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OF TECHNOLOGY**

APPLICATION OF INDIGENOUS MATERIALS IN DRINKING WATER TREATMENT

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Dedicated to my family, parents and Jaajja Yunia Mpagi

LIST OF PAPERS APPENDED

- I. Mpagi Herbert Kalibbala, Olle Wahlberg, Maimuna Nalubega and Bengt Hultman (2006). Performance evaluation of drinking water treatment plants in Kampala – Case of Ggaba II. Conference proceedings of the 32nd WEDC Conference in Sri Lanka, 13 – 17th November 2006. Pg. 231 – 234.
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ABBREVIATIONS

AWWA	American Water Works Association
CBP	Chlorination By-Product
DBP	Disinfection By-Product
DCE-UT	Department of Civil Engineering – University of Toronto
DGSM	Department of Geological Survey and Mines
DOC	Dissolved Organic Carbon
DPD	Diethyl-P-Phenylene Diamine
EC	Electrical Conductivity
GAC	Granulated Activated Carbon
HAA	Halo Acetic Acid
HAN	Halo acetonitrile
HDPE	High Density Poly Ethyl
HK	Haloketon
ICP	Inductively Coupled Plasma
IBM	Inner Murchison Bay
MOC	<i>Moringa oleifera</i> Coagulant
MOC-SC	<i>Moringa oleifera</i> Coagulant extracted with Sodium Chloride
MOC-DW	<i>Moringa oleifera</i> Coagulant extracted with Distilled Water
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Unit
NWSC	National Water and Sewerage Corporation
SDS – PAGE	Sodium Dodecyl Sulphate - Poly Acrylamide Gel Electrophoresis
SEM	Scanning Electron Micrograph
THM	Trihalomethane
TOC	Total Organic Carbon
TTHM	Total Trihalomethanes
UNBS	Uganda National Bureau of Statistics
UNICEF	United Nations Children’s Fund
UVA	Ultraviolet Absorbance
WHO	World Health Organisation
WTP	Water Treatment Plant
WTW	Water Treatment Works

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ABSTRACT

Volcanic ash and *Moringa oleifera* (*M. oleifera*) were investigated as indigenous materials for drinking water treatment based on problems identified at Kampala and Masaka water treatment plants in Uganda. Coagulation experiments were done using swamp raw water at Masaka National Water & Sewerage Corporation water treatment plant and pilot-scale filtration experiments carried out at Ggaba II (Kampala) water treatment plant. The results from the study indicated that there were both operational and design handicaps at the treatment plants in Kampala. There is need to modify the filtration and clarification units to enable production of water meeting both the national and international standards. At Masaka water treatment, there was increase in trihalomethanes concentration as a result of pre-chlorination. Following aeration and pre-chlorination processes, the average increase of total trihalomethanes concentration was over 4000% with over 99% being chloroform. Preliminary results from the jar test experiments indicated that use of alum with MOC-SC as coagulant aid is promising as a first stage in the treatment train for waters with a humic materials and high content of iron, typical of swamp water sources. This would probably eliminate the formation of unwanted by-products by eliminating the pre-chlorination process. Assessment of the characteristics of the volcanic ash showed that it meets the requirements for a filtration material; and results obtained from the pilot study showed that it was a suitable alternative material for use in a dual media filtration system. There was an increase in the filter run length of about two and half fold in the dual media filtration column compared to the mono medium column. Both columns produced similar water quality levels. Therefore, conversion of the rapid sand filters at Ggaba and similar water treatment plants in the country to dual media (volcanic ash on top of sand) systems would probably significantly improve the performance of the filtration systems.

Key words: Coagulant aid, drinking water treatment, dual media filtration, *Moringa oleifera*, primary coagulant, trihalomethanes, volcanic ash

1 INTRODUCTION

1.1 Background

Access to safe drinking water is important as a health and development issue at a national, regional and local level. In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit, since the reductions in adverse health effects and health care costs outweigh the costs of undertaking the interventions (WHO, 2004). This is true for major water supply infrastructure investments compared to water treatment in the home. Experience has also shown that interventions in improving access to safe water favour the poor in particular, whether in rural or urban areas, and can be an effective part of poverty alleviation strategies. However, it is a tragedy that 42% of the world's population, or 2.6 billion people, live in families with no proper means of sanitation and 1.1 billion do not have access to improved drinking water with about 4500 children dying

every day and sentencing their siblings, parents and neighbours to sickness, squalor and enduring poverty (WHO/UNICEF, 2005). There are a number of reasons for the persistence of these problems, in spite of the investment of billions of dollars in safe water by donor agencies and governments.

The rapid population growth, both in rural and urban areas, has stressed existing water supply systems. This is accompanied by the sustainability of operation and maintenance of water supply infrastructure that has hindered access to water by the poor in many developing countries. The situation is again aggravated by deterioration of the quality of water resources, attributed to the direct industrial and municipal waste discharge rendering existing treatment units ineffective to meet the water quality standards, both on a national and WHO level. Large consumption of imported chemicals like alum and chlorine used in the treatment of water renders water expensive. Consequently, the poor are forced

to collect water from less safe sources, such as contaminated springs. Also chemicals like alum have been associated with health problems and chlorine reacts with natural organic materials during pre- and post-chlorination to form chlorination by-products some of which have been reported to be carcinogenic. Although the risks to health from these by-products are extremely small in comparison with the risks associated with inadequate disinfection (WHO, 2004), efforts should be made to avoid the formation of disinfection or chlorination by-products by application of cost effective and appropriate technologies.

Therefore, this research aimed at evaluating the performance of some existing treatment plants, assessing the quality of raw water and effluents from the different process units. This was intended to identify problems or obstacles hindering their performance, and using this as a basis to develop appropriate and cost effective treatment processes that suite the conditions in developing countries, which at the same time would minimise the formation of chlorination by-products such as trihalomethanes (THMs). In this regard, the research evolved around the following questions:

- i) What makes colour removal problematic and why is coagulation that is commonly applied in many water treatment plants in Uganda not effective in some cases?
- ii) How can colour removal be enhanced/ improved?
- iii) Are there locally available materials that can be used as filtration media, coagulants or coagulant aids?
- iv) What is the impact of these materials on the formation of trihalomethanes?

1.2 Motivation

There are various types of raw water sources used in Uganda. Some of these sources are suspected to contain varying and high amounts of colour-causing substances like humic and fulvic acids, and iron where water is abstracted from swamps. However, the

treatment processes used in removing such substances are sometimes ineffective. In addition, the chlorine used at most water treatment plants is known to form chlorination by-products, which are believed to be carcinogenic. Therefore it was necessary to assess the performance of the different unit processes at the existing water treatment plants in order to identify design shortcomings, operation and maintenance problems in addition to the water quality. These would then serve as a basis for recommending and/ or development of appropriate treatment processes that suite the conditions at hand and avoid or minimise formation of unwanted chlorination by-products.

1.3 Objectives

The objectives of the study were:

- i) Evaluate the existing colour/ NOM removal processes with the intention of identifying inherent problems during their application in the field
- ii) Monitor formation of THMs from different treatment stages
- iii) Test performance of alternative coagulants e.g. *M. oleifera*, in the removal of colour-causing natural organic material
- iv) Determine the characteristics of volcanic ash and investigate its performance as a filter medium in a dual filtration system.

1.4 Thesis outline

A general introduction on the research is presented in section 1 and a review of conventional drinking water methods with major emphasis on coagulation, filtration and chlorination is presented in section 2. Application of indigenous materials in water treatment is then presented in section 3. This is followed by section 4 with a summary of materials and methods used. Results from the study carried to assess the performance of water treatment plants in Kampala is presented in section 5. Emphasis in the evaluation is focused on the coagulation and filtration at the water treatment plant. Section

6 contains a summary on the application of volcanic ash as a filtration medium in water treatment while in section 7 a summary is given on the study carried out to assess the control of trihalomethanes formation using *M. oleifera*. Also discussed in the section is the formation of trihalomethanes at Masaka plant. General conclusions and pointers to further research are presented last.

2 CONVENTIONAL DRINKING WATER TREATMENT

2.1 Introduction

Most urban communities collect water from a natural water body in the catchment, whether a stream, river, or underground aquifer. The water collected may then be stored in a reservoir for some time. Unless it is already of very high quality, it then undergoes various water treatment processes that remove chemicals, organic substances or organisms that could be harmful to human health.

The processes and technologies used to remove contaminants from water, to improve and protect water quality are similar all around the world. The most widely applied water treatment technology is a combination of some or all of coagulation, flocculation and sedimentation, plus filtration and has been used routinely for water treatment since the early part of the twentieth century. No single process can, however, solve every water quality problem. Rather, a utility must choose from a wide range of processes that are used for different purposes. Therefore the treatment technology or combination of technologies to be used in a specific situation depends on the types of water quality problems likely to be present, the nature of the contaminant to be removed, the desired qualities of the treated water, the costs of different treatments and the size of the water system.

However, due to the changing quality of raw water, the treatment technologies change constantly and at any given time fall into one of several broad categories: conventional technologies that are in widespread use and

familiar to practicing treatment engineers and operators; alternative technologies that are not as widely used as conventional technologies. Sometimes these technologies have been developed for other fields and adopted by the water community. Some processes of this type have performed satisfactorily in water treatment, but some personnel in the field may not be familiar with them; and emerging technologies that include those that have not been applied to water treatment in an operating system but show great promise for acceptance in the near future. These technologies are likely to be in the research or pilot plant stage.

2.2 Conventional water treatment methods

Coagulation, flocculation and sedimentation, followed by rapid gravity sand filtration, are the key steps in conventional water treatment systems. This is a well-proven technology for the significant removal of colour and particulate matter including protozoa, viruses, bacteria, and other microorganisms. Iron, manganese, tastes and odours may also be removed from the water by these processes. Coagulation and filtration are the most critical unit processes determining the success or failure of the whole treatment system. The two units are so closely linked that the design of one affects the other. When well designed and operated, other units such as flocculation and sedimentation may not be required (Conley, 1961) and the burden on disinfection is reduced.

2.2.1 Coagulation and flocculation

Coagulation can be broadly defined as a treatment process that includes chemical addition, rapid mixing, and flocculation. Coagulation is often the first unit process in water treatment and it is very crucial for the removal of suspended and dissolved particles. Coagulation and flocculation processes are intended to form particles large enough to be separated and removed by subsequent sedimentation, or alternative clarification processes. The coagulation stage occurs when a coagulant, such as alum, is added to the

water to neutralise the charges on the colloidal particles in the raw water, thus bringing the particles closer together to allow a floc to begin to form. It is the act of destabilising stable colloidal particles in suspension. In most cases, coagulation is optimised for the removal of inorganic colloidal particles. It is also used for the removal of natural organic matter by the process of enhanced coagulation (Gregor *et al.*, 1997). In natural waters, colloids are predominantly negatively charged and they are stable by virtue of the hydration or electrostatic charge on their surfaces. Coagulation can remove colloidal particles and natural organic matter by three mechanisms:

- i) Colloidal destabilisation, accomplished by electrical double layer compression, charge neutralisation, enmeshment, or bridging;
- ii) Precipitation; and
- iii) Co-precipitation (sweep flocculation), primarily by occlusion or surface adsorption but conceivably by non-isomorphous inclusion.

Rapid, high energy mixing (for example mechanical mixers, inline blenders, jet spurge mixing) is necessary to ensure the coagulant is fully mixed into the process flow to maximise its effectiveness. The coagulation process occurs very quickly, in a matter of fractions of a second. Poor mixing can result in a poorly developed floc.

The flocculation process, following coagulation, allows smaller particles formed during the rapid coagulation stage to agglomerate into larger particles to form settleable and/or filterable floc particles. After coagulant addition, the process water is mixed slowly for a defined flocculation period, commonly 10 – 30 minutes. The optimum flocculation time will vary depending on the raw water quality and downstream clarification process. Gentle mixing during this stage provides maximum particle contact for floc formation, whilst minimising turbulence and shear which may damage the flocs. Effectiveness of flocculation depends on the delay (or contact) time and mixing

conditions prior to any flocculants being added, the rate of treatment, water temperature and the mixing conditions within the flocculation chamber.

Coagulants and flocculants

Coagulants are chemicals that assist the destabilisation of particles (particularly colloidal sizes). Hydrolysing metal salts, based on aluminium or iron, are very widely used as coagulants in water treatment. The high cationic charge makes them effective for destabilising colloids. These salts bring about destabilisation by adsorption and charge neutralisation as well as by particle entrapment (Duan and Gregory, 2003). Performance of metal salts is significantly influenced by the pH and alkalinity of the solution.

