Use of volcanic ash and its impact on algae proliferation in drinking water filtration
Kalibbala Herbert Mpagi, Kaggwa Rose and Plaza Elzbieta

ABSTRACT
With increasing pollution of the available water resources, development of safe drinking water supplies is increasingly becoming a challenge, both for developing and developed countries. To alleviate the prevailing difficulties, approaches should focus on sustainable water supply and treatment systems that require minimal maintenance and operator skills. In this study, a pre-treatment of water containing algae using a combination of volcanic ash (VA) and sand in a filtration system was assessed. The results indicated that a combination of VA and sand performed better in the removal of algae than sand alone. However, it was noted that different algae genera were removed at different rates within the two types of media arrangement. In addition, there was an increase in the filtration run length of the ash-sand columns with VA on top of sand of about two and half times compared with the sand columns. It is therefore anticipated that pre-treatment of raw water laden with algae using ash-sand would probably improve on the performance of the subsequent conventional processes in removing intact cells of algae and thus reduce the threat of releasing toxins into the water that may not be removed by the subsequent conventional treatment processes.

Key words | algae, drinking water, filtration, intact cells, pre-treatment, volcanic ash

INTRODUCTION
Human activities, including agricultural runoff, inadequate sewage and industrial waste treatment, and runoff from roads, have led to excessive fertilization (eutrophication) of many water bodies. This has resulted in the excessive proliferation of algae in fresh water and thus has had a considerable impact upon water quality. Excessive growth of algal blooms poses a problem to water treatment especially in the tropical areas where the temperatures favour their growth. Algal blooms can result in increased concentration of soluble and biodegradable organics in the water; can cause early filter clogging with increased difficulties associated with filter cleaning, interference of the coagulation process, abnormal smell or taste, toxic substances, residue of soluble metals, and generation of chlorinated by-products on chlorination. Blue-green algae (cyanobacteria) are of most concern because many species are known to produce toxins (cyanotoxins), a number of which are a threat to health (Chow et al. 1999; Kuiper-Goodman et al. 1999; Svrcek & Smith 2004; Teixeira & Rosa 2007). Passage of cyanobacterial cells through the water treatment process, followed by cell lysis and toxin release, is one potential route of human exposure (Dugan & Williams 2006). For example, viable cyanobacteria (Xenococcus sp.) were recovered from drinking water samples taken from Bellaterra Campus of the Autonomous University of Barcelona, Spain (Codony et al. 2003). Intact cyanobacterial cells entering the treatment plant in large numbers may be removed by coagulation, flocculation, sedimentation and filtration but will lyse if oxidants are added first (Drikas et al. 2000a,b). However, the coagulation treatment alone is not sufficient when there are excessive amounts and treatment with chlorine is limited by generation of chlorination by-products and...
ysis of cells. Therefore, when algae blooms occur, water systems need to utilize a strategy to treat the blooms that does not merely kill the algae, since rupturing (or lysing) the algal cells, especially cyanobacterial cells, can release their toxins, and treatment may not be entirely effective in removing toxins. The removal of cyanobacterial cells without cell damage would significantly reduce taste, odour and toxic cell metabolites present in the final water (Chow et al. 1999). A combination of activated carbon with membrane filters was reported to be very effective in the United States and counter current dissolved air flotation was established as a high-rate process for the treatment of low-turbidity, coloured or algal-laden water. Ultrafiltration and microfiltration (MF) membranes effectively removed intact cyanobacterial cells from water without significantly damaging them, but MF membranes were harder to clean. These processes may not be easy to operate and maintain in low income communities especially in the developing world. Therefore, the goal of this study was to assess the kind of algae species contained in the raw water and evaluate removal of intact cells by volcanic ash (VA) as a prefiltration medium in water treatment. The study was done during the period when the algal bloom is at its peak and a problem to the water treatment facilities.

