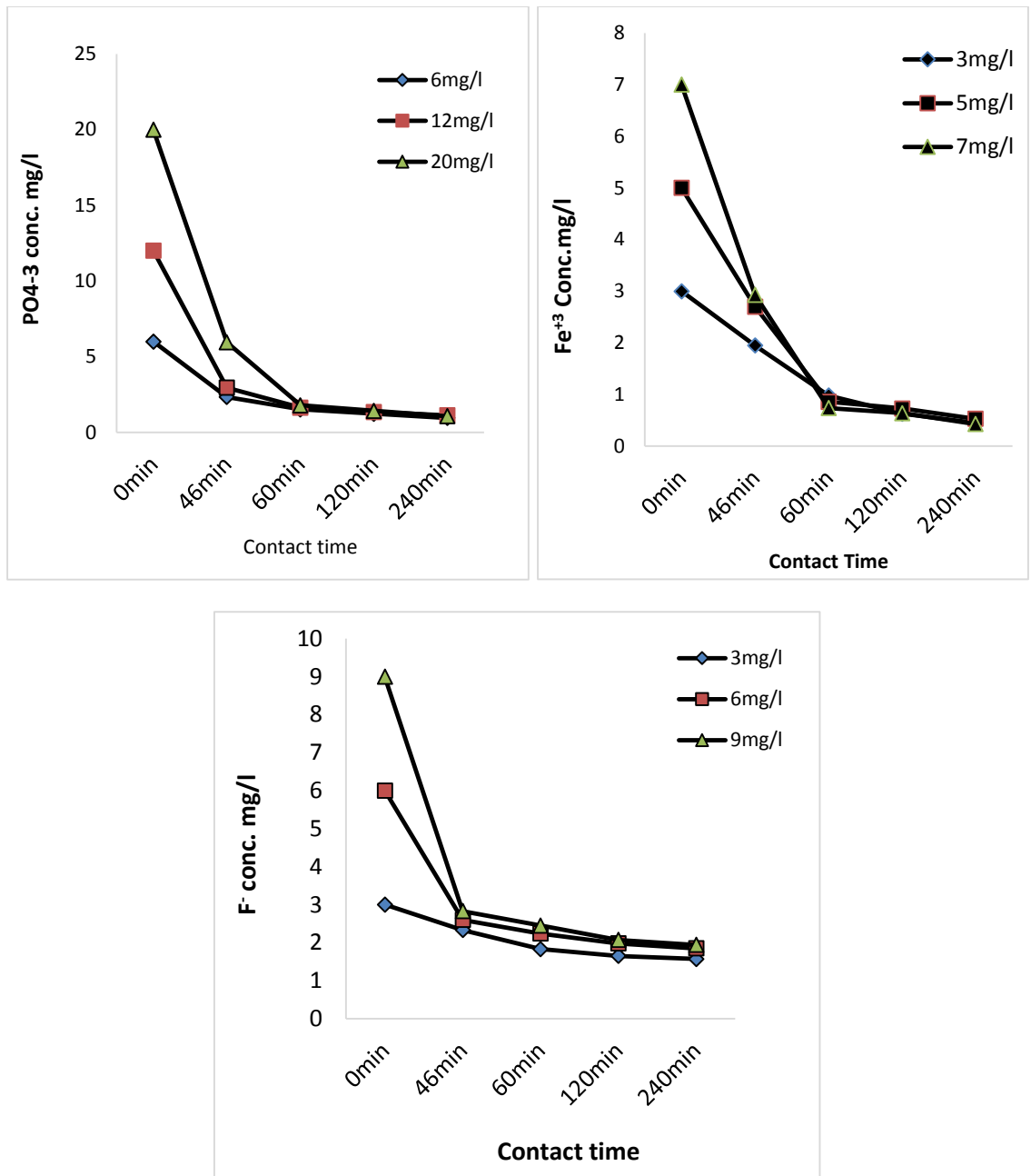
Fig. 5.8 Effect of contact time on PO_4^{-3}, F^- and Fe^{+3} removal of Moringa-VSco

Based on this procedure, PO_4^{-3}, F^- and Fe^{+3} removal quality of Moringa-VSco were indicated in **fig.5.8** separately. As indicated in the graph, PO_4^{-3} and F^- shows clear reduction in the MOs coagulation portion of the setup while Fe^{+3} was less removed. Formation of agglomeration of hydrated ferric oxides and formation of flocs removed by sedimentation would be less relatively in the first setup while adsorption onto the VSco filter media was

fast. This was due to its positively charged surface similarity between the protein of MOs and the iron ions. It was hypothesized by other researchers that due to a negative charge sand can attract floccule of iron, iron and aluminum hydroxide, crystals of carbonates, as well as cations of iron, manganese, and other metals (Huisman & Wood, 1974), including microorganisms and their metabolic products (Edwards, 2007) near the surface of the sand (Jorden, 1963).

The capacity of both setup (coagulation using MOs and VSco filtration) was less satisfactory in removing fluoride than phosphate and Iron. At optimum dosage of 35ml/l of MOs the mean phosphate and iron levels in all the analyzed water samples were below the recommended maximum contaminant level (MCL), i.e. **0.1-1mg/**l for phosphate and **0.3-1mg/l** for iron in drinking water except for fluoride which was above 1.5mg/l.

5.1.5 Effect of contact time on Phosphate, Fluoride and Iron using Moringa-VSco

The effect of contact time on the coagulation flocculation followed by filtration using Moringa-VSco for the removal of PO_4^{-3}, F^- and Fe^{+3} were investigated by the standard procedure for jar test application using MOs coagulant at 46min (1min for rapid mix, 15min for gentile mix and 30min for sedimentation) and evaluated at different treatment time intervals (60, 120, 240min) on VSco filtration. Just based on this procedures, table 5.2 was achieved. As it was indicated, the final result of the treatment was exceedingly time dependent, because when the time of sedimentation followed by filtration increase the removal capacity of Moringa-VSco also increase for all the tree chemical parameters. It was also observed that within this time the use of MOs showed high affectivity in removing PO_4^{-3} than F^- and Fe^{+3}.
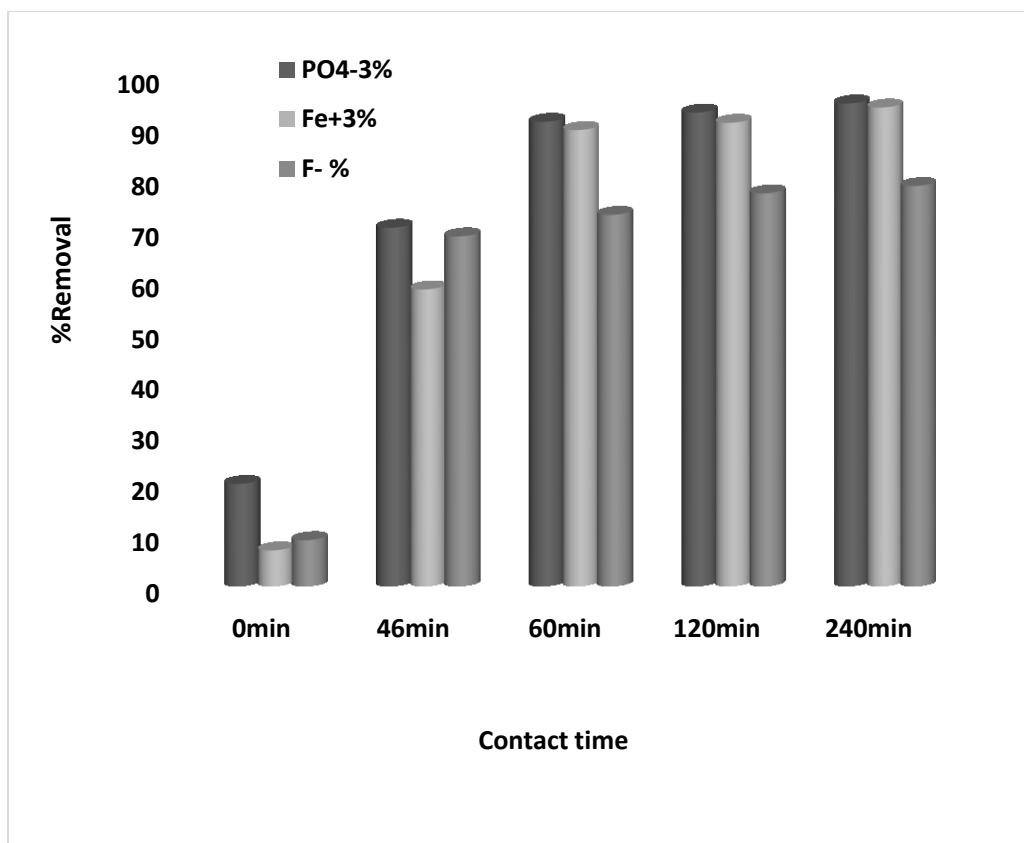
Fig. 5.9 Percent removal of PO_4^{-3}, F^- and Fe^{+3} by using Moringa-VSco

