View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Loughborough University Institutional Repository

Refereed Paper

32nd WEDC International Conference, Colombo, Sri Lanka, 2006

SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Natural Resources for Appropriate Water Treatment

Kebreab Ghebremichael, The Netherlands

The high cost of water treatment has rendered provision of good quality water in the developing world difficult. The search for low-cost treatment options is essential in order to provide safe drinking water. This paper presents a study on the use of Moringa oleifera and pumice as low cost natural materials for improving water treatment systems. Moringa oleifera was found to be very effective for coagulating raw turbid water. The coagulant component was isolated from the seed and purified using a single-step ion exchange purification method. The process was standardized and it can be readily scaled up. The use of pumice for dual media filtration was compared against a mono-medium sand filtration system. In a pilot scale study pumice/sand dual media increased the filter run length two-fold and reduced the volume of backwash water by half.

Introduction

Inadequate sanitation and water services to the urban poor population are among the most serious challenges facing the developing world. About one billion people lack safe drinking water and more than six million people (of which 2 million are children) die from diarrhoea every year (Postnote, 2002). As stipulated in the millennium development goals (MDGs) provision of safe drinking water to the poor is one of the priorities in the agenda. This requires adopting sustainable and appropriate water supply and sanitation systems.

In many of the developing countries treatment plants are expensive, the ability to pay for services is minimal and the availability of skills as well as technology are scarce. The cost involved in achieving the desired level of treatment depends, among other things, on the cost and availability of water treatment chemicals and other treatment materials. In most cases the commonly used water treatment chemicals are expensive and they have to be imported in hard currency. Some of the commonly used chemicals such as aluminum sulphate (alum) are also associated with human health and environmental problems (Crapper et al., 1973; Christopher et al., 1995; Kaggwa, 2001).

In order to alleviate the prevailing difficulties, approaches should focus on sustainable water treatment systems that are low cost, robust and that require minimal maintenance and operator skills. In some cases these problems are tackled by adopting appropriate water treatment methods using locally available resources. In places like India, Latin America and Africa several studies have been conducted to assess alternative coagulation chemicals and filter media that would replace the expensive counterparts. In addition to the use of low cost local materials, the cost of power consumption can be minimized by using hydraulic systems. This can be achieved by proper site selection to exploit the gravity flow of water.

Moringa oleifera (MO)

MO is a tree native to North India and it is drought resistant that grows in hot semi arid regions with annual rainfall of 250-1500 mm as well as in humid area with annual rainfall in excess of 3000 mm (Folkard, 2000).

MO is a multi purpose tree with most of its parts being useful for a number of applications and it is often referred to as the ‘miracle tree’ (Fuglie, 1999). The pods, leaves and flowers are important sources of food. The leaves are specially, rich in vitamins, minerals and proteins. The roots and other parts of the tree are used in traditional medicine. Oil can be extracted from the seed and used in food preparation, fine lubrication of delicate machines and in the cosmetics industry. The dried pods and husks (Fig. 1) can be pyrolysed for activated carbon production (Pollard et al., 1995; and Warhurst et al., 1997).

The coagulant is obtained after oil extraction and the residue, after coagulant extraction, can be used as a fertilizer or processed for animal fodder. The multiple uses of the MO plant indicate the significant potential for commercial applications to generate income. Technically speaking the part that is used for water treatment is a waste product and it can be acquired at a very low cost. Several studies have reported the use of crude and purified extracts from the MO seed for coagulation (Olsen, 1987; Jahn, 1988; Ndabigengesere et al., 1995; Muyibi and Evison, 1995). Apart from turbidity removal MO also possesses antimicrobial properties (Olsen, 1987; Madsen et al., 1987). The use of MO for water treatment at household level is common in some areas in Africa and Asia (Jahn, 1988). Recently efforts are being made to use it for water purification at treatment plants for community water supply.