MATERIALS AND METHODS

Study area

The study was carried out using filtration columns set up adjacent to Ggaba II, one of the water treatment plants at Kampala, Uganda. The plant is located on the shores of the Inner Murchison Bay of Lake Victoria. The plant uses conventional water treatment processes (that is, coagulation, flocculation, sedimentation, rapid gravity sand filtration and disinfection). During the period of high algal bloom, the clarification process was by-passed and raw water fed directly to filters. This did not only affect the filter run lengths but also impacted on the final water quality. It was against this situation that experiments with filtration columns were conducted to find a solution to longer filter run length and reduction of algal residues in the filtrate.

Experimental strategy

In the study, six columns of high-density polyethylene pipes 1.5 m high with a 150-mm internal diameter were used. A 10 cm-deep graded support gravel bed was provided at the bottom of each column to retain the granular filter media with nozzles to ensure uniform filtrate collection and backwashing. Sand and pumice were used as the filtration media with three of the columns containing sand alone while the rest contained sand and VA. The effective size (ES), uniformity coefficient (UC) and depth of the filter materials used in the filtration are given in Table 1. Specific gravities of VA and sand used were 1.8 and 2.8, respectively. The VA had an acid solubility of less than 1% (0.57%) that renders it suitable for use in a wide range of water pH values. The elemental composition and scanning electron microscopy picture of VA are presented in Figures 1 and 2, respectively. Elemental composition was determined by Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) method.

Table 1 | Parameters of filter media used in the study

<table>
<thead>
<tr>
<th></th>
<th>Sand</th>
<th>VA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES (mm)</td>
<td>0.65</td>
<td>1.00</td>
</tr>
<tr>
<td>UC</td>
<td>1.71</td>
<td>1.30</td>
</tr>
<tr>
<td>D (cm)</td>
<td>60</td>
<td>15</td>
</tr>
</tbody>
</table>

ES – effective size, UC – uniformity coefficient and D – depth.
The feed water was pumped from the raw water intake of the plant to a feed-tank where it flowed by gravity to the columns. The hydraulic loading rate to the columns was controlled at 2.7 m h\(^{-1}\) for 70 h, after which period it was adjusted to 3.4 m h\(^{-1}\) for 154 h and finally to 6.8 m h\(^{-1}\) for 23 h. Loading rates were selected based on the fact that rapid sand filters have hydraulic application rate of approximately 5 m h\(^{-1}\) \(\text{per m}^2\) (Qasim et al. 2000). Down-flow configuration was selected because gravity flow filtration is being applied at the Kampala water works. For the measurement of head losses, piezometers were fitted at the inlet, interface (between VA and sand) and effluent points. Head loss measurements were taken every hour for 5 days a week. The experiment was operated 6 h a day over a period of 2 months.

### Water samples

Samples for physicochemical analysis were taken every hour for 5 days a week while samples for quantification of algae were taken every 2 weeks. 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 filtrate 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 ×200). Different identification keys were used to identify the algae genera. Turbidity and colour measurements were done using a portable turbidimeter (Hach, model 2001A) and Hach Spectrophotometer (DR2010), respectively, at the Kampala waterworks plant laboratory.

### Samples of filter media

Samples of filter media were taken from the top 5 cm layer of each column just before backwashing. The sample was then washed with distilled water to remove any organisms attached on the surface. The wash water with detached macro-organisms was quantitatively analysed through subsampling. The supernatant was looked at before preservation to allow proper identification using live organisms, whose quantification was done with a preserved sample. The flora was fixed with Lugol’s solution, sub-sampled into a 2-ml sedimentation chamber and counted under an inverted microscope after 12 h of sedimentation.