The removal capacity of MOs were 75% for phosphate, 70%for fluoride and 58% for iron and the combination of Moringa-VSco indicates **95%, 78% and 94%** at 46 and 240min respectively. But the finding of Sowmeyan indicated that 88% for fluoride, 90 % for copper, 80 % for lead, 60 % for cadmium and 50 % for zinc and chromium after 66min (Sowmeyan *et al.*, 2011).

5.1.6 Possible development of organic matter in treated water

As it was already a focus of attention (Bengtsson, 2003), MOs water purification quality shows slight increase in turbidity as it was clearly observed in this study. This was due to the water sample used was deionized water with 2.63 NTU turbidity level and the MOs paste used was neither extracted nor filtered before application. However, natural sand filtration was an efficient and effective drinking water treatment technique for source water with high turbidity, organic matter, and suspended solids (Ravikumar, Prof.Sheeja, 2013).

Based on this, table 1.3 indicated that the water purified by moringa increment in turbidity. The maximum increment of the water turbidity level after MOs treatment was from 2.63-11 NTU. However, VSco's filtration capacity depicted that recurring the increment of the turbidity to its deionized form was achieved.

Table 1.3 The efficiency of VSco. Filtration on turbidity

Initial Concentration (mg/L)	Turbidity parameters (NTU)			Removal efficiency %
	Initial	MOs cog.	VSco Filt.	
A. Phosphate				PO_4^{-3}
6	2.63	9.4	2.95	68
12	2.63	8.2	2.98	64
20	2.63	10.3	3.13	70
B. Fluoride				F^-
3	2.63	8.8	2.96	66
6	2.63	9.9	2.97	70
9	2.63	11	3.22	71
C. Iron				Fe^{+3}
3	2.63	8.3	2.88	65
5	2.63	9.7	2.95	70
7	2.63	9.8	2.93	70

Based on the design of this study, it was perfectly possible to return the turbidity of the water to its original form by simply passing through VSco filtration setup. Although the study showed that the turbidity level of all source water samples were compliant with WHO of which was < 5NTU (WHO, 1997) the turbidity of the water leaving the VSco remained steadily which was well below 3.22NTU through the test. All the water sample that was passed through VSco results below 3.22NTU.

Fig. 5.10 Moringa-VSco treated water

Therefore, in addition to fully participating in the removal of undesirable chemical residual of the contaminated water, Virgin Scoria was also recommendable to resolve the uncertainty of the development of organic matter of MOs left in the treated water.

5.1.7 Physicochemical characteristics of synthetic and real water sample

The characteristics of both synthetic and raw water were measured at the laboratory, before and after MOs coagulant and VSco treatment systems, unlike the other parameters that were measured just before the jar tests. Three raw water samples were also taken straight from their source for the validation of the setup. The methods used for the overall characteristics of water samples were indicated in table 7. Temperature, pH, turbidity, conductivity and existing phosphate, fluoride and iron were measured before and after jar test and VSco filtration experiments.

On the other hand, alkalinity, TDS, COD, hardness were also calculated and the result were presented in table 7 and 8. The details of those parameters were included in the appendix. Thus, Moringa Oleifera seed coagulation showed reduction in turbidity, TDS, hardness, chlorides, alkalinity, acidity and MPN water samples, which was also confirmed by (Mangale et.al, 2012). Although the degree of Public acceptability of those parameters may

vary considerably from one community to another depending on local conditions, the registered values after VSco -Moringa water purification were fairly stable throughout the experiment period and generally below the Maximum permissible limits WHO norms.

Table 5.4. Methods used for physicochemical study of synthetic and real water.

S.№.	Parameters	Method
Physical Parameters		
1.	pH	pH meter
2.	Turbidity	Nephelometer
3.	TDS	Conductivity meter
4.	Color	Visually
5.	Electrical conductivity	Conductivity meter
6.	Odor	Manually
Chemical Parameters		
1.	Hardness	Titration
2.	Alkalinity	Titration
3.	Chloride	Titration

Table 5.5. Physicochemical characteristics of synthetic water sample before and after Moringa-VSco

Synthetic water samples	Physicochemical Parameters	Retained results			Maximum permissible limits (WHO norms)
		Control	MOs Cog.	VSco Filt.	
Phosphate water	Turbidity (NTU)	2.63	9.4	2.95	5-10
	Conductivity (µS/cm)	163	282	117	250-750
	COD (mg/L)	85.7	136	36.7	Below 20
	TDS (mg/L)	308	111	72	500
	pH	6.98	7.67	7.8	6.0-8.0
Fluoride water	Turbidity (NTU)	2.63	9.9	2.97	5-10
	Conductivity (µS/cm)	152	248	110	250-750
	COD (mg/L)	86.2	128	29.8	Below 20
	TDS (mg/L)	344	104	68	500
	pH	6.98	7.5	7.7	6.0-8.0
Iron water	Turbidity (NTU)	2.63	9.8	2.93	5-10
	Conductivity (µS/cm)	177	245	129	250-750
	COD (mg/L)	79.6	116	27.4	Below 20
	TDS (mg/L)	315	96	47	500
	pH	6.98	7.54	7.74	6.0-8.0

Table 5.6. Physicochemical characteristics of raw water sample before and after Moringa-VSco