By using MO as a coagulant, considerable savings in chemicals and sludge handling cost may be achieved. Apart from being less expensive, it produces readily biodegradable

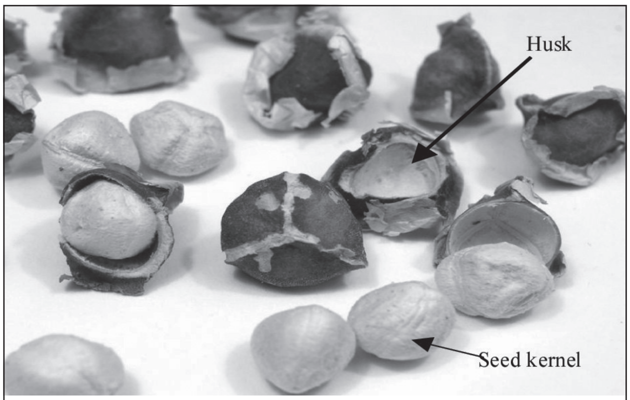

Figure 1. Moringa oleifera seed kernel and Husk

and less voluminous sludge. Ndabigengesere et al. (1995) and Narasiah et al. (2002) reported that sludge produced from MO coagulated turbid water was only 20-30% that of alum treated counterpart.

Pumice

Pumice is a porous pyrochlastic igneous rock with extremely abundant cavities that render it lightweight material. The low specific gravity and high porosity of pumice make it important for a number of applications in water and wastewater treatment processes. Pumice is used as a filter medium in water treatment (Gimbel, 1982; Andrievskaya et al., 1989; Farizoglu et al., 2003), as a support material for microbial growth in wastewater treatment (Şen and Demirer 2003; Kocadagistan et al., 2004) and for adsorbing phosphorus (Njau et al., 2003). The surface structure and porous nature of the material are believed to provide a large number of attachment sites for microbial growth. Thus pumice can be used suitably as a media for biofiltration in water treatment systems.

Because of its low specific gravity (compared to sand), pumice is a convenient material for dual or multi-media filtration with sand. The use of pumice in dual media filtration is reported by Pumex UK Ltd. (2000).

The field investigations

This study is based on the assessment of the performance of a water treatment plant in Asmara, Eritrea. Performance of the treatment plant is not satisfactory. The treated water quality does not often meet the WHO guidelines and outbreaks of water borne diseases are often reported during the rainy season. Poor treatment attributed to the high cost of alum and improper selection of filter media. This paper presents a study on the use of locally available natural resources for coagulation and filtration. The use of pumice for dual-media filtration has been investigated using lab and pilot scale filtration experiments. The study on MO focused on the purification and characterization of the coagulant protein from the seed extract. The potential of the coagulant protein to coagulate clay suspensions was investigated and a simple purification of the coagulant protein was developed.

The main objectives of the studies were to investigate the suitability of pumice in dual media filtration and the characterization and purification of the coagulant protein from the MO seed.

Overview of the problems at Stretta vaudetto

According to SAUR International (1997) the amount of water resource available for the city of Asmara is sufficient for now and the near future. The problem lies in the poor water quality distributed to consumers, particularly during the rainy season. Consequently an assessment of the water supply system, with particular focus on the water quality was made and suggestions were put forwarded to improve the Stretta Vaudetto water treatment plant. The critical problems at the treatment plant are the lack of proper coagulation and poor performance of the filters.

The amount of coagulant dosage applied is often below the optimum required. This is mainly due to lack of financial resources to import alum. Other reasons include lack of laboratory facilities to estimate the required coagulant dosage and problems in the preparation and dosing of the coagulant solution. Results from jar test analysis indicated that the average optimum coagulant dosage during the dry season was 35 mg/L. However, the coagulant dosage applied at the treatment plant was only 20 mg/L. The situation was worse during the rainy season when the coagulant added was only 40-60 mg/L whereas the optimum dose should be 80-100 mg/L. This significantly affects the performance of the sedimentation tanks and filters. For example, the average turbidity removal efficiency of the treatment plant, during the rainy period (in 2002) was 41% and in a number of cases the treated water turbidity exceeded 20 NTU. During the rainy season the water quality often does not meet the WHO guidelines and water borne disease outbreaks are common.