Flocculants (also known as flocculant aids or coagulant aids) assist in the joining and enmeshing of the particles together. As a flocculant aid the chemical is added following coagulant dosing to increase the size, strength and settleability of flocs. Flocculants may be cationic, anionic, or non-ionic. They are produced with varying degrees of ionicity and in a range of molecular weights.

Although these chemicals are effectively and widely used, they have drawbacks: they influence the pH of the water, increase the soluble residues and increase the volume and metal content of the sludge.

In addition to aluminium and iron-based (inorganic) coagulants, organic chemicals known as polyelectrolytes may also be used as coagulants or flocculant aids, to assist in producing low turbidity levels in treated water. Pre-hydrolysed forms of metals such as poly-aluminium chloride and polyaluminosilicate sulphate are good examples. Compared to aluminium and iron salts, these are more effective, produce strong flocs and result in less sludge volume, albeit expensive (Duan and Gregory, 2003). Although, based on material cost, polyelectrolytes are more expensive than aluminium and iron salts, overall operating costs can be lower because of reduced need for pH adjustment, lower sludge volumes and reduced disposal costs.

However, they may not be readily available to some of the developing parts of the world and if they are, the costs may be prohibitive.

Factors affecting coagulation

The performance of coagulation and flocculation is dependent on a large number of factors, many of which are inter-related, making optimisation difficult. Source water characteristics, chemical dose rates, mixing conditions, flocculation times, the selection of chemicals and their order of addition, can all affect performance. Control of pH and alkalinity is also essential to maintain performance.

Depending on the pH of the source water, pH adjustment prior to coagulant addition may be required to achieve the optimum pH levels. The optimum pH for the coagulation process varies with the choice of coagulant. For aluminium sulphate it is usually 5.5 to 7.5, for ferric salts it is within the range 5 to 8.5. The optimum pH will vary with changing raw water characteristics.

For waters of low alkalinity, coagulant addition can consume all of the available alkalinity, depressing the pH to values too low for effective treatment, while high alkalinity waters may require high coagulant additions to depress the pH to values favourable for coagulation. Alum and ferric chloride are more acidic than PACls, and therefore result in greater alkalinity requirement after addition.

Sufficient coagulant must be added to satisfy the charge demand of raw water for effective treatment of NOM (Natural Organic Material). In most situations where NOM is present, it is preferable to determine the NOM instead of the turbidity or other parameters. However, the amount or type of NOM present is less important for the choice of coagulant than the raw water alkalinity. NOM removal will be less at higher pH-values with all coagulants. The required coagulant doses for NOM removal will also probably increase as the water temperature decreases.

For raw waters with a low TOC in which turbidity controls the coagulation, enough coagulant should be added to destabilise

suspended colloids or to create a good settling floc. However, raw water turbidity is less important for coagulant selection and dosage than the raw water NOM and alkalinity. Coagulant doses are higher when the raw water turbidity increases, but the relationship is not linear.

Low temperature affects the coagulation and flocculation process by altering the coagulant solubility, increasing the water viscosity, and retarding the kinetics of hydrolysis reactions and particle flocculation. Poly-aluminium coagulants are more effective in cold water than aluminium, as they are pre-hydrolysed.

Being a sensitive physico-chemical process, coagulation/flocculation is most reliable when raw water quality is consistent, when changes occur slowly, or when adequate automation is used to respond to changes in raw water quality. As raw water conditions change, optimal coagulation dose rates also change and careful control is required to prevent overdosing and under-dosing. Overdosing can lead to excessive concentrations of coagulant entering the distribution system. This can occur if the pH and alkalinity are not controlled at optimum levels.

Health effects

For some time concerns have been raised in the international technical literature and by interest groups about whether there are adverse health effects on consumers from residuals of chemicals in drinking water following treatment (Ministry of Health, 2005). With aluminium salts, there is concern of associated Alzheimer's disease and similar health related problems (Crapper *et al.*, 1973; Miller *et al.*, 1984). Proven concerns do exist for kidney dialysis patients if the water that is used by the patient as the dialysate liquid contains high concentrations of residual aluminium. The monomers used in the manufacture of many polyelectrolytes are toxic, and the manufacturing process needs to be controlled properly to limit the quantity of unreacted monomer in the manufactured polyelectrolytes. Acrylamide (a monomer residual of the manufacture of polyacrylamides) has proven toxicity and

carcinogenicity (Ministry of Health, 2005). In this study, natural coagulant from *M. oleifera* was investigated as an alternative to the above mentioned chemicals.

2.2.2 Rapid gravity filtration

Rapid gravity filtration provides the normal polishing step following coagulation and clarification, and the only floc removal/polishing step in direct filtration plants. Increasingly, direct filtration is being employed where the turbidity of the raw water is not high. Slow sand filtration is not very common, but there is a renewal in interest in using this method as a very useful unit process when organic removal by biological means becomes important. In Uganda, all treatment plants operated by NWSC water utility use the rapid gravity sand filtration.

Like clarifiers, filters can be described by their filtration rate. This is usually expressed as $\text{m}^3/\text{m}^2\text{h}$ or m/h and is the flow rate (m^3/h) that occurs over the surface area (m^2) of the filter bed.

As water passes through a filter bed of media, particulate matter (including micro-organisms) is trapped within the media primarily by a two-step process in which particles are moved to the surfaces of media grains or previously captured floc, and then become attached (adsorbed) to these surfaces. There are a number of mechanisms, which result in the removal of particles from water during rapid sand filtration. Physical straining is only a minor factor in rapid gravity filtration.

Mechanical straining

Granular filters remove particles that are very much smaller than the dimensions of the interstices between their grains. Although there must be some *mechanical straining* effect, it accounts for only a *minor part* of the action of a filter. A granular filter is capable of capturing very fine particles, even in the absence of particles large enough to bridge the interstices.

Adsorption

There are three essential parts of the filtration process in a granular material, that is, a bed of fixed solids (consisting of the filter medium

together with previously deposited impurities); the water passing through the interstices between the fixed solids; and the solid impurities suspended in the water. *Adsorption* of particles of impurities onto the fixed bed (that is, the fine particles stick either to a grain of filter material or to previously deposited and adsorbed impurities) is a major factor in successful filtration through porous media. Adsorption is a process of which the efficiency depends on the surface properties of both the adsorbing matrix and the small particles that are adsorbed. There are two factors in the adsorption of a particle: its ability to *stick* to the matrix when it is brought into contact; and its *transport* to a position where it either contacts the surface or comes close enough to be attracted to it.

The method of attachment of particles is similar to the process of flocculation. A small particle in close proximity to a solid surface is subject to either electrical attraction or repulsion (depending on the surface charges developed by both the particle and the surface when in contact with the water) and to the attraction caused by van der Waals forces. It is also subject to the hydraulic forces resulting from the movement of the water. The electrical forces can either inhibit or enhance the removal of fine particles from the water as it passes through a filter. For most of a filtering period, the grains of filter material are coated with a layer of impurities and, therefore, the surface charge produced on the impurities is important in ensuring a prolonged effective filter operation before cleaning is required. If the water has been treated to give optimum *destabilization of colloids* for effective flocculation and sedimentation, it is likely that the remaining particles will be suitably destabilized for effective filtering.

The forces of adhesion between the deposited impurities and the filter grains can become so strong that the impurities are not readily removed during backwashing. The impurities and filter grains may then lump together to form *mud-balls*, which are very resistant to being cleaned by backwashing; their hydraulic behaviour makes them settle in a fluidised bed

of sand. Care must therefore be exercised to ensure that although the adhesion surface forces are strong enough to trap and hold impurities, they are weak enough to allow their release during backwashing.

Transport

For adsorption to occur, particles must be carried close enough to the matrix surface to become attracted and attached to it. They are carried through interstices in the filter matrix by water flow. There are three main mechanisms by which particles are transported into contact with the filter matrix: interception, sedimentation and diffusion (LeChavallier & Kwok-Keung, 2004) (Fig. 1).

- Interception* is the process whereby a particle being carried along a streamline chances to come close enough to the surface for its attachment. If a particle of effective diameter d_p is moving along a streamline which passes within a distance of $1/2 d_p$ from a solid surface, there is an opportunity for adsorption.
- Sedimentation* is the process in which a particle is deflected from the streamline path by the gravitational effect, resulting from the difference between its weight and its buoyancy. A granular filter has an action that could be considered as an irregular shallow depth sedimentation unit.
- Diffusion* is the process whereby particles are randomly deflected by buffeting resulting from molecular activity (Brownian motion). This will occur under laminar flow conditions.

The effectiveness of interception and sedimentation in a filter increases with an increase in particle size, but the effectiveness of diffusion increases with a decrease in size. Thus, although a filter may remove large particles efficiently by interception and sedimentation, and very small particles by diffusion, there is an intermediate size of particle for which the removal efficiency is relatively low. For practical filters, this is about 1 – 5 micron. Therefore destabilization of colloids with adequate chemical pre-

treatment is an essential aspect of rapid sand filtration.

Dual and multimedia filters

In the conventional rapid sand filters, the media gradation is fine-to-coarse. Only the top fine sand portion is effective in filtration thus resulting in early head loss build-up and short filter run length. This necessitates frequent filter cleaning even when the filtrate quality satisfies the effluent quality requirements. To overcome this problem, two alternatives have been proposed: to replace the mono media by dual or multimedia filtration or to use deep bed filter with coarse media of uniformity coefficient close to one (Qasim *et al.*, 2000). Dual media filters reduce the rate of headloss development, thus increasing the filter run length.

Upgrading a rapid sand filter to a deep bed mono-medium filter cannot be simply

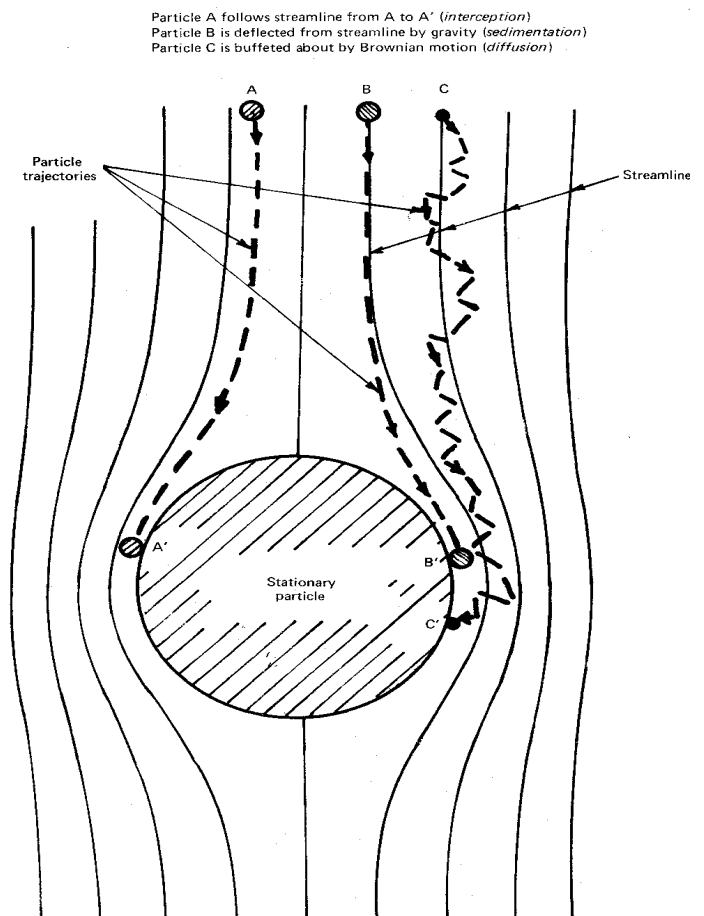


Fig.1. Methods of particle transport (source: www.ctre.iastate.edu)

achieved with replacement of the medium alone. Additional modifications may be required to the filter basin and backwash system. However, existing rapid sand filters can be upgraded to at least up to double the capacity with the nominal expense of replacing the sand with dual or multimedia (HDR Engineering Inc., 2001). By converting a rapid sand filter to dual or multi media filter, loading rates can be increased by 50% to more than 100% without compromising performance (Ghebremichael, 2004). The conventional approach to multimedia filtration is to have three layers of material, for example, coarse (1 mm) anthracite on top, sand of 0.5 mm in the middle and 0.25 mm garnet at the bottom. The size and specific gravity are carefully selected to minimize intermixing. The commonly used media are anthracite coal and sand. The difference in densities ensures that these layers maintain their position also during backwashing.