Real water sample	Physicochemical Parameters	Retained results			Maximum permissible limits (WHO norms)
		Control	MOs cog.	VSco Filt.	
Awetu surface water	Turbidity (NTU)	167	19.5	3.8	5-10
	Alkalinity (mg/L)	35	30	25	Below 150
	Conductivity (μS/cm)	297	183	112	250-750
	pH	7.7	7.94	7.93	6.0-8.0
	COD (mg/L)	117	163	37	Below 20
	TDS (mg/L)	320	72	28	500
	Hardness (mg/L)	40	30	20	300-600
	Iron (mg/L)	1.32	0.32	0.28	0.3-1.0
	Phosphate (mg/L)	2.25	1.5	0.24	0.5-1.0
	Fluoride (mg/L)	BDL	BDL	BDL	1-1.5
JU wastewater discharge	pH	5.5	6.78	7.1	6.0-8.0
	TDS (mg/L)	420	172	128	Below 500
	Temperature (^{o}c)	25	22	22	Below 25
	Turbidity (NTU)	112	18.7	3.45	5-10
	Conductivity (μS/cm)	322	164	117	250-750
	COD (mg/L)	342	334	197	Below 20
	Phosphate (mg/L)	6.67	2.54	0.92	0.5-1.0
JU ground water	pH	7.5	7.8	7.9	6.0-8.0
	Temperature (^{o}c)	18.5	20	20	Below 25
	Turbidity (NTU)	24	8	2.7	5-10
	Conductivity (μS/cm)	48	79	32	250-750
	Fluoride (mg/L)	17	7.2	4.4	1-1.5
	Hardness (mg/L)	40	30	20	300-600
	Iron mg/L	1.87	1.33	0.86	0.3-1
	Phosphate (mg/L)	BDL	BDL	BDL	0.5-1

CHAPTER - SIX
CONCLUSION RECOMMENDATION

1.1 Conclusion

Scarcity of water both in quantity and quality, possess a significant threat to the current and future well beings of the people in the country especially for people in less developed community sector. Low cost treatment of water provides solution to all related issues to access the clean water for poor people in rural areas. MOs acts as a natural coagulant, flocculent, absorbent for the treatment of drinking water producing an aesthetically clear supernatant. It reduces the total hardness, turbidity, alkalinity, TDS except COD after the treatment providing safe drinking water. Applications of this low cost treatment technology at rural and urban people living in extreme poverty leads to provide solution for drinking the highly turbid and even microbial contaminated water.

Based on this finding, MOs coagulant treatment supported with VSco filtration were not only responsible for the removal of suspended particulate matter but also for other chemical pollutant and nutrients that adversely affect the drinking water quality. Water containing undesirable fluoride, phosphate and Iron concentrations was treated successfully by this simple and safe method. Based on the experimental test results; the following conclusion was drawn.

➢ Moringa Oleifera seeds possess effective coagulation properties, the optimum dose of MOs coagulant was achieved at **35 ml/l** for treating water polluted with several undesirable physicochemical conditions.

➢ Various initial chemical constitutes and suspended particulate matter water qualities were treated at this optimum dose (35ml/l) at which 12mg/l of fluoride, 20mg/l of phosphate and 7mg/l iron achieving better result.

➢ The final Moringa-VSco efficiency of removing quality of PO_4^{-3} (20mg/l), F^- (12mg/l) and Fe^{+3} (7mg/l) including turbidity (150NTU) were gained to 89%, 70%, 92% and 96% respectively.

- Virgin Scoria filtration that have been promised after MOs coagulation was suitable for the retaining of the fine flocs remained in MOs treated water in resolving Customer complain.
- The Moringa-VSco removal efficiency increases as the initial fluoride, phosphate and Iron concentration increases.
- Better results were achieved using paste solutions compared to powder (because the suspended particles were settled and also all the active agent of the seed were fit directly with the suspended particles found in the raw water) and pH of the treated water was not affected by moringa in all samples.
- It was an eco-friendly technology that was economically more advantageous than other treatment alternatives.

Therefore, in accordance with the above conclusions, it was suggested that MOs powder paste coagulation and flocculation treatment followed by VSco filtration was considered to be simple, sustainably occurring, environmentally-safe natural drinking water purification alternatives applied for most suitable community sector.

1.2 Recommendations

In order to remove undesirable chemical ions and other form of suspended particulate matter, considering naturally sustainable treatment materials are highly encouraged for both developed and developing community sectors due to their availability, produced locally at low cost, health safety and ease of application. Thus the application of Moringa-VSco in combination is effective for treating the water which contains undesirable concentration of phosphate, fluoride and iron fitting for drinking purpose spatially for less developed community sector because it provided a good, cheap and sustainable alternative. However, the moringa paste and direct use of the powder does not show the same efficiency in contaminant removal, the extracted form shows more effective result than direct use.

MO is an efficient coagulant and does not have an effect on most of the properties of the water, but an increase in COD has noticed. However, letting the remaining fine flocks of the treated water through VSco scoria sand filtration potentially brought promising result even as low as the corresponding values of chemical coagulant, but carefully optimizing the dose for the corresponding load and even filtering the paste with the clean cloth are highly recommended before VSco treatment to reduce the possibility of frequent clogging of the bed. On the other way, since no proof could be obtained that oil extraction from the seeds prior to use improved the treatment quality of moringa, this cannot be recommended at present, because extracting the active agents have an effect on the treatment efficiency. Waiting the moringa treated water for prolonged time before consumption is not recommended because it can cause potential regrowth of bacteria.

Considering the large amount of seeds required, and the extensive on-site investments needed, it is not possible for public water treatment plant to replace the chemical coagulant with Moringa. It is however certainly can be considered as a good, sustainable and cheap solution for point of use. Further studies will continue regarding the combination treatment of alum and Moringa in different proportions to establish their effectiveness in treating raw water at point of use. VSco filtration is a good option for limited budget operations as the filtration is not using any chemicals and requires little or no mechanical assistance.

Reference

Alemayehu, E. Lennartz, B. (2009). Virgin volcanic VSco s: kinetics and equilibrium studies for the adsorption of cadmium from water, J. Hazard. Mater. 169 395–401.

Alemayehu, E. Lennartz, B. (2010). Adsorptive removal of nickel from water using volcanic VScos, Appl. Geochem. (25) 1596–1602.

Alemayehu, T. (2001). The impact of uncontrolled waste disposal on surface water quality in Addis Ababa, Ethiopia. SINET: Ethiopia. J. sci., 24:93-104.

Al-Samawi, A. and Shokral, E. M. (1996). An investigation in to an indigenous natural coagulant. Journal Environment. Sci. Health, A31 (8): 1881-1897.

Amagloh, F. K. and Benang, A. (2009). Effectiveness of Moringa Oleifera seeds as a coagulant for water purifiation, University for Development Studies, Faculty of Applied Sciences, Department of Applied Chemistry and Biochemistry, Navrongo, Ghana.

Amor, Z. Bariou, B. Mameri, N. Toky, M. Nicolas S. and Elmidaoui S. (2001). Fluoride removal from brackish water by electrodialysis, Desalination 133, 215–223.

Appelo C. A. and Postma, D. (1994). Geochemistry, Groundwater and Pollution, A.A. Balkema, Rotterdam,

Arnoldsson E. and Bergman, M. (2007). Assessment of drinking water treatment using Moringa Oleifera natural coagulant. Water Resources Engineering: Eduardo Mondlane University, Maputo, Mozambique, ISSN1101-9824. P.46.