Unsatisfactory performance of the filtration system is attributed to inappropriately selected sand medium, inadequate backwashing and poor pre-treatment. The sand medium has effective size (ES) of 0.67 mm and uniformity coefficient (UC) of 2.36. The large UC value of the medium results in a fine-to-course gradation that leads to early clogging of the upper sand layer, hence rapid headloss development. The rate of headloss development is so high that filter run lengths do not exceed 6 h. Moreover the filter backwash is not adequate due to low pressure of the elevated backwash water tanks; hence effective cleaning of the sand medium is not achieved. Core samples from the filter basins showed considerable amount of mudballs, which are thought to have contributed to the short run lengths.

Possibilities for low cost improvement

Although there are a number of possibilities for improvement of the coagulation and filtration units, it is important that the alternatives considered are affordable and readily available so that they would be acceptable by the water supply authorities. In order to improve performance of the Stretta Vaudetto treatment plant, suggestions were made to conduct in depth studies on alternative systems such as the use of pumice for dual media filtration and MO for coagulation.

Pumice in dual media filtration

The filter units can be upgraded by converting the rapid sand filter to dual media system using pumice in the upper layer. The availability of the material in the area makes it attractive to be used instead of anthracite coal, which has to be imported. Non-conventional filter media such as, high-grade bituminous coal, crushed coconut shell, and burned rice husk have been used successfully for drinking water filtration (Paramasivam et al., 1973 and Okun & Shculz, 1984)

Laboratory and pilot scale studies have been conducted to assess the suitability of pumice for dual media filtration (Ghebremichael and Hultman, 2002). The filtration study of pumice involved characterization of the material, lab-scale and pilot-scale column filtration experiments. In the lab-scale filtration study, performance of pumice was compared to that of commercial anthracite coal (BETWS Anthracite Limited, UK). The experiment was based on tap water spiked with clay suspension. The pilot scale filtration experiment was carried out at the treatment plant site where the performance of pumice/sand (dual media) column was compared with that of mono medium column (sand from the treatment plant filters).

The characteristics of pumice, from the local area, were found to have suitable properties for filtration purposes. The specific gravity (1.6), acid solubility (4.8%) and strength of pumice (Moh's strength 2.5 and attrition loss 1.8%) were in the ranges recommended for filtering materials. The results indicate that pumice is suitable for multi media filtration and it can be used as an upper layer on top of sand and to maintain the desired media gradation (coarse-to-fine in the direction of flow). Although the Moh's strength value (2.5) was less than the recommended value for anthracite coal (2.7, AWWA, 1998), results of backwashing studies indicated that the material was indeed sufficiently strong with only 1.8% attrition loss. Therefore it can be said that the material is durable enough not to require frequent replacement. Pumice from Italy (Pumex UK Ltd., 2000) and Turkey (Farizoglu et al., 2003) have been reported to be suitable for filtration applications.

The lab-scale filtration experiments indicated that pumice and anthracite coal had similar performances in terms of headloss development and filtrate quality. Backwashing studies also indicated that the rate of media expansion of the two materials was not significantly different. Based on the results of the material characterization and lab scale filtration experiments decisions were made to conduct pilot scale study at the treatment plant site using the natural raw water.

The pilot scale studies were conducted in two phases: dry season (phase I) and wet season (phase II). Typical results from the two phases at loading rate of 5.5 m/h are shown in Table 1. In general performance of the dual-media column was superior to the mono-medium column. The average filter run length (FRL) of the dual-media column was more than double that of the mono-medium column while the effluent quality from both columns was similar. This is indicated by the high rate of headloss development in the mono medium column in Fig. 2, that is, due to rapid clogging of the top sand layer. The FRL of the mono-medium and dual-media columns were 14 h and 48 h, respectively. Studies have reported that dual media filters increase the loading rates of mono-medium by 50% to over 100% (Laughlin and Duvall, 1968; Paramasivam et al., 1973). The increase in FRL of the dual media column may be attributed to the higher particle storage capacity provided by the coarser pumice layer. Pumice has also the added advantage of high porosity and surface characteristics (Gimbel, 1982; Andrievskaya et al., 1989). From observations of scanning electron microscope images, Farizoglu et al. (2003) reported that solids that were retained inside the pores of pumice medium that were