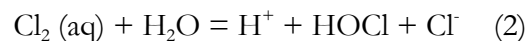
Most studies (Shukairy *et al.*, 1992 a & b; Miltner *et al.*, 1992 a & b) have used granular activated carbon, anthracite and sand as filter media. Others (Ghebremichael, 2004) have used pumice, anthracite and sand. Pumice has also been tested and used in some few parts (for example, Italy, Eritrea) of the world. Volcanic ash is another material that has not received much attention but may hold potential as a filter medium in drinking water treatment. It has been used in Kenya in the de-fluoridation of water (Zevenbergen *et al.*, 1996) and in Ethiopia for adsorption of metals from wastewater (Stuben *et al.*, 2006).

2.2.3 Chlorination

The rate of formation of CBPs, including THMs, haloacetic acids (HAAs), haloacetonitriles (HANs) and haloketons (HKs) has increased in drinking water supplies as a result of increased chlorination in the water treatment process (Chang *et al.*, 2000). Various treatments applied to raw water to remedy undesirable characteristics, for example, colour, taste, odour, dissolved iron and manganese or turbidity, may affect the ultimate quality of the finished water. Pre-chlorination to a free chlorine residual is

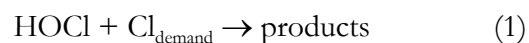
practiced early in the treatment sequence as one method to alter taste- and odour-producing compounds, to suppress growth of organisms in the treatment plant, to remove iron and manganese, and to reduce the interference of organic compounds in the coagulation process.

Chlorine may be used in the form of compressed gas under pressure that is dissolved in water at the point of application, solutions of sodium hypochlorite, or solid calcium hypochlorite. The three forms are chemically equivalent because of the rapid equilibrium that exists between dissolved molecular gas and the dissociation products of hypochlorite compounds. Dissolved aqueous chlorine reacts with water to form hypochlorous acid, chloride ions, and protons as indicated by the equation (2).



The necessity for such treatments or others is determined by the characteristics of the raw water and the selection of one of the various methods to achieve a particular result will be based upon cost-effectiveness in the particular situation. When chlorination is used, the application or point of application in the treatment sequence can affect the undesirable THM content of the finished water. Therefore, the reduction of THM precursors in raw water by coagulation and settling prior to chlorination reduces final THM production (Hoehn *et al.*, 1977; Stevens *et al.*, 1975). For example, the Louisville Water Company reduced THM concentrations leaving the plant by 40%-50% by shifting the point of chlorination from the pre-sedimentation basin to the coagulation basin (Hubbs *et al.*, 1977).

With raw water containing both high concentration of NOM and iron, chlorine reacts, in addition to the oxidation reactions during pre-chlorination, with the NOM to form chlorine related chlorination by-products in the water, that is



Although most water treatment utilities continue to rely on chlorine or hypo chlorite as their primary disinfection/ oxidation

chemicals, the discovery that chlorination can result in the formation of THMs and other halogenated hydrocarbons has prompted the re-examination of available chlorination/disinfection methodology to determine alternative agents or procedures (Morris, 1975).

Factors influencing CBP formation

A number of factors in addition to NOM composition determine the composition of chlorination by-products (CBPs). Reaction time is among the most important factors determining CBP concentrations under conditions where a disinfectant residual persists. The halogenated CBPs that are chemically stable will accumulate in disinfected waters and their concentrations will increase with reaction time for as long as a disinfectant residual exists. However, according to Stevens *et al.* (1975), there are cases where halo acetic acid (HAA) concentrations drop to near zero after long residence times in real drinking water distribution systems, a phenomenon he attributes to biodegradation, and which does not appear to occur with the THMs, appearing to be biodegradable only under anaerobic conditions.

The chlorine dose plays a greater role in CBP formation during pre-chlorination than during post chlorination (secondary disinfection). This is because during pre-chlorination it is usually added in amounts well below the long-term demand and it is the limiting reactant, not the organic precursors. The presence of other ions, such as bromide, temperature and pH all can affect the nature and distribution of the CBPs formed. An increase in temperature has been shown to cause an increase in the rate of both CBP formation and chlorine demand (Clark *et al.*, 2001). This implies that for tropical conditions of which Uganda is part, the rate at which DBPs are formed is to a high extent given the high temperatures in this region.

Health and aesthetic aspects

Health and aesthetics are the principal motivations for water treatment. Regarding health, the use of chlorine and other disinfectants

such as ozone, although reducing the risk of waterborne disease, creates new potential risks, because compounds known as disinfection by-products are formed during the disinfection process. Among all the chlorinated by-products, trihalomethanes, reported to exhibit a potentially carcinogenic activity, have been investigated most thoroughly during the last 20 years. Classical trihalomethanes consist of chloroform (CHCl_3), dichlorobromoform (CHCl_2Br), dibromochloroform (CHBr_2Cl) and bromoform (CHBr_3).

Epidemiological studies have been conducted to evaluate the association from exposure to chlorinated surface water with several adverse outcomes: cancer, cardiovascular disease, and adverse reproductive outcomes, including neutral birth defects. Recent studies have reported increased incidence of decreased birth weight, prematurity, intrauterine growth retardation, and neural tube defects with chlorinated water and in some cases, THMs (AWWA, 1999). In their study, Chang *et al.* (2000) reported that DBPs are potential carcinogenic and teratogenic substances. According to Singer *et al.* (1999), some of these compounds have been found to be carcinogenic or to cause adverse reproductive or developmental effects in animal studies while others have been shown to be mutagenic and hepatotoxic. However, no evidence of reproductive or developmental effects has been reported for chlorine as reported by Cohn *et al.* (1999).

In this study, assessment of performance of *M. oleifera* as a primary coagulant and coagulant aid in the treatment of swamp water with a high content of iron and humic substances was carried out. Iron removal by *M. oleifera* was also assessed as a pre-treatment in place of pre-chlorination to avoid the formation of THMs at an early stage (meant for the oxidation of iron) in water treatment train.

3 APPLICATION OF INDIGENOUS MATERIALS IN WATER TREATMENT

3.1 Introduction

Natural materials have been used in water treatment since ancient times but lack of knowledge on the exact nature and mechanism by which they work has hindered their wide spread application. As a result, they have been unable to compete with the commonly used chemicals. In recent years there has been a resurgence of interest to use natural materials due to cost and associated health and environmental concerns of synthetic organic polymers and inorganic chemicals.

Natural coagulants

A number of effective coagulants have been identified of plant origin. Some of the common ones include nirmali (Tripathi *et al.*, 1976), *M. oleifera* (Olsen, 1987; Jahn, 1988), okra (Al-Samawi and Shokrala, 1996), *Cactus latifaira* and *Prosopis juliflora* (Diaz *et al.*, 1999), tannin from valonia (Özacar and Sengil, 2000), apricot, peach kernel and beans (Jahn, 2001), and maize (Raghuwanshi *et al.*, 2002). Bhole (1995) compared 10 natural coagulants from plant seeds. The study indicated that maize and rice had good coagulation effects when used as primary coagulants or coagulant aid.

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

particulate suspensions (organic or inorganic) and also to treat dissolved organic materials. It has also been reported that chitosan possesses antimicrobial properties (Liu *et al.*, 2000; Chung *et al.*, 2003).

By using natural coagulants, considerable savings in chemicals and sludge handling cost may be achieved. Al-Samawi and Shokrala (1996) reported that 50 – 90% of alum requirement could be saved when okra was used as a primary coagulant or coagulant aid. Apart from being less expensive, natural coagulants produce readily biodegradable and less voluminous sludge. For example, sludge produced from *M. oleifera* coagulated turbid water is only 20 – 30% of that of alum treated water (Ndabigengesere *et al.*, 1995; Narasiah *et al.*, 2002). The coagulation process in water treatment is complimented by filtration. The successfulness of coagulation in most cases determines the performance of the filtration system, which may be of a mono media or dual media type.

Filtration media

In dual or multi media granular filtration anthracite coal and garnet are often used. In many places, these materials are not commonly available and if they are available, they are expensive. Some of the locally available filter media that have been used in single or multi media filtration include crushed coconut shells, burned rice husk (Frankel, 1974), human air (Wasiuddin *et al.*, 2002), crushed apricot shell (Aksogan *et al.*, 2003), pumice (Ghebremichael, 2004) and palm leaves and shrimp shells (Aly *et al.*, 2005). Paramasivan *et al* (1973) reported that high-grade bituminous coal, used in dual media filtration, could be a good substitute for anthracite coal. In his study, Ghebremichael (2004), showed that pumice obtained from Eritrea would be used as a dual filter media to give longer filter runs than obtainable in a single medium (sand) filter. In addition to these materials, another material that has not received much attention and would be used for water treatment is volcanic ash.

3.2 Volcanic ash

Volcanic ash is formed during explosive volcanic eruptions. It consists of very fine rock and mineral particles less than 2 mm in diameter ejected from a volcanic vent (Fig. 2). Ash is created when solid rock shatters and magma separates into minute particles during explosive volcanic activity. The usually violent nature of an eruption involving steam (*phreatic eruption*) results in the magma and perhaps solid rock surrounding the vent, being torn into particles of clay to sand size. Solid material produced and thrown into the air by such volcanic eruptions is called tephra, regardless of composition or fragment size. If the resulting pieces of ejecta are small enough, the material is called volcanic ash, defined as such particles less than 2 mm in diameter, sand-sized or smaller. Unlike the ash that forms from burning wood or other combustible materials, volcanic ash is hard and abrasive, rather than soft and fluffy. It does not dissolve in water, and it conducts electricity, especially when it is wet.

The volcanic ash deposits lie on the surface (Fig. 3), so it is easy to mine. It has varying colours ranging from black, grey, brown and yellow. The specific gravity of volcanic ash obtained from southwestern Uganda was in the range of 2 - 2.5 (DGSM/DCE-UT, 1992). Other materials similar to volcanic ash do have identical values: pumice - 1.96, shale - 2.58, diatomite - 2.65, limestone - 2.69, tile - 2.59

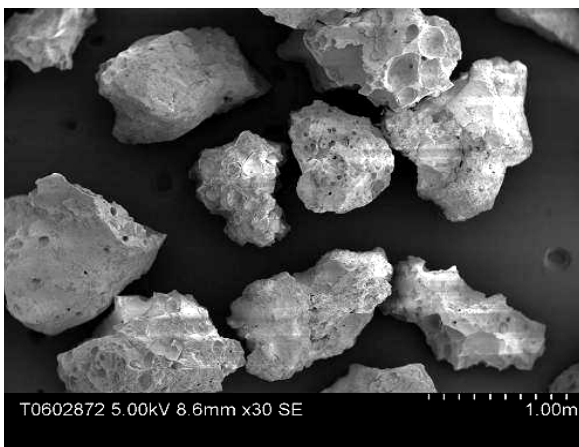


Fig. 2. SEM for volcanic ash from southwestern Uganda

(Perry and Chilton, 1973).

In Uganda, volcanic ash has been employed as aggregate in production of lightweight blocks, in sewage sludge drying bed and in the production of cement. In this study, the performance of the volcanic ash in dual media filtration of drinking water was investigated.

3.3 *Moringa oleifera*

Of all the plant materials that have been investigated over the years, the seeds from *M. oleifera* have been shown to be one of the most effective as a primary coagulant for water treatment. *M. oleifera* is a small, fast-growing, drought resistant and deciduous tree that ranges in height from 5-12 m with an open, umbrella shaped crown, straight trunk, 10 – 30 cm thick, with corky, whitish bark. The evergreen foliage, depending on the climate, has leaflets 1-2 cm in diameter; the flowers are white or cream coloured. The fruits or pods are initially light green, slim and tender, eventually becoming dark green, firm and up to 120 cm long, depending on the variety. Fully mature dried seeds are round or triangular shaped, the kernel being surrounded by a lightly wooded shell with three papery wings. It can be easily established by cutting or by seed. In a favourable environment an individual tree can yield 50 to 70 kg of pods in one year (Schwarz, 2000).

Since the early 1970's a number of studies have been carried out to determine the



Fig. 3. Deposit of volcanic ash in southwestern Uganda

effectiveness of the seeds for the treatment of surface water (Olsen, 1987; Jahn, 1988; Sutherland *et al.*, 1994; Muyibi & Evison, 1995 & 1996; Ndabigengesere & Narasiah, 1998; Okuda *et al.*, 2001a & b; Ghebremichael, 2004) using different extraction methods for the active coagulant from *M. oleifera*. Utilising 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). 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.*, 1995).

