Comparative analysis on the effectiveness of various filtration methods on the potability of water

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ABSTRACT

This paper comparatively assessed the effectiveness of potable water filtration methods, commonly used in the hinterlands in some Ghanaian communities. Physico-chemical and microbiological analysis were carried out on pond, dam and river water samples, using spectrophotometric, pour plate count and the most probable number (MPN) methods. For the unfiltered water samples the total dissolved solids (TDS) and colour were the only parameters with values within recommended standards. The other parameters, total suspended solids (TSS), turbidity, total coliforms and bacterial counts levels were above their standard recommended values. All the filtration methods showed reduction in the levels or better accepted values of the physico-chemical and microbiological parameters. The ceramic filters and the household sand filters showed outstanding results, with all analysed parameters being within the acceptable standards levels. These two methods could be promoted for use to treat untreated drinking water. It is envisaged that a combination of a number of these methods would produce even better results, especially when agents such as alum and activated carbon are included. Follow-up research in this regard is therefore recommended.

Key words | filtration, microbiological, potability, spectrophotometric, turbidity

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INTRODUCTION

Filtration is the process of removing undesirable chemicals, biological contaminants, suspended solids from contaminated water, so as to produce safe and clean drinking water. Filtration methods include reverse osmosis filtration, slow sand filtration, activated carbon filtration, ceramic filtration, membrane filtration, cloth filtration, rapid sand filtration and household sand filtration. Boiling and cloth filtration of water is often recommended by health workers to communities where pipeborne water does not exist. In most of the hinterlands in Ghana, wells, dams, lakes, boreholes, rainwater, rivers and streams are the main sources of drinking water. Some of these water sources are not clean, others have various types of odour. Some of the surface water types collect debris and excreta from surface run-off rain water which leads to contamination, and subsequently cause waterborne diseases. The objective of this research is to assess the effectiveness of common water filtration methods in use, especially in the hinterlands where pipeborne water is not available and ponds, dams and streams are often used for drinking and for carrying out other household activities. This work is aimed at addressing the challenges associated with using water from different sources, which leads to contracting water-related diseases that eventually affects the health of people and their economic activities.

Improved drinking water coverage in sub-Saharan Africa is still considerably lower than in other regions. However, in recent times, it has increased from 49% in 1990 to 58% in 2006 which means that an additional 207 million Africans are now using safe drinking water (WHO 2008). Water shortage could be attributed to a number of factors: uncontrolled deforestation brings about the drying up of rivers and streams; there is also the issue of drought caused by the green house effects and global warming (Nsiah-Gyabaah 2001).

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Water source, water collection and storage practices are major parameters in determining household water quality (Sobsey 2002). Treatment of water including addressing issues of turbidity and contaminants through clarification and disinfection processes are paramount to improve the quality to meet standards and avert disease outbreaks (Suarez *et al.* 2003; Murcott 2006). Physical technologies to remove unwanted substance in water include ceramic and biosand filters, cloth filters, coagulation and flocculation. Boiling, solar disinfection and chlorination are also examples of technologies that improve the water quality.

In developing countries, household water treatment (HWT) ceramic filters are used as a better treatment option for both unpurified and insufficiently disinfected water (Lantagne 2005; Clasen & Boisson 2006). These are also recommended by the United Nations Children's Fund (UNICEF) (2006) and WHO (2009), who regard the device as a user friendly and commercially attractive option to improve the quality of drinking water. Clay is rich in mineral composition. Well-sorted pure red clay is very suitable as a drainage material for water purification application due to its low permeability. Pore sizes are about 12–20 microns (WHO 2009).

The membrane filtration method is common in evaluating microbiological characteristics of water. Membrane filters have pores of 0.45 μm in diameter. Slow sand filters have filtration rates of 0.1 m/hr to 0.2 m/hr as opposed to rapid sand filtration of 10 m/hr (Haarhoff & Cleasby 1991). Slow sand filtration is used to deliver potable water to the public or for household water treatment. It consists of flat stone, clean fine sand and coarse stone. The sand removes parasites, bacteria and other microbes. The organisms become attached to the surface of the sand particles and form an active biological layer that traps additional pathogens. These filters also reduce the water turbidity by up to 48–90% (WHO 2009). Cloth filters are a simple and inexpensive appropriate technology for reducing the contamination of drinking water (Ramya 2010).