Arnoldsson, E. Maria, B. Nelson, M. and Kenneth, M. (2008). Assessment of drinking water treatment using moringa oleifera natural coagulant-VATTEN 64:137–150.

Assefa G. (1984). The mineral industry of Ethiopia: present conditions and future prospects, J. African Earth Sci. 3 (3) 331–345.

Ayoob, S. and Gupta, A.K. (2006). *Crit. Rev. Environ. Sci. Technol.* 36, 433–487.

Bates, R. L. and Jackson, J. A. (1987). Glossary of Geology, third Ed. American Geological Institute, page 593.

Bengtsson, J. (2003). Pretreatment of municipal waste before anaerobic treatment, Unpblished MSC Thesis, Department of Water Supply and Wastewater Technology, Lunds University of Technology

Bhole, A. G. (1995). Relative evaluation of a few natural coagulants. Journal SRT-Aqua, 44(6): 284-290.

Bodlund, I. (2013). Coagulant Protein from plant materials: Potential Water Treatment Agent. School of Biotechnology, Royal Institute of Technology (KTH), AlbaNova University Center, Stockholm, Sweden, P.32.

Borchardt, R. John, C. and James, H. (2012). MWH's water treatment: principles and design. (3rd ed.). ISBN 9780470405390.

Bryan, S.E. (2004). Pumice rafting and faunal dispersion during 2001–2002 in the Southwest Pacific: record of a dacitic submarine explosive eruption from Tonga, Earth Planetary Sci. Lett. 227, 135–154.

Carr, R. and Strauss, M. (2001). Excreta-related infections and the role of sanitation in the control of transmission (Chapter 5). In: Fewtrell, L. and Bartram, J. (eds.) Water Quality: Guidelines, Standards and Health; Assessment of Risk and Risk Management for Water-related Infectious Disease. International water Association (IWA) on behalf on the World Health Organisation, London, UK, pp. 89-113.

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

Chung, Y. C. Wang, H. L. Chen, Y. M. and Li, S. L. (2003). Effect of abiotic factors on the antimicrobial activity of chitosan against waterborne pathogens. Bioresources Technol., 88 (3), pp. 179 –184.

Cloern, J. E. (2010). Eutrophication. Encyclopedia of Earth. Eds. Cutler J. Cleveland. Environmental Information Coalition, National Council for Science and the Environment.

Crapper, D. R. Krwashnan, S. S. and Dalton, A. J. (1973). Brain aluminum distribution in Alzheimer's disease and experimental neurofibrillary degeneration. Science, 180 (4085): 511 – 513.

Davikaran, R. and Pillai, V. N. (2001). Flocculation of kaolinite suspension in water by chitosan. Wat. Res. 35 (16), pp. 3904 – 3908.

Diaz, A. Rincon, N. Escorihuela, A. FernandeZ, N. Chacin E. and Forster, C. F. (1999). A preliminary evaluation of turbidity removal by natural coagulants indigenous to Venzuela. Process Biochemistry, 35 (3), pp. 391 – 395.

Doerr, B. (2005). Moringa Water Treatment, An ECHO technical note, ECHO, USA, *http://www.echotech.org/mambo/images/DocMan/MorWaterTreat.pdf.*

Duan, J. and Gregory, J. (2003). Coagulation by hydrolyzing metal salts. Advances in Colloidal and Interface Science: 100 (102): 475-502.

Edward, P. (2007). Evaluation of household BioSand filters in Ethiopia. (Master thesis, Cranfield University).

EPA, U.S. (2001). Office of water. National secondary drinking water regulations. In Code of Federal Regulations, 612-614.

EPA. (2013). "Secondary drinking water regulations: guidance for nuisance chemicals", United States Environmental Protection Agency

EPA. U.S. (1999). Preliminary Data Summary of Urban Storm Water Best Management Practices, in Epa-821-R-99-012

Fan, X. Parker, D.J. and Smith, M.D. (2003). Adsorption kinetics of fluoride on low cost materials, Water Res. 37, 4929–4937.

Farmer, A. (2001). Reducing phosphate discharges: the role of the 1991 EU urban wastewater treatment directive. Wat. Sci. Tech. 44, 41-48.

Fetene, Y. Alemayehu, E. and Tegegn, M. (2015). Design Phosphate Removal Technology using Volcanic Rocks: Kinetics and Equilibrium Studies. *International Journal of Engineering Reaserch & Technology*. ISSN: 2278-0181, Vol.4, PP 155.

Folkard, G. K Sutherland, J. P. and Shaw, R. (2000). Water clarification using Moringa oleifera seed coagulant.

Folkard, G. K. Sutherland, J. P. Grant, W. D. (1993). 'Natural coagulants at pilot scale' In: Pickford (ed). Water, environment and management.UK.

Fufa, F. Alemayehu, E. and Lennartz, B. (2014). "Sorptive removal of arsenate using termite mound," Journal of Environmental Management, vol. 132, pp. 188-196.

Fuglie, L. J. (1999). The Miracle Tree Moringa Oleifera: natural nutrition for the tropics. Dakar.

Gandhi, R. (1993). National Drinking Water Mission, Prevention and Control of Fluorosis in India.

Gao, B. Y. Hahn H. H and Hoffman, E. (2002). Evaluation of aluminum silicate polymer composite as a coagulant for water treatment. Water Res. 36, 3573–3581.

Gassenschmidt, U. Jany, D. K. and Tauscher, N. H. (1994). Isolation and characterization of a flocculating protein from Moringa oleifera Lam. Biochemica, Biophysica Acta 1243, pp. 477-481.

Ghebremichael, K. A. (2004). Moringa seed and pumice as alternative natural materials for drinking water treatment. KTH Land and Water Resources Engineering.

Ghebremichael, K. A. Gunaratna, K. R. and Dalhammar, G. (2006). Single-step ion exchange purification of the coagulant protein from Moringa oleifera seed. Appl Microbiol Biot 70, 526-532.

Ghorai, S. and Pant, K.K. (2004). Investigations on the column performance of fluoride adsorption by activated alumina in a fixed-bed, Chem. Eng. 98, 165–173.

Grabow, W. O. Slabert, J. L. Morgan, W. S. Jahn, S. A. (1985). Toxicity and mutagenicity evaluation of water coagulated with Moringa oleifera seed preparations using fish, protozoan, bacterial, enzyme and Salmonella assays. Water, pp. 9–14.

Gupta A. and Chaudhuri, M. (1995). Enteric virus removal/inactivation by coal-based media. Water research 29 (2), 511-516.

Gupta, V.K. Gupta M., and Sharma, S. (2000). Process development for the removal of lead and chromium from aqueous solutions using red mud—an aluminum industry waste, Water Res. 5, 1125–1134.

Hall, T. (1998). A guide to Water Treatment Practices. WRc Publication № 854.

Hallberg, R. O. and Martinell, R. (1988). Method of purifying groundwater U.S. Vol 14, UNESCO, 2004. Groundwater resources of the world and their use. Edited by Zekster S, Everett G.

Homoncik, S. C. MacDonald, A. M. Heal, K. V. Dochartaigh, B. E. and Ngwenya, B. T. (2010). Manganese concentrations in Scottish groundwater, Science of the total Environment 408, 2467-2473.

Homsi, J. (2000). The present state of sewage treatment. Water supply. 18(1), pp. 325-7.