To avoid increasing suspended and organic materials in the water, extraction of the active coagulant in *M. oleifera* seed using various methods has been done. A lot of progress has been made in investigating the coagulation potential of crude seed extracts as well as purified seed proteins from *M. oleifera*, which have been proven to be the main active agent in seed based coagulants. In their research, Jahn (1979) investigated the potential of plant seeds and roots on removal of turbidity and compared it with alum. He extracted the coagulating agent from seed powder and roots using water and observed that in terms of turbidity removal, the crude seed suspension compared well with that effected by alum. Due to the drawbacks of extracting the active coagulant from *M. oleifera* using water, researchers such as Ndabigengesere *et al* (1995) and Okuda *et al* (1999 & 2001a) went ahead to purify and characterise active coagulating agent from *M. oleifera* seeds using other methods. Ndabigengesere *et al* (1995) used ammonium precipitation, dialysis, ultrafiltration, SDS-PAGE, ion exchange chromatography, polyacrylamide gel isoelectric in the extraction and purification of the active components (proteins) and lyophilization technique to concentrate the purified proteins.

They observed that the active agent is a water-soluble cationic protein that harbours very good coagulation properties which is used in extremely low dosages than that used for crude seed extract. However, the extraction and purification methods involved seem to be mainly for experimental purposes and are most likely difficult to be scaled up for its ultimate use in water treatment facilities in poor countries. Okuda *et al* (1999 & 2001a) extracted *M. oleifera* coagulant (MOC) using 1.0 mol l⁻¹ NaCl solution and the extracted coagulant (MOC-SC) showed better coagulation activity with dosage 7.4 times lower than that of MOC - DW for removal. The improvement in coagulation activity was attributed to the salting – in mechanism of salt on proteins present in the seed powder suspension. Ghebremichael (2004) working with *M. oleifera* came up with a simple and rapid method of extraction and purification of *M. oleifera* coagulating proteins that would be scaled-up to full-scale plant application.

In this study, investigations on the performance of MOC as both a primary coagulant and coagulant aid in treatment of swamp water were carried out.

4. MATERIALS AND METHODS

4.1 Plant performance evaluation

In the assessment of the Ggaba II plant, different treatment stages were evaluated on the basis of design criteria, treatment effectiveness, operation and maintenance procedures. Evaluation was based on one-year (2005) data. Samples were taken at points 1, 2, 3 and 4 for raw, clarified, filtered and final treated water respectively (Fig. 4). The service water samples were taken from the backwash tank. Water of samples taken daily during the year 2005 and the water quality parameters measured were pH, EC, colour, turbidity, free chlorine and total chlorine. Colour was used as a surrogate parameter for organic matter. Additional information related to the raw water source, the plant operation and design was obtained from NWSC staff.

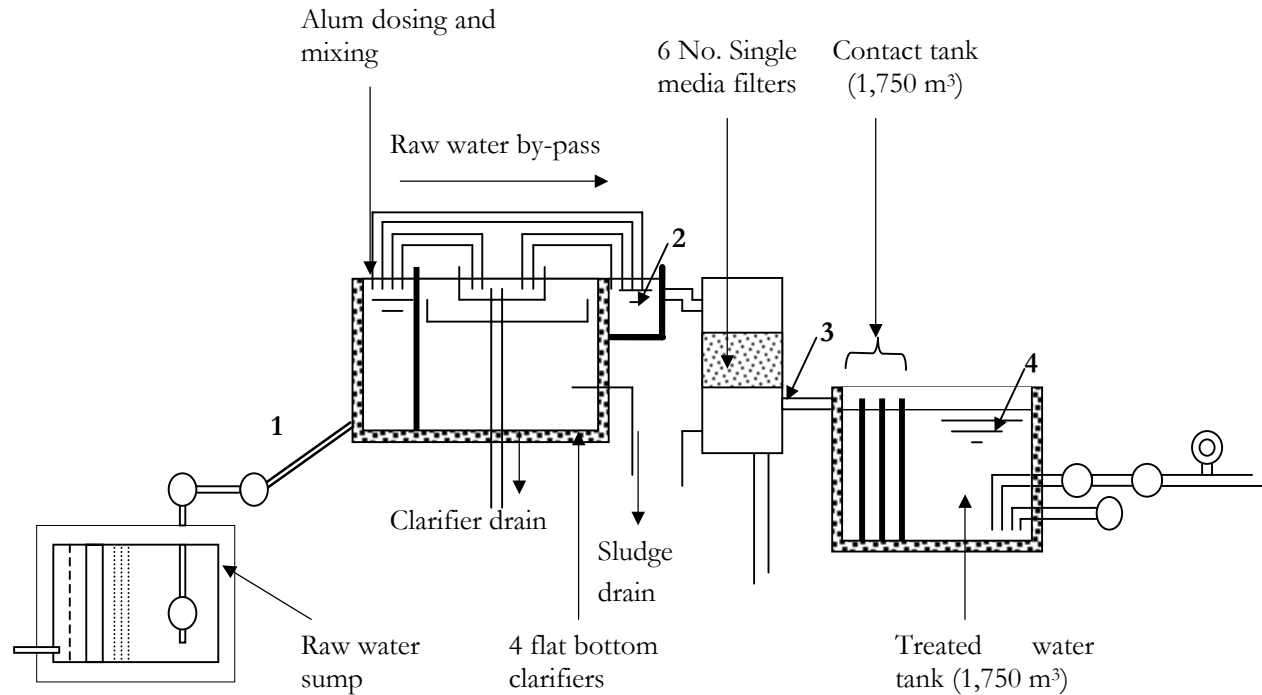


Fig. 4. Ggaba II water treatment plant process units

All analyses were done following the standard methods for analysis of water and wastewater (APHA/AWWA/WEF, 1998). Colour and turbidity of samples were measured using DR 4000 spectrophotometer at the Public Health and Environmental Engineering Laboratory, Makerere University. pH was measured using portable turbidimeter (Hach, model 2001A) and chlorine with Hach DPD calorimetric method. EC was measured using handheld WTW Cond 330i conductivity meter. All meters were calibrated each day readings were taken. The results were compared with both the WHO and National guidelines.

4.2 Pilot-scale filtration column experiments

4.2.1 Characterisation of filtration media

Volcanic ash samples were obtained from Kabale deposits in southwestern Uganda, crushed, sieved and graded to the size gradation suitable for drinking water filtration. Sand used in the study was sampled from that used at the treatment plant filters. The

properties of the volcanic ash tested included chemical composition, loss on ignition, specific gravity, acid solubility and hardness. For sand only the specific gravity was determined.

4.2.2 Filtration experimental set-up

Pilot-scale filtration columns were set up adjacent to Ggaba II water treatment plant in Kampala. Two columns of high-density polyethylene pipes each of which measured 1.5 m high and 150 mm internal diameter were used with support gravel at the bottom to retain the granular filter media. To ensure uniform effluent collection and backwashing, nozzles were provided at the bottom of 10 cm-deep graded gravel bed. Water was supplied to the columns from feeding tank by gravity with loading rates of 2.7, 3.4 and 6.8 m/h. For headloss measurements, piezometers were fitted at the inlet, interface and effluent points. The effective size (ES), uniformity coefficient (UC) and depth of the media used in the filtration columns are given in Table 1.

Table 1: Parameter values of filter media used in the pilot scale filtration study

	Sand			Volcanic ash		
	ES (mm)	UC	Depth (cm)	ES (mm)	UC	Depth (cm)
Mono medium	0.65	1.71	60	-	-	-
Dual media	0.50	1.30	15	1.10	1.20	45

4.2.3 Analytical methods

Turbidity measurements were done using a portable turbidimeter (Hach, model 2001A) while colour was measured using Hach Spectrophotometer (DR2010) at the plant laboratory. All measurements were done at time intervals of 1 hour. For loading rates of 2.7, 3.4 and 6.8 m/h, the total number of samples taken was 71, 141 and 24 respectively. Sieve analysis was carried out in accordance with procedures laid down in BS 1377 (1990). The specific gravity was determined according to the pycnometer method in BS 1377 (1990) while the acid solubility of volcanic ash was determined following American water works association standards for filtering materials (AWWA, 1998). The material strength was determined by scratching it with the different minerals in the Mohr's scale. The mineral composition and loss on ignition (LOI) of volcanic ash were determined using ICP techniques and ignition at Analytica Laboratory, Malmö in Sweden.

Quantification of algae was done at the Department of Zoology, Makerere University, Kampala. An aliquot of 10 ml from each of the column influent and effluent samples was fixed with Lugol's solution, sub-sampled into a 2 ml sedimentation chamber and counted after 12 h of sedimentation under an inverted microscope (Hund Wetzlar: magnification x 200). Different identification keys were used to identify the flora to genera.

4.3 Jar test experiments

4.3.1 *M. oleifera* and alum used

The *M. oleifera* seeds used in this study were obtained from the Faculty of Veterinary medicine, Makerere University. The seeds were stored in dry conditions at room temperature of about $24 \pm 1^\circ\text{C}$.

The aluminium sulphate (Regular grade) was obtained from Kampala water treatment works. The coagulation experiments with alum alone were performed for comparison purposes. A 1% solution of alum in distilled water was used. The alum powder was totally soluble in the water.

4.3.2 Preparation of *M. oleifera* extract

Only seeds of dry pods were used. The winged seed cover was shelled just before the extraction using 1 N sodium chloride solution. The kernel was ground to a fine powder by using a kitchen blender. Oil was removed by mixing the powder in 95% ethanol (5 -10% w/v) for 30 minutes. The solids were separated by centrifugation and dried at room temperature for a period of 24 hours. From the dried sample, 5.0 g of the seed powder was mixed with 500 ml of the extractant (1 N NaCl). The suspensions were stirred for 30 minutes using a magnetic stirrer and filtered first through Whatman No 3 then through a fibreglass filter and finally through 0.45 μm filter. The filtrate (MOC-SC) was used for coagulation experiments either immediately or after storing of up to 3 days at room temperature.

4.3.3 Experimental procedure

Jar tests were carried out to evaluate coagulation activity of MOC-SC both as a primary coagulant and coagulant aid. 5 sets of jar tests were conducted. Raw water used in the experiment was obtained from river Nabajjuzi flowing through a swamp. Each of the six jars (1000 ml) was filled with raw water up to the 1000 ml-mark and placed on each slot in a jar tester (ECE Compact Laboratory Mixer). Alum was added into each beaker at doses ranging from 0 to 110 mg/l and was agitated at 150 rpm for 1 min. The mixing speed was reduced to 30 rpm to allow gentle mixing for 30 minutes. After gentle mixing,

sedimentation was allowed to take place for 1 hour. The same procedure was followed with MOC-SC as a primary coagulant. To assess the performance of MOC-SC as a coagulant aid, MOC-SC was added at the start of gentle mixing period. The concentration of MOC-SC is stated in mg/l on the assumption that all the MOC dissolved. After sedimentation, an aliquot of 100 ml was sampled from the mid depth of each beaker for quality analysis. All experiments were run at room temperature and no pH adjustment was exercised. Very low pH-value (pH 5.5) is often recommended to maximise organic matter removal in alum addition (Pernitsky, 2003). Annual water quality data for Masaka source for year 2005 is presented in Table 2.

Table 2: Masaka raw water quality (N = 66)

Parameter	Mean	Max	Min	Median
pH-value	5.2	6.0	4.7	5.0
Turbidity (NTU)	35.8	78.0	7.0	39.0
Colour (PtCo)	223.7	420.0	121.0	218.0
EC (μ S/cm)	50.5	64.0	37.5	53.0
Alkalinity (as mgCaCO ₃ /l)	14.0	24.0	3.7	14
Iron (mg/l)	4.6	7.7	1.6	4.5

4.3.4 Analytical methods

The parameters analysed were turbidity, pH, conductivity, colour and iron. The analytical methods followed the standard methods for the examination of water and wastewater (APHA/AWWA/WEF 1998). Turbidity, colour and iron were measured using Hach Spectrophotometer DR/2000. Iron was measured according to Hach ferrozine method 260. pH was determined using a pH meter (Hach sensION1) while conductivity was measured using handheld WTW Cond 330i conductivity meter. Calibration of meters was done each day experiments were taken.

Analysis of THMs was carried out at Umgeni Water Laboratory, South Africa. 500 ml sample bottles with solid ground glass stoppers were used to collect the samples. The bottles and stoppers were baked in a furnace for 3 hours at $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$ and

allowed to cool to room temperature. A small amount (spatula full) of sodium thiosulphate was added in each bottle to react with the chlorine present in the water, and thereby prevent further THM formation. Sample bottles were filled and sealed carefully so that no air bubbles were entrapped. The samples were stored in a refrigerator before transportation to Umgeni water laboratory. Analysis of THMs was done by gas chromatography (GC) (Hewlett Packard; Column: DB-624 or equivalent; detector: electron capture detector; auto-sampler: automatic liquid sampler and software: HP GC Chemstation). Apart from THMs, all measurements and experiments were conducted at Masaka water treatment plant laboratory.