### RESULTS AND DISCUSSION

#### Algal content in filtrate

The removal of different algal genera in the sand and VA/sand columns is presented in Table 2. Six genera of cyanobacteria (Anabaena, Aphanothece, Coelospherium, Merismopedia, Microcystis and Oscillatoria) and eight genera of chlorophyceae (Ankistrodesmus, Closterium, Cystodinium, Pediasstrom, Scenedesmus, Selenastrom, Spirulina and Staurastrum) were identified in the raw water. Spirulina (2.5 × 10^4 cells/ml) and Anabaena (2.9 × 10^4 cells/ml) were the most dominant of chlorophyceae and cyanobacteria, respectively. It was observed that the removal of different algal types varied with different media arrangement. Of the cyanobacteria genera identified, Anabaena and Oscillatoria were poorly removed in either column configurations, while of the chlorophyceae genera, Selenastrom and Cystodinium were poorly removed in sand and VA/sand columns, respectively.

The corresponding algal content in the raw water and filtrate from the filtration columns is presented in Figure 3, while the mean values for each genus are presented in Figures 4 and 5. The overall removal efficiencies for chlorophyceae in the sand and volcanic/sand media columns were 73 and 65%, respectively. The efficiencies are in good
comparison with Demur & Atay (2002) who achieved chlorophyceae removal efficiencies of 76% in the sand filters for which the filter influent had been pre-treated by coagulation and sedimentation.

A comparison of removal rates of Microcystis, Oscillatoria and Anabaena in this study and other studies carried out elsewhere is presented in Table 3.

As noted, most studies were carried out on pre-treated water and almost achieved the same removal efficiencies for the mentioned algae genera. There was good removal of Microcystis in both filters. However, the poor removal of Anabaena and Oscillatoria observed is of concern in the drinking water industry. Some species of Microcystis, Oscillatoria and Anabaena have been reported to produce hepatotoxins (WHO 2011) while Chlorella, Closterium, Oscillatoria and Anabaena are listed as filter-clogging algae (APHA, AWWA & WPCF 2005). Production of hepatotoxins by cyanobacteria is thought to be affected or influenced by a number of physical and environmental factors.
parameters, including nitrogen, phosphorus, trace metals, growth temperature, light, and pH (Pearson et al. 2010).

The difference in removal rates of the different algal genera with different filter configurations is most likely a result of elemental composition of the VA, although no leaching studies were carried out during the study. Single-cell and filamentous algae and cyanobacteria are particularly susceptible to the acute effects, which include reductions in photosynthesis and growth, loss of photosynthetic pigments, disruption of potassium regulation, and mortality. In addition, chromium, which appears to be a dominant element in the VA, inhibits growth in algae (USEPA 2011). The VA had content of chromium and copper of about 922 and 454 mg kg$^{-1}$, respectively. Sensitive algae may be affected by free copper at low parts per billion (ppb) concentrations in freshwater.

Given the differences in removal rates of algal cells, there was no significant difference in colour and turbidity of the filtrate from the VA-sand and sand columns (Colour: $p = 0.871 > 0.05$; Turbidity: $p = 0.067 > 0.05$). The colour was reduced from 114 ± 27 platinum-cobalt colour units (PtCo) to 68 ± 20 PtCo and 63 ± 21 PtCo in the sand and VA-sand columns, respectively, while turbidity was reduced from 8.20 ± 2.45 to 4.4 ± 0.89 nephelometric turbidity units (NTU) and 4.1 ± 0.88 NTU in the VA-sand and sand columns, respectively, at a loading rate of 3.4 m h$^{-1}$.

**Head loss development**

In addition, at the sampling interval used, doubling the hydraulic loading rate did not give rise to change in the filtrate quality in either the sand or the VA-sand columns. However, it did affect the head loss development in both filters (Figures 6, 7 and 8). At all loading rates, the dual media

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**Table 3 | Comparison of removal rates of algal cells in this study and other studies carried out elsewhere**