Hsu, R. Midcap, S. and De, L. (2006). International Course on Economic Botany, National Herbarium Leiden, the Netherlands.

Huisman, L. and Wood, W. (1974). Slow sand filtration. Geneva; Albany: World Health Organization.

Ityel, D. (2011). "Ground water: dealing with iron contamination." Filtration and Separation 48(1): 26-28.

Jahn, S. A. (2001). Drinking water from Chinese rivers: challenges of clarification. Water Supply Res. Technol., 50:15-27.

Jang, S. K. Seong, T. Y. Jong, H. L. Soon, O. K. and Ho, Y. J. (2010). Removal of divalent heavy metals (Cd, Cu, Pb, and Zn) and arsenic (III) from aqueous solutions using scoria: Kinetics and equilibrium of sorption. Journal of Hazardous Materials 174, 307–313.

Jiménez, B. (2003). Health risk in aquifer recharge with recycled water. In Aertgeerts, R. and Angelakis, State of the Art Report Health Risks in Aquifer Recharge Using Reclaimed Water (Report No. EUR/03/5041122), pp. 54−190.

Jorden, R. M. (1963). Electrophoretic studies of filtration. Journal - American Water Works Association, 55(6), 771-782

Kaggwa, R. C. Mulalelo, C. I. Denny, P. and Okurut, T. O. (2001). The impact of alum discharges on a natural tropical wetland in Uganda. Water Res. 35(3): 795-807.

Kartinen, E. O. and Martin, C. J. (1995). An overview of arsenic removal processes. Desalination 103, 79-88

Katayon, S. Noor, M. Ahmad, J. Khor, B. C. and Suleyman, A. M. (2006). Effects of storage conditions of Moringa Oleifera seeds on its performance in coagulation, Bioresource Technology, 97(13), 1455-1460.

Kemira, K. (2003). About water treatment, ISBN: 91-631-4344-S

Knutsson, G. and Morfeldt, C. (1995). Grundvatten teorioch tillämpning, Andra upplagan, AB Svensk byggtjänst, ISBN: 91-7332-740-9.

Kwon J.S, Yun S.T, Kim S.O, Mayer B, Hutcheon I. 2005. Sorption of Zn (II) in aqueous solution by scoria, Chemosphere 60 (10), 1416–1426.

Kwon, J. S. Yun, S. T. Kim, S.O. Mayer, B. Hutcheon, I. (2005). Sorption of Zn (II) in aqueous solution by scoria, Chemosphere 60 (10), 1416–1426.

Kwon, J. S. Yun, S. T. Kim S. O. and Mayer, B. I. (2005). Sorption of Zn (II) in aqueous solution by scoria, Chemosphere 60, 1416–1426.

Kyzas, G. and Kostoglou, M. (2014). "Green Adsorbents for Wastewaters: A Central Review," Materials, vol.7, 333-364.

Li, Y. H. Wang, S. Cao, A. Zhao, D. Zhang, X. Xu, C. Luan, Z. Ruan, D. Liang, J. Wu, D. and Wei, B. (2001). Adsorption of fluoride from water by amorphous alumina supported on carbon nanotubes, Chem. Phys.350, 412–416.

Liu, F. Guan, Y. Yang, D. Li, Z. and Yao, K. (2000). Antibacterial action of chitosan and carboxyl methylated chitosan. Journal of applied polymer science, 79(7):1324-1335.

Mangale Sapana, M. Chonde Sonal, G. and Raut, P. (2012). Use of Moringa oleifera seed as Natural Absorbent and an Antimicrobial agent for Ground water Treatment, Research Journal of Recent Sciences Vol. 1(3), 31-40.

McKee, R. H. and Jhonston, W. S. (1984). Removal of fluoride from drinking water, Ind. Eng. Chem. 26, 849–850.

Miller, R. G. Kopfler, F. C. Kelty, K. C. Stober, J. A. and Ulmer, N. S. (1984). The occurrence of aluminum in drinking waters. J. AWWA, 76: 84-91.

Moufti, M. R. Sabtan, A. A. El-Mahdy, O. R. and Shehata, W. M. (2000). Assessment of the industrial utilization of scoria materials in central Harrat Rahat, Soudi Arabia, Eng. Geol. 57 155–162.

Moufti, M.R Sabtan, A.A. El-Mahdy, O.R. Shehata, W.M. (2000). Assessment of the industrial utilization of scoria materials in central Harrat, Soudi Arabia, Eng. Geol. 57, 155–162.

Mpagi, K. Herbert, (2007). Application of Indigenous Materials in Drinking Water Treatment, 14-15.

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

Narasiah, K. S. and Vogel, N. N. (2002) Coagulation of turbid waters using Moringa oleifera seeds from two distinct sources. Wat Sci Technol - Water Supply. 2:5-6:83-88.

Ndabigengesere A. and Narasiah, K. S. (1998). Use of Moringa oleifera seed as a primary coagulant in wastewater treatment, Environ. Technol. 19, pp. 789-800.

Ndabigengesere, A. Narasiah K. S. and Talbot, B. G. (1995). Active agents and mechanism of coagulation of turbid waters using Moringa oleifera. Wat. Res. 29 (02): 703-710.

Obiri-Danso, K. Weobong, C. A. Jones, K. (2005). Aspects of health-related microbiology of the Subin, an urban river in Kumasi, Ghana. Journal of Water and Health. 3 (1), pp. 69-76.

Olsen, A. (1987). Low technology water purification by bentonite clay and amoring oleifera seed flocculation as performed in Sudanese village: effects on Schistosoma mansoni cercariae. Water Res., 21 (5): 517-522.

Osman, M. and Mohammed, E. (2009). Water Purification Using Moringa Seeds. (Master thesis, University of Khartoum) P. 29-33.

Pan, J. R. Huang, C. Chen, S. and Chung, Y. (1999). Evaluation of a modified chitosan biopolymer for coagulation of colloidal particles. Colloidal and Surfaces A: Physiochemical and Engineering Aspects, 147:359-364.

Peter, M. (1999). Rural water supply and sanitation, second ed. Zimbabuwe Blair research laboratory, pp. 255-258.

Raghuwanshi, P. K. Mandloi, M. Sharma, A. J. Malviya, H. S. and Chaudhari, S. (2002). Improving filtrate quality using agro-based materials as coagulant aid. Water quality research of Canada, 37(4): 745-756.

Ramos, R. L. Turrubiartes, J. O. and Castillo, M. A. (1999). Adsorption of fluoride from aqueous solution on aluminium-impregnated carbon, Carbon 37, 609–617.

Ravikumar, K. and Prof.Sheeja, A. K. (2013). Fluoride Removal from Water using Moringa oleifera Seed Coagulation and Double Filtration International, Journal of Scientific & Engineering Research, ISSN 2229-5518. Volume 4: 0.3-05.

Reardon, E. J. and Wang, Y. (2001). Activation and regeneration of a soil sorbent for defluoridation of drinking water, Appl. Geochem. 16, 531–539.

Reimann C, Bjorvatn K. Frengstad B. Melaku Z. Tekle-Haimanot R. Siewers U. 2003. Drinking water quality in the Ethiopian section of East African Rift Valley I–data and health aspects, Sci. Total Environ. 311 (2003) 65–80.