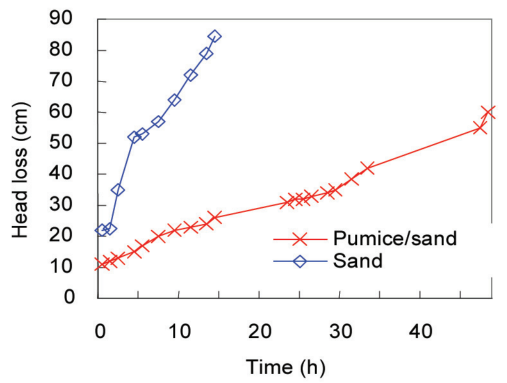

Figure 2. Typical headloss curve from the pilot plant filtration columns at 5.5m/h in phase I.

Table 1. Average filtration parameters from a pilot plant column study at filtration rate of 5.5 m/h

Phase	Turbidity (NTU)			Terminal Headloss (m)		Filter Run Length (h)	
	Influent	Effluent					
		Mono medium	Dual media	Mono medium	Dual media	Mono medium	Dual media
I	4.6 ± 1.6	1.3 ± 0.9	1.3 ± 0.5	77.3 ±9.6	55.2 ± 6.8	16.6 ± 3.5	43.4 ± 11.4
II	17.8 ± 3.1	6.4 ± 1.6	6.0 ± 2.3	49.9 ± 17.5	31.4 ± 14.2	8.7 ± 1.8	22.1 ± 10.7

effectively removed after backwashing. In phase II, filter runs in both columns were often terminated as a result of turbidity breakthrough. During days of heavy rains, it was not possible to collect useful data because the turbidity of the settled water was excessive, due to poor pretreatment.

Importance of the dual media system was also demonstrated by the considerable reduction in the velocity and volume of backwash water requirement. The rate (and amount) of backwash water in the dual media was reduced by more than 50%, compared to that of the mono-medium column. On average, the percentages of backwash water were 1.9% and 10.5% of the total production, in the dual-media and mono-medium columns, respectively. Typical percentage of wash water, for a well performing filter is 1-5% (Cleasby and Logsdon, 1999). Consumption of large amount of clean water for filter washing is not justified for a system, which is already running at a budget deficit.

MO for coagulation

In this study the coagulant protein was purified in order to avoid the draw backs of the crude extract, that is, adding organics and nutrients to the water to be treated. Since the existing methods of purifying the coagulant protein are complex and very expensive, it was intended to come up with a simple and affordable method of purification that can be used at large scale.

Characteristics of the coagulant protein

The Moringa oleifera coagulant protein (MOCP) was isolated from the crude extract solution by ion exchange (IEX) chromatography. A typical chromatograph of the proteins eluted from the IEX matrix is shown in Fig. 3. Absorbance spectrum of the eluted proteins at 280 nm indicates the presence of three distinct peaks (a, b and c). The corresponding coagulation activity of the eluted proteins are also indicated. Protein peaks 'b' and 'c' showed coagulation activity whereas protein peak 'a' was not an effective coagulant. The presence of two coagulant protein peaks may arise from the heterogeneity of one or more active proteins in the extract. Protein peaks b and c were further studied to determine their chemical characteristics as well as coagulation properties. The non-adsorbed fraction did not have coagulation activity.

The coagulant protein was found to have molecular mass of less than 6.5 kDa and isoelectric point (pI) higher than 9.6. Previous studies have reported that the molecular mass of the protein from MO seed was 6.5-13 kDa and isoelctric point above 10 (Gassenschmidt et al., 1995; Ndabigengesere et al., 1995). Proteins may be denatured during extraction, purification or storage. Extreme temperature is one of the physical factors that denature proteins. MOCP was found to have high thermal resistance and it remained active after 5 h boiling at 95-100^{o}C. Such a high thermal resistance renders it easy to handle and process.