5 PERFORMANCE EVALUATION OF DRINKING WATER TREATMENT PLANTS IN KAMPALA

5.1 Introduction

Most urban communities collect water from natural water bodies in the catchment, whether a stream, river, or underground aquifer. Unless it is already of very high quality, it then undergoes various water treatment processes that remove any chemicals, organic substances or organisms that could be harmful to human health. The choice of treatment to use depends in addition to the characteristics of the water, the types of water quality problems likely to be present and the costs of different treatments, on the operation and maintenance costs and skill levels required of water treatment plant operators. All these factors greatly affect the performance and output product of drinking water treatment systems.

In this study, assessment of the performance of Ggaba II water treatment plant in Kampala was carried out to detect the main problems and to suggest improvements in operation of the plants in the face deteriorating water quality, increased water demand and receding water levels in the Lake Victoria.

5.2 Results

5.2.1 Design and operation of Ggaba II plant

The selection of the treatment process train is influenced among others by the ability to meet finished water quality objectives, considering both seasonal and long-term changes in raw water, and hydraulic requirements. Conventional water treatment is used at the plant. The water undergoes settlement, clarification (coagulation, flocculation and sedimentation), rapid gravity sand filtration and disinfection. Raw water flows by gravity to the raw water sump from where is pumped to alum dosing chamber where rapid mixing is performed by a hydraulic jump.

The design capacity of all treatment plants (Ggaba I and II) is 117,270 m³/day while the average total production is 113,907 m³/day, 97% of the design capacity. The design capacity of Ggaba II alone is 80,000 m³/day with an average production of about 70,252 m³/day. The unaccounted for water lost within the distribution system is 37.2%. However, with this production, only 67% of the original target population of 1,302,138 is served despite the fact that Kampala alone at present has a population of 1.2 million with a population growth rate at 3.9% and daily transient population of 2.5 million (UNBS, 2002). The escalated population growth and expanded service area, puts the percentage of population served far below 67%. This has stressed the plants because production is increased beyond the design loads to cater for the increased demand at peak hours. As a result units like clarifiers that are very sensitive to rapid changes in the hydraulic loading rates are by-passed. The retention time in the clarifiers is about 2 hours and the overflow rate is 58.4 m/day (2.4 m/hr). The clarifiers are bypassed to increase the throughput at period of high demand.

When the clarifiers are in operation, part of the accumulated sludge blanket is removed to avoid floc or sludge carryover to the filters. However, the bleeding was inadequate because the bleeding system is located on one side of the clarifiers (Fig. 5). In addition, due

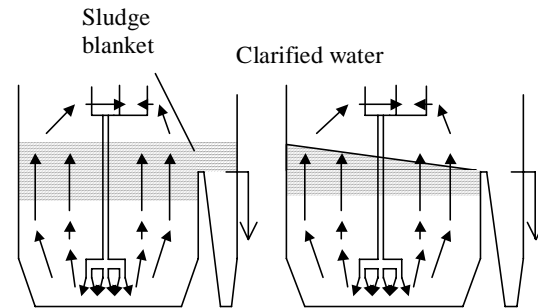


Fig. 5. Clarifiers at two stages of operation a) sludge blanket draining needed, b) sludge blanket not leveled after draining

to the high day temperatures, the sludge blanket is raised so high causing a lot of carryover to the filters. There were also shrimps in the clarifiers that disturbed the sludge blanket that probably led to carryover of flocs or sludge particles into the filters.

The filters in operation are rapid gravity sand filters with single media and are operated manually. The automatic system failed as soon as the plant was commissioned. There are 6 units with a combined surface area of 376 m², bed depth of 1.26 m and design filtration velocity of 9.1 m/hr. The filter run ranged from 12 – 18 hours depending on the quality of the incoming water. The short filter runs were probably as a result of algal bloom, increase in the load of suspended material from water that was not clarified and floc carryovers when the clarifiers were in operation. The backwash cycle lasted for 30 to 45 minutes compared to 8 to 15 minutes reported in the literature (Quasim, *et al.*, 2000).

The spacing and elevation of the wash water troughs is an important consideration. If the troughs are too low, filter media may be washed out. The troughs should be designed to ensure free weir flow over the lip of the trough. At Ggaba II, the elevation of the lip of the trough was raised by 200 mm from the original design height of 100 mm to avoid excessive loss of filter media. Despite the increase in the elevation, a lot of media was still being lost.

The results from sieve analysis indicated that sand media was not of the right sizes with a lot of dirt in some filters. Two of the filters had more of the course media size while one had more of the fine size. There was also difficulty in removing dirt during backwashing. The wash drain are located at only one side of each filter unit and after the backwashing process, the filters are not given time to ripen. This may lead to high turbidity spikes in the finished water quality.

Although Ggaba III was under construction to help to meet the increased demand, there were challenges of raw water quality that similarly need attention.

5.2.2 Water quality and performance

Data analysed showed that there was a significant change in the raw water quality (at 5% significant level) with respect to the colour (Fig. 6a) with an increase of about two fold at the intake works in the period 1997 to 2005. The colour increased regardless of the change in the rainfall pattern (Fig. 6b). Between 1997 and 1999, the annual mean colour increased with rainfall from 64.2 to 69.1 PtCo probably due to pollutants from the catchment brought by runoff into the IMB. In 2000, colour continued to increase despite a significant reduction in rainfall. Between 2001 and 2005, the colour increased from 70.9 to 146.6 PtCo despite a declining trend in rainfall. These trends imply that there would be other factors in addition to rain that contribute to the water quality change.

A summary of results from the assessment of the performance of the Ggaba II water treatment plant is given in Tables 3 and 4. The colour of treated water increased with increase

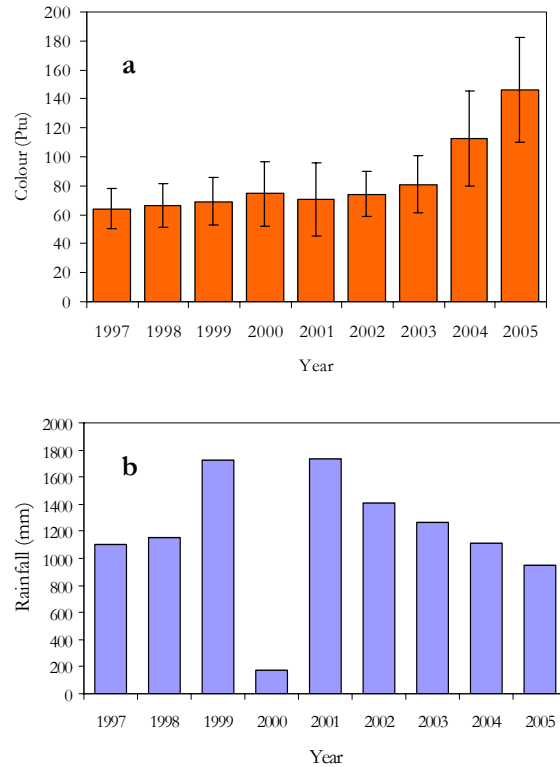


Fig. 6. Mean annual daily a) colour and b) rainfall

of colour of raw water. The clarification process is effective in reducing colour (Fig. 7 & 8). However, regardless of whether the clarifiers were in operation or not, the colour of the water increased in the subsequent treatment stages. The annual mean colour of the finished water was significantly above the WHO value of 15 PtCo. 53.4% of samples taken were not compliant with the guideline. Despite the longer filter runs, the water quality of the filtrate was poor. Algal growth within the filters was also evident. There was also

Table 3: Annual final water quality at Ggaba II plant for year 2005 (N = 322 samples)

Parameter	Mean (Standard deviation)	Compliance (%)
pH	6.65 (\pm 0.29)	21.6
Colour (PtCo)	31.91 (\pm 33.72)	53.4
Turbidity (NTU)	2.36 (\pm 2.08)	9.3
Electrical conductivity (μ S/cm)	144.73 (\pm 19.87)	
Free chlorine (mg/l)	1.11 (\pm 0.30)	
Total chlorine (mg/l)	1.29 (\pm 0.33)	

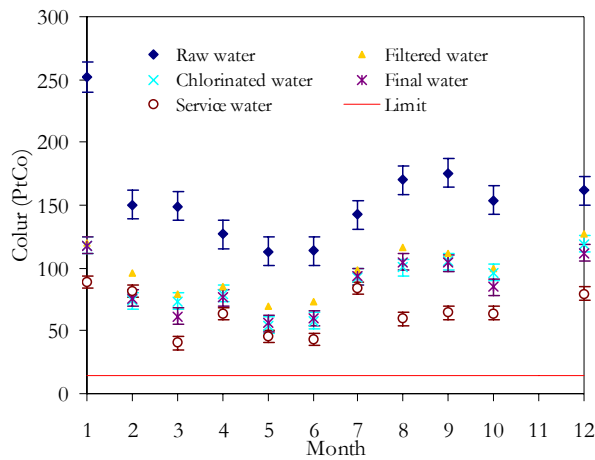


Fig. 7. Performance of Ggaba II WTP without the clarification stage

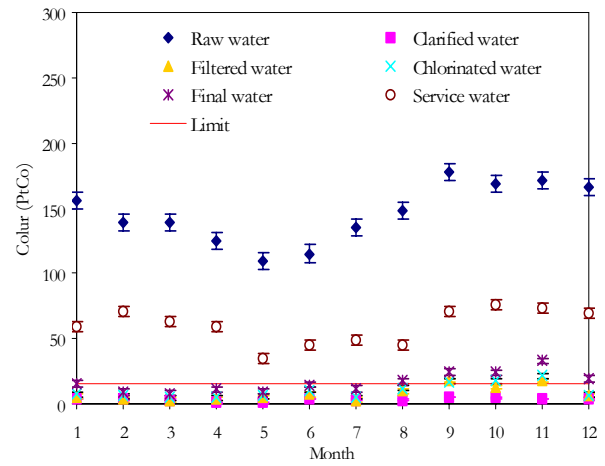


Fig. 8. Performance of Ggaba II WTP with the clarification stage in operation

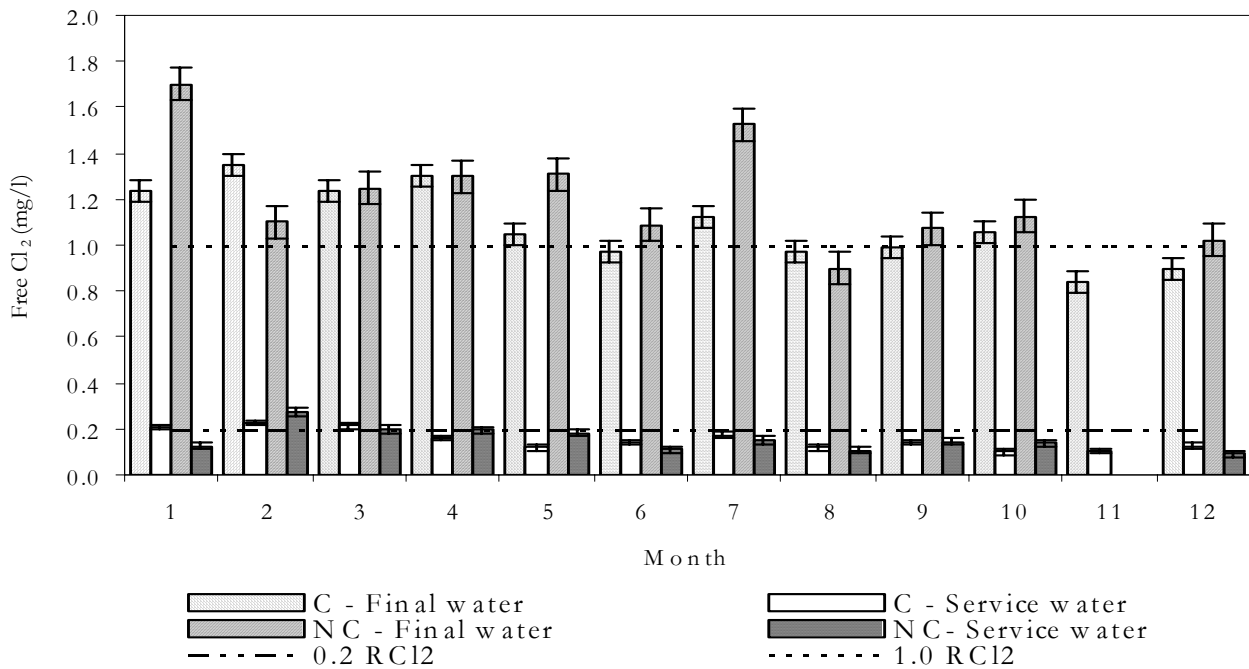


Fig. 9. Free chlorine residual at Ggaba II water treatment premises (C = with clarification process, NC = without clarification of raw water)

rapid drop of the residual chlorine concentration within the water treatment plant premises (Fig. 9). Recommended conditions of disinfection for conventional water treatment purposes specify a free chlorine residual of at least 0.5 mg/l after contact time of 30 minutes at pH < 8.0 with mean turbidity not exceeding 1.0 NTU (WHO, 2002). From the assessment done when the clarification is in operation and when it is not, results indicated that clarification was a significant factor (p-value = 0) in determining the

performance of the subsequent treatment processes except for the service water quality (p-value = 0.231) at 5 % significant level (Table 5). The period of the year (month) did not affect significantly the effluent quality from units after clarification but it was significant for the raw water quality (p-value = 0.034).