<table>
<thead>
<tr>
<th>Type of algae</th>
<th>Removal efficiency (%)</th>
<th>Filter composition</th>
<th>Loading rate (m h$^{-1}$)</th>
<th>Type of pre-treatment</th>
<th>Scale of experiment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcystis</td>
<td>99.9</td>
<td>Sand</td>
<td>3.4</td>
<td></td>
<td>Pilot</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>Dual media (VA and sand)</td>
<td>3.4</td>
<td></td>
<td>Pilot</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td></td>
<td>10</td>
<td>Ferric iron and cation polymer, DAF and sedimentation</td>
<td>Pilot</td>
<td>Vlaski et al. (1996)</td>
</tr>
<tr>
<td></td>
<td>3.4–3.9 log</td>
<td>Sand</td>
<td>7.2</td>
<td>Alum coagulation, flocculation, sedimentation</td>
<td>Pilot</td>
<td>Drikas et al. (2002a)</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td></td>
<td></td>
<td>Alum coagulation, flocculation, sedimentation</td>
<td>Full-scale</td>
<td>Jurczaka et al. (2005)</td>
</tr>
<tr>
<td>Microcystis and Anabaena</td>
<td>2.5–4.3 log</td>
<td>Dual media (Anthracite and sand)</td>
<td>7 &amp; 10</td>
<td>Aluminium sulphate &amp; cation polymer; ferric chloride &amp; cationic polymer</td>
<td>Full-scale</td>
<td>Dugan &amp; Williams (2006)</td>
</tr>
<tr>
<td>Anabaena</td>
<td>99</td>
<td></td>
<td></td>
<td>Alum coagulation, flocculation, sedimentation</td>
<td>Full-scale</td>
<td>Jurczaka et al. (2005)</td>
</tr>
<tr>
<td>Oscillatoria</td>
<td>100</td>
<td></td>
<td>3.2</td>
<td>Anionic polyelectrolyte combined with alum and soda ash</td>
<td></td>
<td>Dugan &amp; Williams (2006)</td>
</tr>
</tbody>
</table>
filtration columns gave rise to lower head losses than observed in the sand columns.

Ghebremichael (2004) made a similar observation with pumice and sand. The colour of the influent ($p = 0.024 < 0.05$), the media ($p = 0.000 < 0.05$) and loading rate ($p = 0.000 < 0.05$) had a significant impact on head loss. The increase in the filtration run length of the VA-sand column may be attributed to the surface characteristics of the VA providing more storage capacity for the suspended particles than the sand.

In addition, results from quantification of algae on the media after doubling the loading rate from 3.4 to 6.8 m h$^{-1}$ indicated higher number of *Anabaena* and *Chlorella* cells on sand than on VA whereas *Closterium* and *Oscillatoria* existed on sand only (Figures 9 and 10). *Anabaena*, *Closterium*, *Oscillatoria* and *Chlorella* are some of the named filter- and screen-clogging algae (APHA, AWWA &
This probably explains too short filter runs obtained in the mono media filter columns compared with the dual media columns.

Using sand in suspension, Pan et al. (2011) observed removal efficiencies of *Amphidinium carterae* and *Chlorella* species after 240 min of 26 and 7%, respectively, though none of these species were identified in this study.

**CONCLUSIONS**

Different algal genera showed different removal rates in the dual (VA/sand) and mono (sand) media. The two types of filter media columns show that VA/sand performed better than sand in the removal of algae. Removal of different organisms by different filter media would be used as a tool to work with different kinds of water and also for removal of target algal genera.

Some algal species are known to be filter clogging, and the longer filter runs achieved in the VA/sand columns indicated a better resilience of this filter configuration to these species. However, there was no significant difference in the quality of the filtrate from the columns with respect to colour and turbidity. Therefore, in parts of the world like the developing countries where alternative materials like activated carbon, membrane filters and use of chemicals are not readily available or expensive to sustain, VA could be used to eliminate target algal genera other than *Anabaena*, *Merismopedia*, *Oscillatoria* and *Cystodinium*.

There is also a need for further assessment of the impact of backwashing on the release of toxins into the treated water and the treatability of the water by coagulation after pre-filtration.

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**REFERENCES**


Teixeira, M. R. & Rosa, M. J. 2007 Comparing dissolved air flotation and conventional sedimentation to remove
cyanobacterial cells of *Microcystis aeruginosa* Part II: The effect of water background organics. *Separation and Purification Technology* 53, 126-134.


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