Purification of the coagulant protein

Based on the results of IEX chromatography, MOCP was purified using a batch purification procedure. The optimum

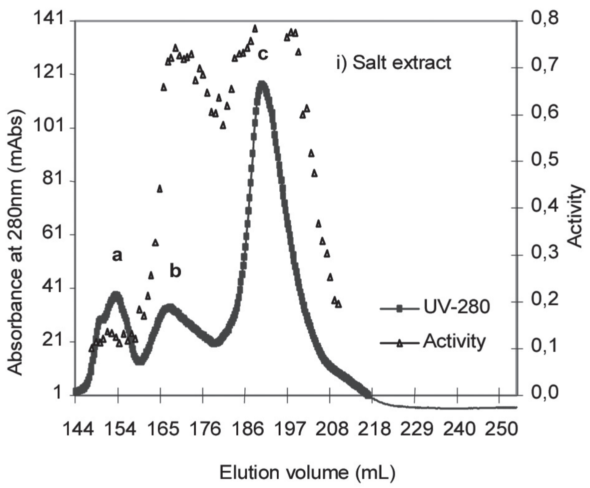

Figure 3. High-Trap CM fast flow IEX chromatography and coagulation activity for salt extract. Ammonium acetate buffer (50 mM, pH 7) was used for equilibration and it was eluted in step gradient with 1 M concentration of the same buffer.

operating parameters (pH, ionic strength, elution volume and equilibrium constants) were determined for large volume purification.

Batch IEX purification experiments were carried out to determine optimum values of adsorption and elution parameters that can be used for large-scale purification. The equilibration buffer used during the purification process was ammonium acetate (10 mM, pH 6.7). Elution was carried out using NaCl solution.

Studies were carried out to estimate the kinetics and adsorption capacity. It was observed that the rate of protein adsorption to the IEX matrix was rapid in the first 10-20 min followed by a decreased rate. Adsorption equilibrium was reached after 90-120 min when maximum adsorption of the coagulant protein was observed. Equilibrium adsorption parameters were estimated from the Langmuir adsorption model (Faust and Aly, 1987). Accordingly, maximum adsorption capacity and dissociation constant of the system (based on purified protein) were 68 mg/g and 0.049 mL/g, respectively.

In the IEX chromatography (Fig. 3), the eluted fraction from the matrix comprised of three protein peaks (a, b and c) of which peaks 'b' and 'c' were active coagulants. It was possible to remove peak 'a' by two-step elution: 0.3 followed by 0.6 M NaCl. Such a procedure can give pure coagulant protein, however a single step elution would be sufficient for applications in water treatment (this is further discussed below).

Based on the optimised parameters, purifications of 1 L and 5 L crude extract samples were carried out. In the case of 1 L purification adsorbed proteins were eluted in two steps (0.3 M followed by 0.6 M NaCl). Coagulation activity test indicated that the crude extract and both the eluted fractions were effective coagulants whereas the non-adsorbed fraction did not have coagulation capacity (Fig. 4). The effective coagulation property of the 0.3 M eluted fraction indicates that, loss of coagulant protein is evident when elution is carried out in two steps. Purification of the 5 L was performed in a similar way (as for the 1 L procedure) but with a single-step of 0.6 M elution. In both cases the organic and nutrient loads were removed along with the non-adsorbed fraction. The 0.3 M and 0.6 M eluted fractions did not add organic or nutrient loads to the water (Ghebremichael et al., 2005). This indicated that, for the purpose of water treatment application, two-step elution is not necessary. Single-step elution not only simplifies the purification procedure particularly in large-scale production, but it also increases the yield.

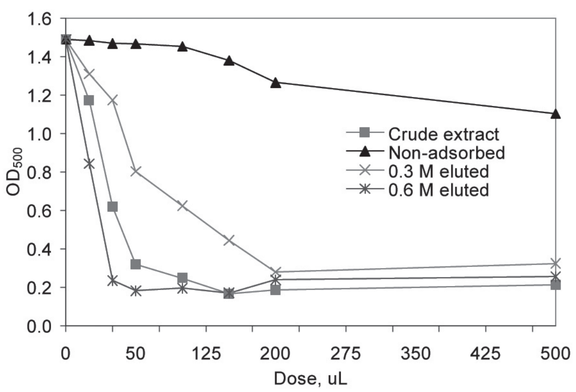

Figure 4. Coagulation activity of the crude extract and various fractions from IEX purification. Samples were taken from the top part of the suspension after 1h settling and OD500 was measured using a UV-Visible spectrophotometer (Cary 50 Bio).