5.3 Discussion

Following the assessment of Ggaba II water treatment plant in Kampala a number of shortcomings were identified that probably led to the poor quality of the plant effluent. Design problems of the clarifiers and filtration units, inadequate operation and maintenance of filters were some of the problems identified.

Regarding the clarification unit, the desludging hoppers are located on one side of the clarifiers resulting in inadequate sludge blanket removal and carryover to the filters. The unequal distribution of water to the different units, the shrimps and algae in the units also probably contributed to the break-up of the sludge blanket thus carryover to the filters.

Table 4: Comparison of plant performance when the clarifiers are in operation (1) and when they are not in operation (2)

	Mean (PtCo)	Std Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Raw water				
1	145.900	6.015	132.498	159.302
2	157.564	6.539	142.994	172.133
Filtered water				
1	8.075	3.773	-0.332	16.482
2	98.820	4.102	89.681	107.960
Chlorinated water				
1	9.867	4.354	0.166	19.568
2	89.394	4.733	78.848	99.940
Final water				
1	16.533	3.887	7.871	25.195
2	87.633	4.226	78.217	97.050
Service water				
1	59.783	3.452	52.092	67.475
2	66.290	3.753	57.928	74.651

During periods of high algal bloom the blanket has a tendency of becoming buoyant due to production of oxygen during times of high algal blooms. This may also have resulted in a billowing of the floc blanket and subsequent carry-over of floc on to the filters.

This necessitates installation of screens downstream small enough that would probably prevent passage of the shrimps or installation of roughing filters downstream of the clarification system. The later seems to be more viable given the poor quality at the raw water source. There is need for raw water source quality management to reduce on the rate of eutrophication that leads to algal bloom and other related water quality problems.

Table 5: Tests of between-subjects effects (ANOVA)

Source	F-value	P-value
Raw water ($R^2 = 0.790$; Adjusted $R^2 = 0.539$)		
Month	3.320	0.034
Clarification process	1.723	0.219
Filtered water ($R^2 = 0.966$; adjusted $R^2 = 0.926$)		
Month	1.317	0.336
Clarification process	265.089	0.000
Chlorinated water ($R^2 = 0.944$; adjusted $R^2 = 0.877$)		
Month	1.211	0.385
Clarification process	152.925	0.000
Final water ($R^2 = 0.945$; adjusted $R^2 = 0.880$)		
Month	1.808	0.180
Clarification process	153.315	0.000
Service water ($R^2 = 0.716$; adjusted $R^2 = 0.375$)		
Month	2.188	0.114
Clarification process	1.628	0.231

Modification of the clarifiers by either installing sludge hoppers on either side of the basins is also necessary to allow uniform removal of sludge over the basins. Inspecting and levelling the outlet weirs to ensure that all receive equal flows can correct the non-uniform flow to the different units. These measures combined would probably improve the general performance of the plant.

Bypassing the clarifiers resulted in overloading of the filters and production of inadequately treated water. The problem was aggravated by floc carryover from the clarifiers, improper size and inadequate depth of the filtration medium. High population of algae and

plankton are difficult to coagulate and usually float (Quasim *et al.*, 2000) and probably carryover from the clarifiers also contributed to the poor performance of the filters. As result, the filtration run lengths are shortened and a lot of water has to be used during backwashing. Modification of the filters to dual media system would probably improve the filter run length and the quality of effluent. Dual media filters have been reported to handle higher loadings and to give longer filtration run lengths than mono medium filter with same level of effluent quality (Ghebremichael, 2004). It also anticipated that the new Ggaba III treatment plant would help to meet the demand during peak hours. However, unless the distribution system is upgraded, the production will be restricted by lack of adequate reservoirs. It is therefore recommended that the distribution system should be upgraded to meet the increased production. The inadequate water quality from the treatment plant would have resulted from the shortcomings above. If remediation measures are put in place, it is expected that colour and turbidity removal will significantly improve. This will also increase the amount of residual chlorine in the distribution system which is probably consumed by the organic material left in the final water as indicated by the colour and turbidity values.

In addition to operational and design handicaps, there were also changes in the raw water quality that probably contributed the inadequate performance of the plant. The change in quality would probably be attributed to a combination of factors including dilution, storm water runoff during the wet periods and concentration effects during dry periods. High colour could also indicate a high propensity to produce by-products from disinfection processes (WHO, 2004). Colour is a surrogate measure for organic matter and there is a possibility that high colour would result in the formation of trihalomethanes during the subsequent chlorination process. Trihalomethanes have been reported to exhibit a potentially carcinogenic activity (Chang *et al.*, 2000; AWWA, 1999; Singer *et al.*, 1999). The high colour in the final water

probably resulted in the rapid consumption of the residual chlorine at the plant premises. This indicates that water might reach the furthest consumer point without enough residual chlorine.

6 APPLICATION OF VOLCANIC ASH AS A FILTRATION MEDIUM IN DRINKING WATER TREATMENT

6.1 Introduction

Developing safe drinking water supplies is one of the most urgent challenges facing developing nations. In order to alleviate the prevailing difficulties, approaches should focus on sustainable water supply and treatment systems that are cost effective. It is important that these technologies are affordable and preferably use local materials. Cost effectiveness in the case of filtration systems means that filter run lengths between filter-cleanings are long enough to offset the cost of filter downtimes and increasing filter backwash volumes. In most cases, filter run length is based on turbidity; however, raw water turbidity alone is not considered an adequate predictor of filter-run length (Cleasby *et al.*, 1984). In addition to turbidity, quantification of raw water algal content is essential for judging the acceptability of the raw water into the filters. This is especially important for eutrophic water because the algal bloom greatly affects the performance of the treatment plant (Rositano *et al.*, 2001; Hiroshi *et al.*, 2002).

6.2 Results

6.2.1 Material characteristics

Specific gravities of volcanic ash and sand were 1.8 and 2.8 respectively. Hardness on Moh's scale and acid solubility value obtained were 6.5 and 0.57% respectively. Ghebremichael (2004) reported a specific gravity of 1.6 for pumice obtained from Eritrea. AWWA (1998) recommends specific gravity values greater than 1.4; acid solubility of less than 5% loss in 1:1 HCl solution after 2 hours and hardness values greater than 2.7 for anthracite coal. Paramasivam *et al* (1973)

recommended hardness values greater than 2 and acid solubility values of less than 2% loss in 10% v/v HCl solution after 24 hours for bituminous coal. The material characteristics were in compliance with values recommended by other researchers (Fig. 10). The volcanic ash had a loss on ignition of 0.20% compared to Rwenzori volcanic ash and Mbeya pumice that had losses on ignition of 0.00% and 3.60% respectively.

6.2.2 Water treatment performance

The summary of results of water quality from the pilot filtration columns are presented in Table 6 while the plots of turbidity, colour and headloss values against time are shown in Figures 11 and 12. Both columns produced filtrate of similar quality levels.

Table 6: Summary of water quality results from the pilot-scale filtration columns

Dependent Variable: Effluent turbidity				
Loading rate (m/h)	Mean ^(a) (NTU)	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Dual media				
2.70	4.952	0.108	4.740	5.165
3.40	4.724	0.077	4.573	4.875
6.80	5.057	0.161	4.741	5.374
Mono medium				
2.70	4.366	0.108	4.154	4.578
3.40	4.992	0.077	4.841	5.143
6.80	4.788	0.161	4.472	5.105
Dependent Variable: Effluent colour				
Loading rate (m/h)	Mean ^(b) (PtCo)	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Dual media				
2.70	94.398	3.604	87.315	101.481
3.40	71.389	1.827	67.799	74.979
6.80	79.020	3.593	71.959	86.080
Mono medium				
2.70	90.417	3.604	83.334	97.500
3.40	76.946	1.827	73.356	80.536
6.80	76.552	3.593	69.492	83.613

Covariates appearing in the model are evaluated at the following values: ^(a) Influent turbidity = 10.3171 NTU and ^(b) Influent colour = 136.5720 PtCo

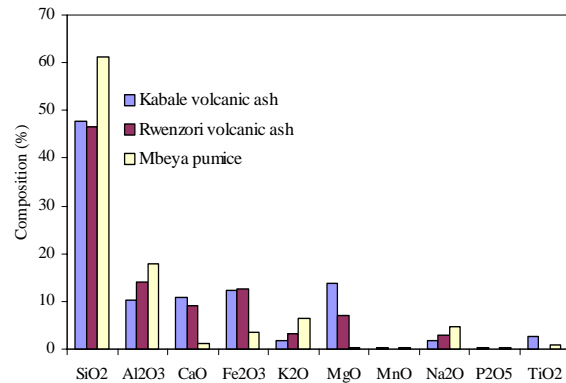


Fig. 10. Mineral composition of study volcanic ash (Kabale) in comparison with Rwenzori deposit and Mbeya (Tanzania) pumice

The type of filter did not have significant impact on the effluent colour (p-value = 0.997) and turbidity (p-value = 0.295) while the influent quality was significant factor in determining the effluent quality (p-value = 0 for colour and turbidity). There was a significant turbidity removal at the interface in dual media column with quality levels similar to effluents of both columns. There was an increase of filter run lengths in dual-media column of about two and half folds that of the mono media filter (Fig. 11). Ghebremichael (2004) made a similar observation with pumice as dual medium. At the 35th hour, the mono-medium column had reached a headloss of 65 cm while at the same time the dual media column had a headloss of 40 cm. There was corresponding turbidity values were 3.52 NTU and 3.04 NTU for the mono-medium and dual media columns respectively. The dual media was backwashed at the 96th hour when the turbidity had reached 5.41 NTU while at this time the sand was due for the third backwashing.

Algae in the influent and growth within the filtration columns affected the operation of the filters. The pilot study indicated slightly different growth and removal rates of the different algae genera in filtration columns (Table 7). While there was an increase of 80% blue-green algae and a reduction of 76% green algae in the mono medium (sand) filtration column, reductions of 0.23% and 48% were