Salem, M. H. Eweida, A. E. and Farag, A. (2000). Heavy metals in drinking water and their environmental impact on human health, 542-556.

Sheila Murphy, (2005) USGS Water Quality Monitoring, available at http://www.water.usgs.gov/nawqa/circ-1136.html.

Singh, G. Kumar, B. Sen, P.K. and Majumdar, J. (1999). Water Environ. Res. 71, PP. 36.

Sowmeyan, R. Santhosh, J. and Latha, R. (2011). Effectiveness of Herbs in Community Water Treatment, International Research Journal of Biochemistry and Bioinformatics (ISSN-2250-9941), Vol. 1(11) pp. 297-303.

Srimurali, M. Pragathi, A. and Karthikeyan, J. (1998). A study on removal of fluorides from drinking water by adsorption onto low-cost materials, Environ. Pollut. PP.285–289.

Srimurali, M. Pragathi, A. Karthikeyan, J. (1998). A study of removal of fluorides from drinking water by adsorption on to low cost materials. Environmental pollution 99 (2), 285-289.

Sutherland, J. P. Folkard, G. K. Mtawali M. A. and Grant, W. D. (1994). Moringa oleifera as a natural coagulant. 20th WEDC Conference: Affordable water supply and sanitation. Colombo, Sri Lanka.

Teka, G., (1982). Defluoridation. Water supply – Ethiopia. An Introduction to an Environmental Health Practice. Addis Ababa University Press: P. 137.

Thanh, N. C. and Hettiaratchi, J. P. (1982). Surface water filtration for rural werea: Guidelines for design, construction, and maintenance. Environmental sanitation information center, Bangkok, Thailand.

Tredoux, G. Israel, S. Cave, L. (2004). The Feasibility of in situ groundwater remediation as robust low-cost water treatment option. Water Research Commission Report No 1325/1/04.

Vaaramaa, K. and Lehto, J. (2003). Removal of metals and anions from drinking water by ion exchange, Desalination 155, 157–170.

Vance, D. B. (1994). "Iron- the environmental impact of a universal element." National Environmental Journal 4(3): 24-25.

Wang, Y. and Reardon, E. J. (2001). Activation and regeneration of a soil sorbent for de fluoridation of drinking water. Appl Geochem; 16:531–9.

Weber, J. McGinley, P. and Katz, L. (1991). Sorption phenomena in subsurface systems: concepts, models and effects on contaminant fate and transport. Water Res; 25 (5):499–528.

WHO (2006). Guideline for drinking-water quality (electronic resources): incorporating first addendum. Vol. 1, Recommendations, 3rd edition. Internet:

WHO and UNICEF, (2000). Global water supply and sanitation assessment 2000 report. World Health Organization and United Nations Children's Fund.

WHO, (1996). Guidelines for drinking water quality. In Health criteria and other supporting information, vol. 2, 248-253, Geneva: world Health Organization.

WHO, (**2008**). International Standards for Drinking Water, 3rd ed., Geneva.

WHO/UNICEF, (2011). Joint Monitoring program for Water Supply and Sanitation (JMP) Drinking Water Equity, Safety and Sustainability: Thematic report on drinking water.

Wilson, A. Parrott K. and Ross, B. (1999). Iron and manganese in House hold water, Virginia Cooperative Extension, 356-478.

Yin, Y. (2010). Emerging usage of plant-based coagulants for water and wastewater treatment. Process Biochem 45, 1437-1444.

Yin, Y. B. Cui, D.C. (2006). Sewage Treatment Technology of Constructed Wetland Chemical Industry Press, Beijing.

APPENDICES

Appendix A. Steps for Point of use (PoU) Water Treatment

The common protocol for conducting the Moringa coagulation process is outlined in steps 1 through 11 based on procedures outlined by Jahn (1986, 1988), Folkard *et al.* (1999), Doerr (2005) and summarized by Lea (2010):

1. Harvest mature (brown) seed pods from the tree.
2. Remove the seeds from the pods and allow them to dry for 2-3 days in direct sunlight (and do not use discolored or soft seeds).
3. Remove the seed coat/husk from the white-yellow kernels, and discard the husks.
4. Using a mortar or grinding stone, pound and crush the seed kernels.
5. Sieve the seed powder through a 0.8 mm mesh, such as a tea strainer, if this is available.
6. Transfer approx. 3g of seed powder (which is equal to approx. 4 heaping tablespoons, or 4 heaping bottle caps full) into a clean, transparent bottle.
7. Add a small amount of clean water (~100 mL) to the bottle and shake vigorously to form a paste.
8. Add clean water to the bottle to required amount and shake for 1 min to form the coagulant suspension.
9. Filter this solution through a muslin/cotton cloth or fine mesh screen and into the container of turbid water to be treated.
10. Stir the treated water rapidly for at least 1 min, and then slowly for 15-20 min.
11. Let the water sit undisturbed for 1 to 2hr and decant off the clear supernatant into a clean safe-storage container.

Appendix B. Analysis on effect of MOs dose on Turbidity, pH of Synthetic Water.

Table 2. Effect of MOs dose on turbidity, pH of synthetic water

<table>
<tr><th colspan="8">Exprement I . Effect of MOs dose</th></tr>
<tr><td rowspan="4">Test</td><td rowspan="4">Dosage of MOs</td><td colspan="6">Choosen Turbidity = 100NTU</td></tr>
<tr><td colspan="6">Parameters</td></tr>
<tr><td rowspan="2">Code</td><td rowspan="2">pH</td><td>Initial NTU</td><td>Final NTU</td><td>Stock Solution</td><td>Removal Efficiency</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">In the form of powder direct use</td></tr>
<tr><td>A</td><td>30mg/l</td><td>MP_{30}</td><td rowspan="6">6.98</td><td rowspan="6">100</td><td>21.6</td><td rowspan="6">Powder</td><td>78%</td></tr>
<tr><td>B</td><td>50mg/l</td><td>MP_{50}</td><td>18.5</td><td>82%</td></tr>
<tr><td>C</td><td>70mg/l</td><td>MP_{70}</td><td>13.2</td><td>87%</td></tr>
<tr><td>D</td><td>100mg/l</td><td>MP_{100}</td><td>9.5</td><td>91%</td></tr>
<tr><td>E</td><td>150mg/l</td><td>MP_{150}</td><td>17.4</td><td>83%</td></tr>
<tr><td>F</td><td>200mg/l</td><td>MP_{200}</td><td>29.4</td><td>71%</td></tr>
<tr><td colspan="8">In the form of Paste from 1g/LMOs powder</td></tr>
<tr><td>A</td><td>15ml/l</td><td>$MP1_{15}$</td><td rowspan="6">6.98</td><td rowspan="6">100</td><td>20</td><td rowspan="6">1g/L Paste</td><td>80%</td></tr>
<tr><td>B</td><td>25ml/l</td><td>$MP1_{25}$</td><td>16.8</td><td>83%</td></tr>
<tr><td>C</td><td>35ml/l</td><td>$MP1_{35}$</td><td>10.4</td><td>90%</td></tr>
<tr><td>D</td><td>50ml/l</td><td>$MP1_{50}$</td><td>12.4</td><td>88%</td></tr>
<tr><td>E</td><td>75ml/l</td><td>$MP1_{75}$</td><td>15.5</td><td>85%</td></tr>
<tr><td>F</td><td>100ml/l</td><td>$MP1_{100}$</td><td>24.3</td><td>76%</td></tr>
<tr><td colspan="8">In the form of Paste from 2g/L MOs powder</td></tr>
<tr><td>A</td><td>15ml/l</td><td>$MP1_{15}$</td><td rowspan="6">6.98</td><td rowspan="6">100</td><td>16.7</td><td rowspan="6">2g/L Paste</td><td>83%</td></tr>
<tr><td>B</td><td>25ml/l</td><td>$MP1_{25}$</td><td>14</td><td>86%</td></tr>
<tr><td>C</td><td>35ml/l</td><td>$MP1_{35}$</td><td>8.3</td><td>92%</td></tr>
<tr><td>D</td><td>50ml/l</td><td>$MP1_{50}$</td><td>10.2</td><td>90%</td></tr>
<tr><td>E</td><td>75ml/l</td><td>$MP1_{75}$</td><td>14.7</td><td>85%</td></tr>
<tr><td>F</td><td>100ml/l</td><td>$MP1_{100}$</td><td>20.9</td><td>79%</td></tr>
</table>