Coagulation comparison with alum

The coagulation activity of the MO and alum were compared using a small volume coagulation assay method. The coagulation assay, that uses 1 mL cuvette was developed to facilitate the assessment of coagulation activity study. The comparison was made by measuring absorbance at 500 nm (OD500) in a spectrophotometer. Coagulation activity was estimated from the difference in OD500 at initial and final settling times in relation to a control sample. Compared to the standard jar test analysis, this method is preferable when large number of samples are to be compared. The method is simple and it reduces sample volume and coagulant dosage. It is possible to run large number of experiments simultaneously (versus a maximum of 6 in the standard jar test experiment) thus significantly reducing the time needed for data acquisition. In the case of IEX purification, for example, it was possible to rapidly screen out the coagulant fractions from a very large number of eluent samples.

Results from the assay method indicated that the coagulation activities of the alum and the crude and purified coagulants from the MO seed were similar for high turbidity (250-300 NTU) clay suspensions. For low initial turbidity coagulation performance of alum was better than the crude extract and MOCP. Sutherland et al., (1990) and Muyibi and Evison (1995) reported that MO was less effective for low turbidity waters. In such cases MO coagulant may be used as a coagulant aid.

Conclusions

This study was carried out based on an assessment of a water treatment plant in Eritrea. It includes an investigations on the suitability of pumice from the local area for dual media filtration and the characterization as well as purification of the coagulant component from *Moringa oleifera* seed.

Lab- and pilot-scale filtration studies indicated that pumice from the local area is suitable as an upper layer in dual media filtration. In a pilot scale study a dual-media (pumice-sand) column showed more than a two-fold increase in filter run length and a 50% reduction in the amount of backwash water requirement, compared to a mono-medium sand from the treatment plant filters.

The MO coagulant protein (MOCP) was identified as a small molecular mass protein with high surface charge. It showed similar coagulation effect as aluminum sulfate.

A single-step batch ion exchange purification of MOCP was developed and the optimum parameters for large-scale purification of the coagulant were estimated. The purification method can be readily scaled-up and carried out using locally available facilities.

The multiple purposes of the MO tree, a simple purification method and effective coagulation properties are thought to promote the sustainable use of the seed for community water treatment. This study has revealed the possibilities to use a combination of natural resources for water treatment purposes.

References

Andrievskaya, M. D., Shvidenko, O. G., Yaroshevskaya, N. V. and Kul'skii, L. A., (1989). Possibility of using slag pumice and granulated slag as granular filter materials. *Soviet Journal of Water Treatment and Technology*, 11(3):253-256.

AWWA, (1998). *AWWA Standard for Filtering Material*. ANSI/AWWA B100-96.

Christopher, H. M., Michael, P. S. and Doyle, G. G., (1995). *In Vitro* acrylamide exposure alerts growth cone morphology. *Toxicology and Applied Pharmacology*, 131:119-129.

Cleasby, J. L. and Logsdon, G. S., (1999). Granular bed and precoat filtration, In: *Water Quality and Treatment: a handbook of community water supplies*, 5th edition, Ch. 8, R. D. Letterman [Editor] McGraw-Hill.

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

Farizoglu, B., Nuhoglu, A., Yildiz, E. and Keskinler, B., (2003). The performance of pumice as a filter bed material under rapid filtration conditions. *Filtration & Separation*, 40(3):41-47.

Faust, S. D. and Aly, O. M., (1987). *Adsorption Processes for Water Treatment*. Butterworths.

Folkard, G. K., Sutherland, J. and Shaw, R., (2000). Water clarification using *Moringa oleifera* seed coagulant. http://www.lboro.ac.uk/well/resources/technical-briefs/60-water-clarification-using-moringa-oleifera-seeds.pdf, accessed in June 2004.