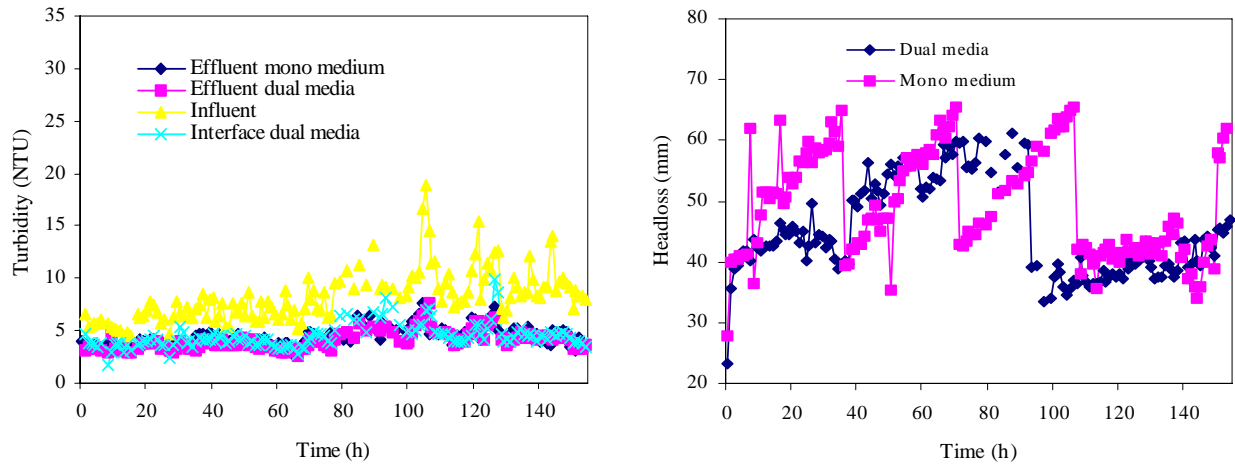


Fig. 11. Turbidity and head loss at loading rate of 3.4 m/h

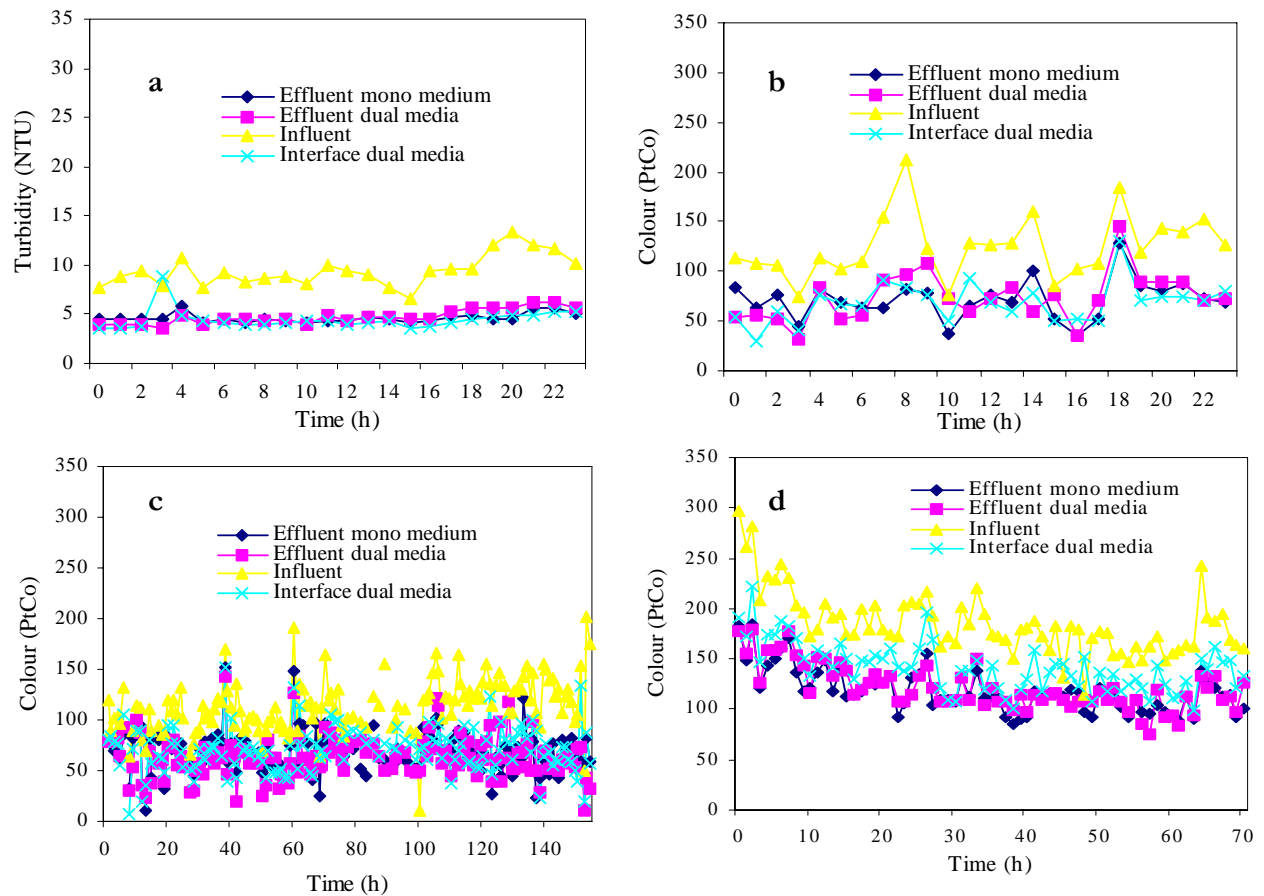


Fig. 12. Turbidity at loading rate of 6.8 m/h (a) and colour at loading rates of 6.8 m/h (b), 3.4 m/h (c), and 2.7 m/h (d)

observed for blue-green algae and green algae in the dual media filtration column. There was a significant increase of *Anabaena* in the effluent from the mono media column and *Oscillatoria* in effluents from both columns.

Microcystis, *Oscillatoria* and *Anabaena* have been reported to produce hepatotoxins (WHO, 2004). Standard method for water and wastewater examination (APHA/AWWA/WPCF 1989) lists *Chlorella*, *Closterium*,

Table 7: Blue-green algae and green algae counts from the pilot scale filtration study

Genera	Influent	Sand Effluent	Reduction %	Volcanic ash/sand Effluent	Reduction %
Blue Green Algae (Cyanobacteria)					
<i>Anabaena</i>	24,250	71,500	-195	27,000	-11
<i>Merismopedia</i>	11,250	9,500	16	13,000	-16
<i>Microcystis</i>	3,625	-	100	-	100
<i>Oscillatoria</i>	750	1,750	-133	1,750	-133
<i>Aphanothece</i>	500	-	100	500	0
<i>Coelosphaerium</i>	13,000	13,500	-4	11,000	15
Total	53,375	96,250	-80	53,250	0.23
Green Algae (Chlorophyceae)					
<i>Ankistrodesmus</i>	1750	1,000	43	1,500	14
<i>Closterium</i>	1000	-	100	-	100
<i>Pediastrum</i>	1250	500	60	1,000	20
<i>Scenedesmus</i>	4500	1,000	78	2,000	56
<i>Selenastrum</i>	1000	-	100	500	50
<i>Spirulina</i>	23000	4,500	80	6,500	72
<i>Staurastrum</i>	500	-	100	500	0
<i>Cystodinium</i>	2250	1,500	33	6,500	-189
Total	35,250	8,500	76	18,500	48

Oscillatoria and *Anabaena* as filter-clogging algae. The raw water (influent) to the columns had 53,375 units/ml of blue-green algae and 35,250 units/ml of green algae. Raw water algae concentration (clump count) of less than 1,000 units/ml is recommended as acceptable for treatment by direct filtration (McCormick and King 1982).

6.3 Discussion

The physical and chemical characteristics of the volcanic ash were investigated to determine its suitability as a filter medium. The characteristics were compared against values for other materials (bituminous coal, anthracite and pumice) that have been used elsewhere. The specific gravity of volcanic ash of 1.8 compares well with values of materials used in dual media filtration systems elsewhere (Ghebremichael, 2004). The material characteristics of volcanic ash qualify it as a suitable medium for use in dual media filtration systems. Acid solubility of 0.56% renders it suitable for use in a wide range of water pH values without losing it due to

corrosivity. With a hardness value on the Moh's scale of 6.5 (greater than 2.7 recommended by AWWA, 1998), the volcanic ash grains can withstand the abrasive forces during the process of backwashing without getting damaged.

The dual-media column gave longer filter run lengths than the mono medium column. This is a basic advantage of dual media system over mono-medium filters, where only the top few cm layer of the medium is utilised. Ghebremichael (2004) made a similar observation with pumice and sand. This increase in the filtration run length of the dual media column may be attributed to the surface characteristics of the volcanic ash providing more storage capacity for the suspended particles than the sand. It also indicates that turbidity removal was distributed over the whole media depth implying that particles were able to penetrate down to the lower layer indicating an effective use of the entire depth. Similar levels of water quality at the interface of dual media column and effluents of both columns indicate a significant contribution of

volcanic ash in the filtration process compared to sand.

The influent was not suitable for direct filtration as indicated by the high algae counts. However, overall, the dual media column indicated better removal of algae than the mono medium column. Probably, dual media filters would be used for waters with a high algal content with less impact on the final water than mono medium filter system. The high algal counts indicate the need to pre-treat the water to remove algal bloom before it enters the clarifiers and filters. This would probably be by use of rough filtration as the first stage in the treatment train and using volcanic ash as a medium.

7 CONTROL OF THMs FORMATION IN WATER TREATMENT USING *MORINGA OLEIFERA*

7.1 Introduction

In drinking water treatment, the coagulation process is used to destabilise suspended particles and to react with dissolved organic materials in the raw water. Proper coagulation is therefore essential for good filtration performance and for by-product control in disinfection. However, coagulation of water with low pH-value, low alkalinity, a high content of natural organic materials and iron (typical of swamp water) is expensive because it involves application of a number of chemicals. In developing countries, procurement of chemicals is very costly in terms of foreign exchange and as a result most drinking water treatment plants supply water that is only partially treated due to this handicap. GAC adsorption and membrane technologies such as nanofiltration that are applied elsewhere for such types of water are also expensive to install, operate and maintain in developing countries. In Uganda, pre-chlorination followed by coagulation, is commonly used as a first stage in the treatment of swamp water with a high content of iron. However, pre-chlorination of such waters would lead to the production of chlorination by-products. Concentrations of total organic carbon greater than 50 mg/l have

been reported in swamp waters (Kavanaugh, 1978). Therefore, it would be appropriate to avoid chlorination early in the treatment train and devise means of removing the chlorination by-products precursors and iron. The possible alternative could be the application of indigenous, naturally derived coagulants generally of plant origin like seeds from the multi-purpose tree *M. oleifera* in water treatment.

In this study, *M. oleifera coagulant* extracted with salt solution (MOC-SC) was used as a primary coagulant and coagulant aid in treatment of swamp water and the results were compared to alum addition. Its impact on iron removal and electrical conductivity of the settled water was also assessed.

7.2 Results

7.2.1 THMs formation at full-scale plant

The trend of THM concentrations of the treated water after each treatment stage at Masaka treatment is presented in Figure 13. There was an increase in trihalomethanes concentration at the treatment plant. At the aeration and pre-chlorination processes, the average increase was over 4000%. The total trihalomethane (TTHM) concentrations recorded were 5.64, 238.5, 87.3, 85.9 and 137.05 µg/l in the raw, pre-chlorinated, clarified, filtered and disinfected water, respectively. This corresponded to a reduction of about 63% and 1.5% on clarification and filtration, respectively, and an increase of 60% was obtained on disinfection. Over 99% of the TTHM formed was chloroform, which is reported to be carcinogenic by various researchers (AWWA, 1999; Chang *et al.*, 2000; Water Quality & Health Bureau, 2003). The Italian new regulation on drinking water (Legislative Decree 31/01) indicates a restrictive maximum concentration level of 30 µg/l (Sorlini & Collivignavelli, 2005) while US EPA specified a maximum contaminant level of 80 µg/l under the Stage 1 disinfection by-products rule (US EPA, 1998). The challenge is removal of iron without creating THMs.

7.2.2 Jar test experiment results

The experimental results on the quality of the water treated by alum aided with MOC-SC both as a coagulant and coagulant aid as well as alum alone as a coagulant are presented graphically in Figures 14, 15 and 16. At initial colour and turbidity of 291 PtCo and 10.11 NTU, the colour and residual turbidity using the MOC-SC increased with dosage ranging from 0 to 110 mg/l and thereafter rapidly reduced. Lowest colour value of 9 PtCo was observed at a MOC-SC dose of 230 mg/l (equivalent to 23 ml) corresponding to about 96% removal and turbidity of 1.13 NTU at 88.8% reduction (Fig. 14).

Alum gave turbidity and colour values of 1.22 NTU and 20 PtCo at an optimum dosage of 50 mg/l which values are comparable with those obtained with MOC-SC as a primary coagulant. Using alum with MOC-SC as a coagulant aid reduced the optimum dosage of alum from 50 mg/l to 30 mg/l to give the same level of residual colour and turbidity. The optimum dosage of MOC-SC as coagulant aid was found to be 100 mg/l (equivalent to 10 ml). In all cases turbidity and colour values were less than values recommended by the WHO. Similar results were obtained at a pilot scale water treatment plant used to treat turbid surface water with processed *M. oleifera* seed and alum as primary coagulants (Muyibi & Alfugara, 2003; Liew *et al.*, 2006). Therefore, results from this study are in agreement with the findings from other researchers that when alum is used together with *M. oleifera* as a coagulant aid, better performance is achieved.

The pH-value decreased with increasing alum dose while MOC-SC had no significant impact in pH-value though an increasing trend was observed with increasing dosage (Fig.15a). There was no significant difference in pH-value drop with alum alone and alum aided by MOC-SC. At an optimum alum dose of 50 mg/l, the pH-value dropped to 4.8 and with alum aided by MOC-SC, the pH-value had dropped to about 5.0.