Water may be purified by natural means by passing through the earth, resulting in microbes being filtered out. Combined action by sunlight, sedimentation, dilution of impurities and destruction of bacteria are often used. Small-scale water purification can be done through boiling and chemical disinfection with 5 drops (0.25 mL) 2% tincture of iodine per 1 litre of water. Cloudy water can be strained through clean cloth to remove sediments and floating matter before treatment with heat or iodine. In large-scale (municipal) water purification, using the slow filtration method, water is passed directly into beds of fine sand of 30–150 cm (1–5 feet) thick, supported by graded layers of gravel, underneath which is a drainage system. Prior treatment of water by coagulation and sedimentation is necessary for effective filtration. After filtration water is further treated with chlorine (chlorination). This can be the simple type using chlorine gas, chloramines, or the super chlorination (using large doses of chlorine with subsequent removal of the excess). Granular activated carbon is mixed with filtered water to remove odour. Ion-exchange process is done to remove dissolved limestone from hard water (Smith 1985). Ceramic filters are prepared using fine sawdust mixed with powdered clay in a 20:80% (1:4) ratio. This is well mixed with water in a machine, and the product is then moulded into various shapes and thicknesses (2.0 cm, 2.5 cm and 3.0 cm), and sun dried before subjecting to oven drying with an initial temperature of 100 °C for 1 hour, before increasing the temperature to 150 °C for 9 hours. Ceramic filters, with pore sizes ranging from 0.6 μm to 3 μm, are capable of removing bacteria, reducing turbidity and colour, but are not effective against viruses, which are small enough to pass through the pores (WHO 2009).

MATERIALS AND METHODS

Sampling

Water samples were taken from three sources: stream, pond and dam. The upstream, midstream and downstream portions of the stream were sampled; for each of the water sources, samples were taken from the upper, middle and bottom layers by completely immersing the sterile bottles to avoid collection of surface water. The samples were transported to the laboratory in an ice-chest for physico-chemical and bacteriological examinations, before and after filtration.

Method and procedure

The various filtration methods, slow sand filtration, cloth filtration, household filtration and ceramic filtration were used to obtain testing samples. The slow sand filtration method, as described by Calvo-Bado *et al.* (2003), was used in this study. It is generally considered to be an effective and relatively cheap way of controlling pathogens in recirculating irrigation water (Stewart-Wade 2011). A similar filtration method was also adopted and used in Watkins (2011), which the author described as a simple and inexpensive technology for water treatment. This study also adopted the cloth filtration method in Huq *et al.* (1996), which the authors described as an easy to do method of making water safe for drinking and other uses. The ceramic and house filtration method used for the study was constructed based on the method described by Vigneswaran & Sundaravadivel (2004).

The unfiltered waters from each of the water sources were used as controls. Various test parameters including total dissolved solids (TDS), total suspended solids (TSS), colour, turbidity and microbial analysis were carried out using specific instruments and methods.

TDS were measured using the Hanna Instruments HI 9032 microcomputer conductivity meter. The HACH DR2400 spectrophotometer was used to measure TSS and colour. The HACH turbidity instrument was used to determine the turbidity. For the bacteriological examination, the most probable number (MPN) method was used to determine the presence and numbers of coliforms. From the number and distribution of positive and negative reactions, levels of the MPN of indicator organisms in the sample were estimated, with the aid of the MPN statistical tables (APHA 1998). The pour plate count method was used to determine the bacterial count per 1 mL of test water sample. In so doing, the bacterial load for each of the test water samples was determined by multiplying average counts by the dilution factor.

RESULTS AND DISCUSSION

The unfiltered water sample, the control, showed all the tested parameters were above the acceptable levels, except for the TDS, colour and turbidity.

In contrast to the various non-filtered water samples, the pond water samples exhibited relatively higher numerical values or worse water quality parameters, followed by the dam and then those of the stream water samples. The turbidity of the pond water sample (6.5 NTU) was even above the 5.0 NTU acceptable thresholds.

The various filtration methods showed better and relatively acceptable levels for the various parameters, although the slow sand filtration and the cloth filtration methods showed total coliform levels of 2 MPN/100 mL as against acceptable maximum levels of 1 MPN/100 mL. The household sand filtration and the ceramics filters gave the best results, recording zero (0) MPN/100 mL for total coliform results. In contrast, the 3 cm ceramic filters gave slightly better results than the 2 cm filters, as shown in Tables 1, 2 and 3. This thus confirms why the household sand and ceramic filtration methods are recommended for use in areas where potable pipeborne or deep dug wells are not available (Lantagne 2005; Clasen & Boisson 2006; United Nations Children's Fund (UNICEF) 2006; WHO 2009).

Table 1 | Levels of various test parameters on filtered stream water samples

No.	Filtration method	TDS (ml/L)	TSS (mg/ L)	Colour (Hazen)	Turbidity (NTU)	Total coliform (MPN/100 mL)	Bacterial count (CFU/mL)
1	Slow sand filter	40.0	4.0	8.0	4.0	1.0	13.0
2	Cloth filter	40.0	0.0	3.0	2.1	0.0	4.0
3	Household sand filter	60.0	2.0	5.0	2.1	0.0	1.0
4	Ceramic filter (2 cm)	42.0	1.0	3.0	2.0	0.0	2.0
5	Ceramic filter (3 cm)	45.0	0.0	2.0	1.8	0.0	1.0
6	Unfiltered water (control)	40.0	8.0	12.0	5.0	78.0	TNTC
Standard values		1,000	5	15	5	1*	500*

TDS, total dissolved solids; TSS, total suspended solids; NTU, number of turbidity units; TNTC, too numerous to count; CFU, colony forming units; MPN, most probable number.
*Standard values (WHO 2004) and Smith (1985), APHA (1998).