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

Gassenschmidt, U., Jany, K. K., Tauscher, B. and Niebergall, H., (1995) Isolation and characterization of a flocculating protein from *Moringa Oleifera* lam. *BBA Biochemica et Biophysica Acta*., 1243:477-481

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

Ghebremichael, K. and Hultman, B., 2002. An investigation of the suitability of pumice for improving filter performance at Stretta Vaudetto water treatment plant. Presented in the International Symposium: research for Nation Development, Asmara, June 2002.

Ghebremichael, K. and Hultman, B., 2004. Alum Sludge Dewatering Using *Moringa Oleifera* as a Conditioner. *Water Air and Soil Pollution*, 158:153-167.

Ghebremichael, A. K., Gunaratna, K. R., and Dalhammar, G. (2005). Single-step ion exchange purification of the coagulant protein from *Moringa oleifera* seed. Appl Microbiol Biotechnol (In Press)

Gimbel, R., 1982. The Influence of Filter Grain Structure on the Behaviour of Deep Bed Filters. Gas-Wasserfach Wasser-Abwasser 123:5, 220-228 (English Summary).

Jahn S. A. A., 1988. Using *Moringa Oleifera* Seeds as Coagulants in Developing Countries. *JAWWA* 80:6, 43-50.

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

Kocadagistan, B., Kocadagistan, E., Topcu, N. and Demircioğlu, N., (2004). Wastewater treatment with combined upflow anaerobic fixed-bed and suspended aerobic reactor equipped with a membrane unit. *Process Biochemistry*, 40(1):177-182.

Laughlin, J. E., and Duvall, T. E., (1968). Simultaneous plant-scale tests of mixed media and rapid sand filters. *Journal AWWA*, 60(9):1015-1022.

Madsen, M., Schlundt, J. and Omer, El-F. E., (1987). Effect of water coagulation by seeds of *Moringa oleifera* on bacterial concentration. *Journal of tropical Medicine and Hygiene*, 90:101-109.

Muyibi, S. A., and Evison, L. M., 1995. Optimizing Physical Parameters Affecting Coagulation of Turbid Water with *Moringa Oleifers. Wat. Res*. 29:12, 2689-2695.

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

Ndabigengesere A., Narasiah K. S. and Talbot B. G., 1995. Active Agents and Mechanisms of Coagulation of Turbid Water Using *Moringa Oleifera*. Wat. Res. 29, 703-710.

Njau, K. N., Minja, R. J. and Katima, J. H., (2003). Pumice soil: a potential wetland substrate for treatment of domestic wastewater. *Water. Sci. Technol*., 48(5):85-92.

Okuda, T., Baes, A. U., Nishijima, W. and Okada, M., (2001). Isolation and characterization of coagulant extracted from *Moringa oleifera* seed by salt solution. *Water Res*., 35(2):405-410.

Okun, D., A.. and Schulz R. C., 1984. Surface water Treatment for Communities in Developing Countries. Intermediate Technology Publications

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

Paramasivam, R, Gadkari, S. K., Joshi, N. S., and Deshpande, A. W., 1973. Bituminous Coal- A Substitute for Anthracite Filter Media in Two Layer Filtration of Water. India Journal of Environmental Health. 16:3, 178-188

Pollard, S. J. T., Thompson, F. E. and McConnachie, G. L., (1995). Microporous carbon from *Moringa oleifera* husks for water purification in less developed countries. *Water. Res*., 29(1): 337-347.

Postnote, (2002). Access to water in developing countries. No 178. www.parliament.uk/post/pn178.pdf accessed in July 2004.

Pumex UK Ltd., (2000). Brochure of pumice as used in water and wastewater treatments.

SAUR International, 1997. Technical and Institutional Rehabilitation Study of Asmara Water Supply System.

Şen, S. and Demirer, G. N., (2003). Anaerobic treatment of real textile wastewater with a fluidized bed reactor. *Water Res*., 37(8):1868-78.

Warhurst, A. M., McConnachie, G. L. and Pollard, S. J. T., (1997). Characterization and applications of activated carbon produced from *Moringa oleifera* seed husks by single-step steam pyrolysis. *Water. Res*., 31(4):759-76.

Contact address

Kebreab Ghebremichael,
Department of Municipal Infrastructure,
UNESCO-IHE, Westvest 7, 2601 DA,
Delft, The Netherlands