Experment II. Effect of Turbidity							
Test	Various Turbidity NTU	Effective MOs					
		Parameters					
		Code	pH	Effective MO Dose	Final NTU	Stock Solution	Removal Efficiency
In the form of powder direct use							
A	30	TP_{30}	6.5-7.5	100mg/l	19.7	Powder	34%
B	50	TP_{50}			17.4		65%
C	100	TP_{00}			14.3		86%
D	150	TP_{150}			10		93%
E	200	TP_{200}			15.5		92%
F	300	TP_{300}			26.3		91%
In the form of Paste from 1g/LMOs powder							
A	30	$TP1_{30}$	6.5-7.5	35mL/L	17.5	1g/L	42%
B	50	$TP1_{50}$			12.3		75%
C	100	$TP1_{00}$			10.4		90%
D	150	$TP1_{150}$			9.6		94%
E	200	$TP1_{200}$			16.2		92%
F	300	$TP1_{300}$			22.7		92%
In the form of Paste from 2g/L MOs powder							
A	30	$TP3_{30}$	6.5-7.5	35mL/L	16	2g/L	47%
B	50	$TP3_{50}$			13.3		73%
C	100	$TP3_{00}$			9.2		91%
D	150	$TP3_{150}$			8		95%
E	200	$TP3_{200}$			12.4		94%
F	300	$TP3_{300}$			23		92%

Exprement III. Effect of pH

Test	Various pH	Choosen Turbidity = 100NTU					
		Parameters					
		Code	Initial NTU	Effective MO Dose	Final NTU	Stock Solution	Removal Efficiency
In the form of powder direct use							
A	6	pH_6	100	100mg/L	16.7	Powder	83%
B	6.5	Ph6.5			10.8		89%
C	7	pH_7			10.5		90%
D	7.5	$pH_{7.5}$			11.2		89%
E	8	pH_8			16.5		84%
F	8.5	$Ph_{8.5}$			17.8		82%
A	6	pH_6	100	35mL/L	15.6	1g/L	84%
B	6.5	Ph6.5			10.6		89%
C	7	pH_7			9.6		90%
D	7.5	$pH_{7.5}$			10.5		90%
E	8	pH_8			14.8		85%
F	8.5	$Ph_{8.5}$			17.3		83%
A	6	pH_6	100	35mL/L	14.7	2g/L	85%
B	6.5	Ph6.5			8.9		91%
C	7	pH_7			8.4		92%
D	7.5	$pH_{7.5}$			9.2		91%
E	8	pH_8			14.2		86%
F	8.5	$Ph_{8.5}$			16.3		84%

Experment IV. Effect of pH							
Test	Various pH	Effective MOs and Turbidity					
		Parameters					
		Code	Initial NTU	Effective MO Dose	Final NTU	Stock Solution	Removal Efficiency
In the form of powder direct use							
A	6	pH$_6$	150	30mg/l	18.8	Powder	81%
B	6.5	pH$_{6.5}$		50mg/l	12.2		88%
C	7	pH$_7$		70mg/l	10.8		89%
D	7.5	pH$_{7.5}$		100mg/l	11.2		89%
E	8	pH$_8$		150mg/l	15.5		85%
F	8.5	Ph$_{8.5}$		200mg/l	19.5		81%
A	6	pH$_6$	150	15ml/l	15.6	1g/L	84%
B	6.5	Ph6.5		25ml/l	11.2		89%
C	7	pH$_7$		35ml/l	9.4		91%
D	7.5	pH$_{7.5}$		50ml/l	10.7		89%
E	8	pH$_8$		75ml/l	12.4		88%
F	8.5	Ph$_{8.5}$		100ml/l	19.3		81%
A	6	pH$_6$	150	15ml/l	16	2g/L	84%
B	6.5	Ph6.5		25ml/l	8.9		91%
C	7	pH$_7$		35ml/l	8.2		92%
D	7.5	pH$_{7.5}$		50ml/l	9		91%
E	8	pH$_8$		75ml/l	13.5		87%
F	8.5	Ph$_{8.5}$		100ml/l	16.3		84%

Appendix C. Analysis of turbidity with effective MOs dose and VSco filtration.

Table 3. Effect of turbidity on effective MOs) and VSco

Turbidity of Sample water	Turbidity (NTU)		Removal efficiency %
	MOs cog.	VSco Filt.	
Powder form (mg/L) with 70mg/L from direct powder…………………….…………………………….. round One			
30	**22**		
50	**20**		
100	**18.4**		
150	**12**	**3.53**	**92-97**
200	**16.4**		
300	**26**		
Paste form (mL/L) with 35mL/L from 2g/L powder paste……………………………………………………… round Two			
30	**20**		
50	**17.2**		
100	**13.7**		
150	**8**	**2.92**	**94-98**
200	**10**		
300	**23**		

Appendix D. Analysis of effective MOs dose for the removal of PO_4^{-3}, F^- and Fe^{+3}.

Table 4. Effective Moringa MOs dose and VSco for the removal of PO_4^{-3}, F^- and Fe^{+3}.

Experment IV = MOs Coagulation						
	Effective MOC dose = 35mL, 6.5-7.5pH					
Initial Concentration of PO_4^{-3} mg/L	Parameters					Removal Efficiency
	Code	Initial NTU	MOs cog. NTU	MOs.cog. PO_4^{-3} mg/L	Avg.PO_4^{-3} mg/L	
6	P_6		9.2	2.32	2.34	61%
	P_6dupl.		9.6	2.36		
	P_6cont.		2.63	6	6	
12	P_{12}	2.63	8.1	2.93	2.95	75%
	P_{12}dupl.		8.3	2.97		
	P_{12}cont.		2.63	12	12	
20	P_{24}		10.5	5.92	5.95	70%
	P_{20}dupl.		11.6	5.98		
	P_{20}cont.		2.63	20	20	

Given

0.765g/L Stack solution of KH_2PO_4

1mL KH_2PO_4 = 500µg PO_4^{-3} = 0.5mg PO_4^{-3}

1L = 500mg

$C_1V_1 = C_2V_2$

500mg*v = 6mg*1000mL

v_6 = 12mL/L

v_{12} = 24mL/L

v_{20} = 40mL/L

Experment V = VSco. Filtration								
Initial Concentration of PO_4^{-3} mg/L	Effective MOC dose = 35mL, 6.5-7.5pH							
	Parameters							Removal Efficiency
	Code	Turnidity after MOs	PO_4^{-3} after MOs mg/L	Turnidity after VSco	PO_4^{-3} after VSco. mg/L			
					0hr	2hrs	4hrs	
6	P_6	9.4	2.34	2.95	1.52	1.23	1.12	81%
	P_6dupl.							
12	P_{12}	8.2	2.95	2.98	2.22	1.92	1.44	88%
	P_{12}dupl.							
20	P_{24}	10.3	5.95	3.13	2.42	2.25	2.01	90%
	P_{20}dupl.							