Table 2 | Levels of various test parameters on filtered pond water samples

No.	Filtration method	TDS (mL/L)	TSS (mg/L)	Colour (Hazen)	Turbidity (NTU)	Total coliform (MPN/100 mL)	Bacterial count (CFU/mL)
1	Slow sand filter	42	4.0	9.0	4.5	2.0	15
2	Cloth filter	41	1.0	5.0	2.0	1.0	8
3	Household sand filter	63	2.0	5.0	2.0	0.0	2
4	Ceramic filter (2 cm)	43	1.0	3.0	2.0	0.0	2
5	Ceramic filter (3 cm)	44	0.0	2.0	2.0	0.0	2
6	Unfiltered water (control)	41	10.0	14.0	6.5	105	TNTC
Standard values		1,000	5	15	5	1*	500*

TDS, total dissolved solids; TSS, total suspended solids; NTU, number of turbidity units; TNTC, too numerous to count; CFU, colony forming units; MPN, most probable number.
*Standard values (WHO 2004) and Smith (1985), APHA (1998).

Table 3 | Levels of various test parameters on filtered dam water samples

No.	Filtration method	TDS (mL/L)	TSS (mg/L)	Colour (Hazen)	Turbidity (NTU)	Total coliform (MPN/100 mL)	Bacterial count (CFU/mL)
1	Slow sand filter	40	4.0	8.0	4.2	2.0	13
2	Cloth filter	40	1.0	4.0	2.1	2.0	6
3	Household sand filter	58	2.0	4.0	2.0	0.0	2
4	Ceramic filter (2 cm)	45	2.0	3.0	2.1	0.0	2
5	Ceramic filter (3 cm)	44	1.0	3.0	2.0	0.0	1
6	Unfiltered water (control)	40	4.0	13.0	5.0	140.0	TNTC
Standard values		1,000	5	15	5	1*	500*

TDS, total dissolved solids; TSS, total suspended solids; NTU, number of turbidity units; TNTC, too numerous to count; CFU, colony forming units; MPN, most probable number.
*Standard values (WHO 2004) and Smith (1985), APHA (1998).

The analysis for the TDS revealed an increase in quantity for the filtration method, especially those of the household sand and ceramics method: 63–43 mL/L as against the unfiltered water values of 41–40 mL/L, as seen in Tables 1, 2 and 3. This alludes to earlier findings that substances like calcium, magnesium, bicarbonates, chlorides and sulphates from some filters could cause an increase in TDS (WHO 2006).

This research finding revealed that the TSS generally reduced from 8–10 mg/L to 0–4 mg/L for various water samples; similar was experienced with turbidity values, reducing from 5–6 NTU, for non-filtered water samples, to 1.8–4.5 NTU depending on the filtration method used, as indicated in Tables 1, 2 and 3. The total coliform levels also reduced from 78–140 MPN/100 mL for unfiltered water samples to as low as 0–2 MPN/100 mL for the filtered water samples. Those of the bacterial count reduced drastically from levels of too numerous to count (TNTC) to 1–15 CFU/mL for various filtered water samples. This trend of results agrees with earlier findings by Fogel *et al.* (1993).

CONCLUSION

The filtration methods are simple to develop and easy to use and the materials needed for the activity are readily available within the communities. Thus, where pipeborne water or deep dug wells are not available these could be alternative treatment methods to provide relatively safe or potable water. All the filtration methods reduced the level of physico-chemical and microbiological parameters and thus made the sampled water relatively acceptable for drinking and other domestic uses, even though a few parameters produced results outside the WHO standards. The results indicate that the ceramic filters and household sand filters are comparatively speaking the most effective methods.

RECOMMENDATIONS

Filtration methods, in particular the ceramic and household filtration methods, should be encouraged especially for communities that lack pipeborne and dug well water, as these methods gave better and acceptable results and the materials needed for the treatment process are local, available and relatively less costly.

Government, local assemblies and private organizations should invest more in improved forms of these methods for use to augment the conventional general water treatment.

Public education on water filtration, through conferences, workshops, seminars or fora should be made available, to share knowledge and skills for proper implementation.

Further research could be carried out to ascertain the best combination of these filtration methods, as far as potability of water is concerned. The work could include research into the rational use of alum to coagulate and sediment particle before filtration, as well as use of activated carbon to remove water odour. This would help raise the level of potability of water and thus improve water health-related issues.

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