There was a slight increase in the conductivity with alum whereas with MOC-SC, the

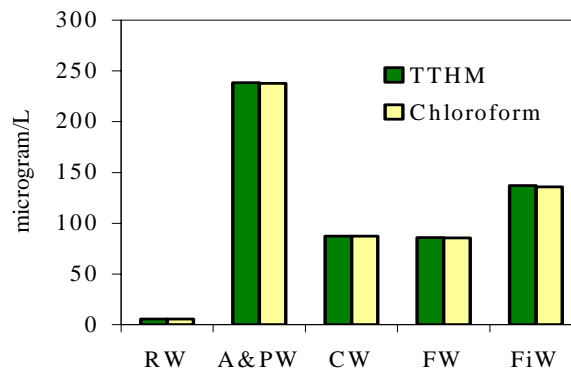


Fig. 13. TTHM and Chloroform production at Masaka water treatment plant (RW – raw water, A&PW – aerated and pre-chlorinated water, CW – clarified water, FW – filtered water and FiW – final water)

conductivity increased gradually with dosage (Fig.15b). Application of alum aided by MOC-SC also resulted in an increase in conductivity that remained stable at about 1030 $\mu\text{s}/\text{cm}$. Such ionic strength often causes corrosion in water supply and distribution networks.

Residual iron values less than 1.0 mg/l were obtained with MOC-SC doses above 120 mg/l, 1.38 mg/l with alum and MOC-SC as coagulant aid, and 3.05 mg/l with alum (Fig. 16). MOC-SC as a primary coagulant gave the lowest residual iron concentration with values less than the WHO recommended value of 0.3 mg/l at dosages of 220 mg/l and above. Therefore a combination of alum with MOC-SC as coagulant aid would give a better option in the removal of iron and avoid the formation of THMs by pre-chlorination.

7.3 Discussion

The increase in TTHM concentration of over 4000% after prechlorination was probably due to the reaction of chlorine and natural organic materials in the water. Swamp waters are known to contain very high concentrations of organic matter greater than 50 but less than 500 mg/l TOC (Kavanaugh, 1978). Over 99% of the TTHM formed was chloroform, which is reported to be carcinogenic by various researchers (Water Quality & Health Bureau, 1993; AWWA, 1999; Chang *et al.*, 2000).

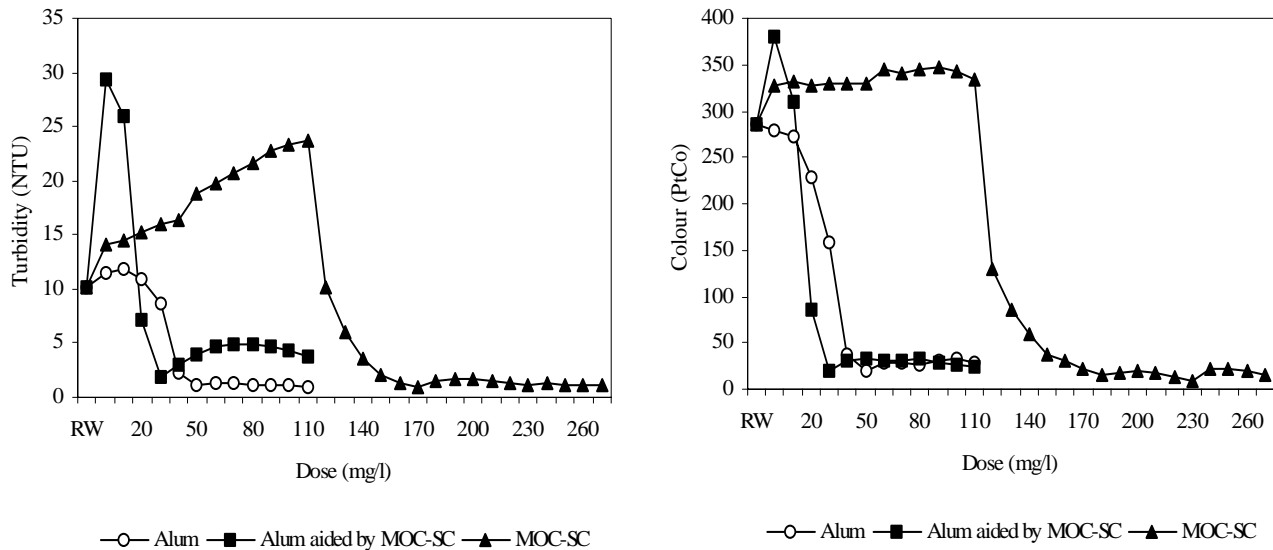


Fig. 14. Effect of using MOC-SC, alum and alum with MOC-SC on a) turbidity and b) colour of the clarified water

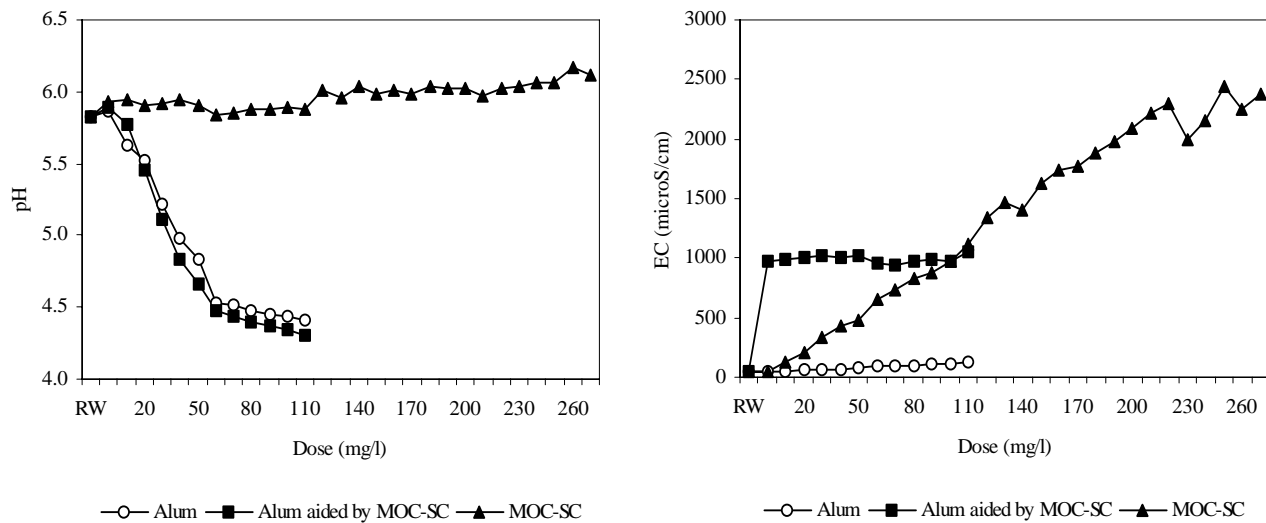


Fig. 15. Effect of using MOC-SC, alum and alum with MOC-SC on a) pH and b) conductivity of the clarified water

Although there were reductions of about 63% and 1.5% on clarification and filtration, respectively, the increase was 60% on disinfection. This probably indicates that there were still more natural organic materials in the filtered water that reacted with the chlorine meant for disinfecting the water. Although clarification is a significant process reducing the formed TTHM, the reduction will depend on what comes in. Therefore, it is not appropriate to apply chlorine before removal of CBP precursors especially in cases where

the subsequent treatment units have limited capacity to remove CBPs.

The performance of MOC-SC as a coagulant aid was probably due to bridging mechanism facilitating the coming together of floc particles that settle easily at lower alum dosage. The residual colour and turbidity increased after the optimum dosage when using alum and MOC-SC as a coagulant aid. This was probably due to re-stabilisation of the colloidal particles and natural organic

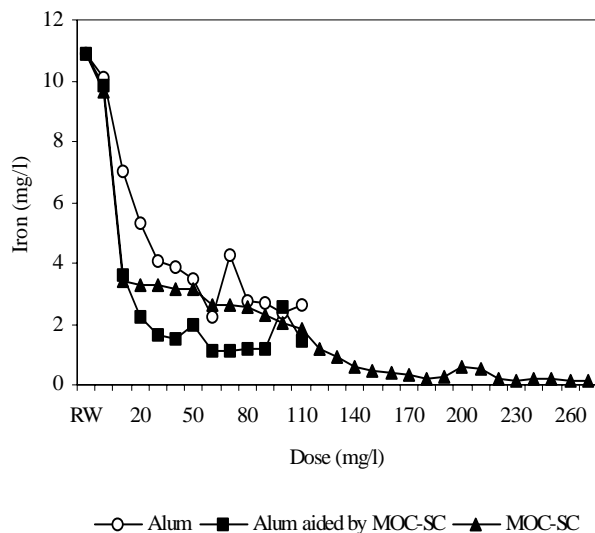


Fig. 16. Effect of using MOC-SC, alum and alum with MOC-SC on iron content of the clarified water (From 3 jar test sets)

materials. The further reduction in turbidity with increased alum dosage is termed enhanced coagulation and it results in lower pH values and higher sludge volumes. Enhanced coagulation would not be recommended for developing countries faced with problems of chemical importation. The sudden reduction of the residual colour and turbidity when on application of MOC-SC as a primary coagulant was probably because most of the organic materials remain in solution until their binding capacity has been satisfied that precipitation starts to take place.

The study gave promising results for using MOC-SC in the removal of iron at the coagulation stage. Therefore, the removal mechanism by MOC-SC probably involved adsorption, enmeshment and bridging.

The low pH-values resulting from the addition of alum necessitates application of alkali like lime or sodium hydroxide to correct the pH-value. The increase in conductivity could probably be attributed to the use of NaCl in the extraction of MOC. This is indicated by the almost constant conductivity resulting from the use of alum aided by MOC-SC with a constant concentration. This is further verified by the same conductivity value when MOC-SC is acting as a primary coagulant and a coagulant aid at concentration of 100 mg/l.

Such increase in ionic strength often causes corrosion in water supply and distribution networks.

CONCLUSIONS

The results from this study indicated that there were both operational and design handicaps at the treatment plants in Kampala. There is need to modify some of the unit processes to enable achieving water meeting both the national and international standards.

Modification of the clarifiers should be done by installing sludge hoppers on either side of the basins. It is also necessary to allow for uniform removal of sludge over the basins and levelling the outlet weirs to ensure that all receive equal flows to correct for non-uniform flow to the different units. It is also necessary to modify the filters to dual media system. Dual media filters have been reported to handle higher loadings and to give longer filtration run lengths than mono medium filter and same level of effluent quality. These should be done hand-in-hand with water quality remediation intervention at the source.

With the anticipation that the new Ggaba III treatment plant would help to meet the demand during peak hours, the distribution system should also be upgraded. Otherwise the production will be restricted by lack of adequate reservoirs. This will help to meet the demand during peak hours of the day and put less stress on the unit treatment processes, as is the case for the filters at Ggaba II.

The physical and chemical characteristics of the volcanic ash indicated that it meets the requirements for a filter material and can thus be used a filter medium in a dual media filter system. However, the cost of processing and transporting the material from various deposits around the country was not done during this study. In addition, the preliminary results from the pilot scale column study indicated an increase in the filtration run length of the dual media column that may be attributed to the surface characteristics of the volcanic ash providing more storage capacity

for the suspended particles than the sand. The two columns gave effluents of similar quality.

Following aeration and pre-chlorination processes, the average increase was over 4000%. There is need to control the formation of THMs at the pre-chlorination stage meant for the oxidation of iron prior to consequent processes in the treatment train. Results from the study indicated that use of alum with MOC-SC as coagulant aid is promising as a first stage in the treatment train for waters with a humic materials and high content of iron. This would eliminate the formation of unwanted pre-chlorination by-products.

FURTHER RESEARCH

The study was carried out to assess the performance of indigenous materials (*M. oleifera* and volcanic ash) in water treatment. It was noted that MOC-SC was effective both as a primary coagulant and coagulant aid to alum. It would be applied as first treatment stage in water with high content of both humic materials and high iron concentration. However, the impact of the filtration and post-chlorination processes on the water

There was a high increase in THMs concentration at the Masaka water treatment plant as a result of the pre-chlorination. reated using MOC-SC were not investigated in this study. Therefore, the following areas are proposed for further research:

- Characterisation of natural organic material in the raw water and optimisation of the coagulation process for their removal using the indigenous materials, in this case *M. oleifera* and volcanic ash should be done. Assessment of impact of filtration and chlorination of water treated by *M. oleifera* should also be done.
- Determine the performance of the coagulants at variable pH/ alkalinity with respect to natural organic matter removal (TOC/ DOC, UVA254); characterisation of the NOM before and after treatment with the coagulants and after filtration through a dual media bed of volcanic ash and sand should also be assessed.

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