Experment VI = MOs Coagulation						
Initial Concentration of F⁻mg/L	Effective MOC dose = 35mL, 6.5-7.5pH					
	Parameters					Removal Efficiency
	Code	Initial NTU	MOs cog. NTU	MOs.cog. F^- mg/L	Avg.F^- mg/L	
3	F_6	2.63	8.5	2.43	2.33	22%
	F_6dupl.		9.1	2.23		
	F_6cont.		2.63	4	4	
6	F_9		10.2	2.66	2.6	57%
	F_9dupl.		9.8	2.54		
	F_9cont.		2.63	6	6	
9	F_{12}		10.6	2.87	2.83	69%
	F_{12}dupl.		11.2	2.79		
	F_{12}cont.		2.63	8	8	

Given

0.2210g/L Stack solution of NaF

$1mLNaF = 100ug \ F^- = 0.1mg \ F^-$

$0.5mLNaF = 200ug \ F^- = 0.2mg \ F^-$

$1LNaF = 200mg \ F^-$

$C_1V_1 = C_2V_2$

$200mg*v = 3mg*1000mL$

$v_3 = 15mL/L$

$v_6 = 30mL/L$

$v_9 = 45mL/L$

Experment VII = VSco. Filtration								
Initial Concentration of F⁻ mg/L	Effective MOC dose = 35mL, 6.5-7.5pH							
	Parameters								Removal Efficiency
	Code	Turnidity after MOs	F- after MOs mg/L	Turnidity after VSco	PO4-3 after MOs mg/L			
					0hr	2hrs	4hrs	
3	F_6	8.8	2.33	2.95	1.83	1.65	1.57	48%
	F_6dupl.							
6	F_9	10	2.6	2.97	2.24	1.98	1.85	69%
	F_9dupl.							
9	F_{12}	10.9	2.83	3.22	2.45	2.07	1.94	78%
	F_{12}dupl.							

		Experment VIII = MOs Coagulation				
Initial Concentration of Fe^{+3} mg/L	Effective MOC dose = 35mL, 6.5-7.5pH					Removal Efficiency
	Parameters					
	Code	Initial NTU	NTU after moc.	MOs.cog. Fe^{+3} mg/L	Avg.Fe^{+3} mg/L	
3	Fe^{+3}_3		8.6	2.05	1.95	35%
	Fe^{+3}_3 dupl.		8	1.85		
	Fe^{+3}_3 cont.		2.63	3	3	
5	Fe^{+3}_5	2.63	9.6	2.75	2.7	46%
	Fe^{+3}_5 dupl.		9.8	2.65		
	Fe^{+3}_5 cont.		2.63	5	5	
7	Fe^{+3}_7		9.12	2.98	2.93	58%
	Fe^{+3}_7 dupl.		10.5	2.88		
	Fe^{+3}_7 cont.		2.63	7	7	

Given

0.5g/L Stack solution of $FeCl_3$

1ml $FeCl_3$ = 0.2mg Fe^{+3}

$C_1V_1 = C_2V_2$

200mg*v = 3mg*1000mL

v_3 = 15mL/L

v_5 = 25mL/L

v_7 = 35mL/L

	Experment IX = VSco. Filtration							
	Effective MOC dose = 35mL, 6.5-7.5pH							
Initial Concentration of Fe^{+2} mg/L	Parameters							Removal Efficiency
	Code	Turnidity after MOs	Avg.Fe^{+3} mg/L	Turnidity after VSco	Fe^{+3} after VSco. mg/L			
					0hr	2hrs	4hrs	
3	$Fe^{+3}{}_{3}$ / $Fe^{+3}{}_{3}$ dupl.	8.3	1.95	2.88	0.98	0.63	0.45	85%
5	$Fe^{+3}{}_{5}$ / $Fe^{+3}{}_{5}$ dupl.	9.7	2.7	2.95	0.86	0.73	0.53	89%
7	$Fe^{+3}{}_{7}$ / $Fe^{+3}{}_{7}$ dupl.	9.8	2.93	2.93	0.74	0.64	0.43	94%

Appendix F. Laboratory work procedures

Sieve Analysis
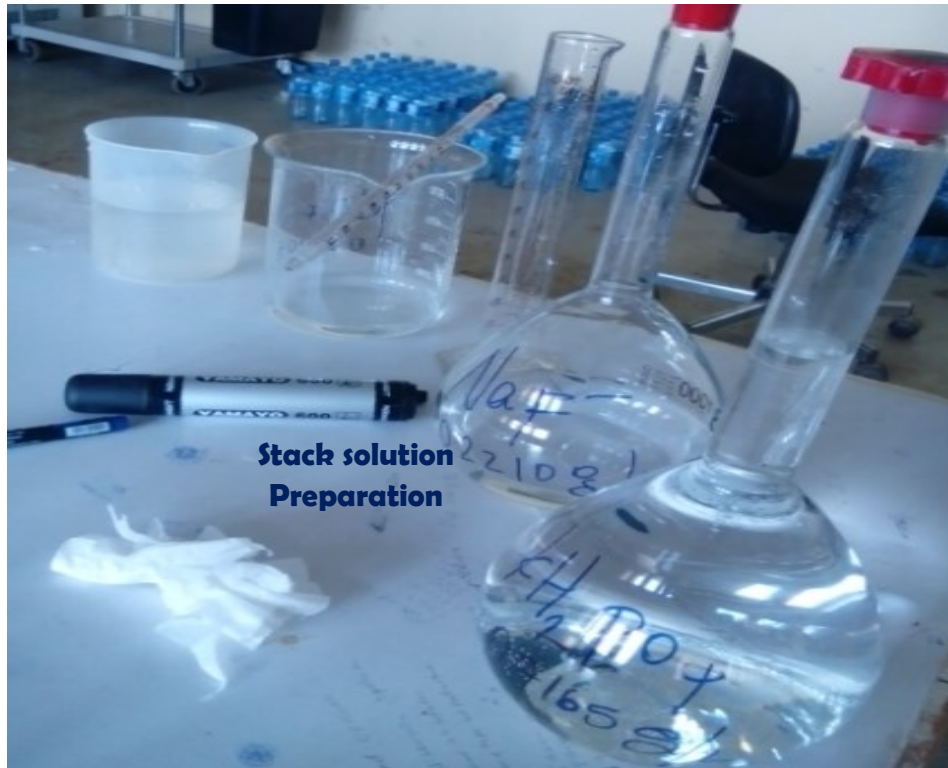
Stack solution Preparation

Sample taking

Jar test experiments of raw water

Jar test experiments after (MOs) treatment