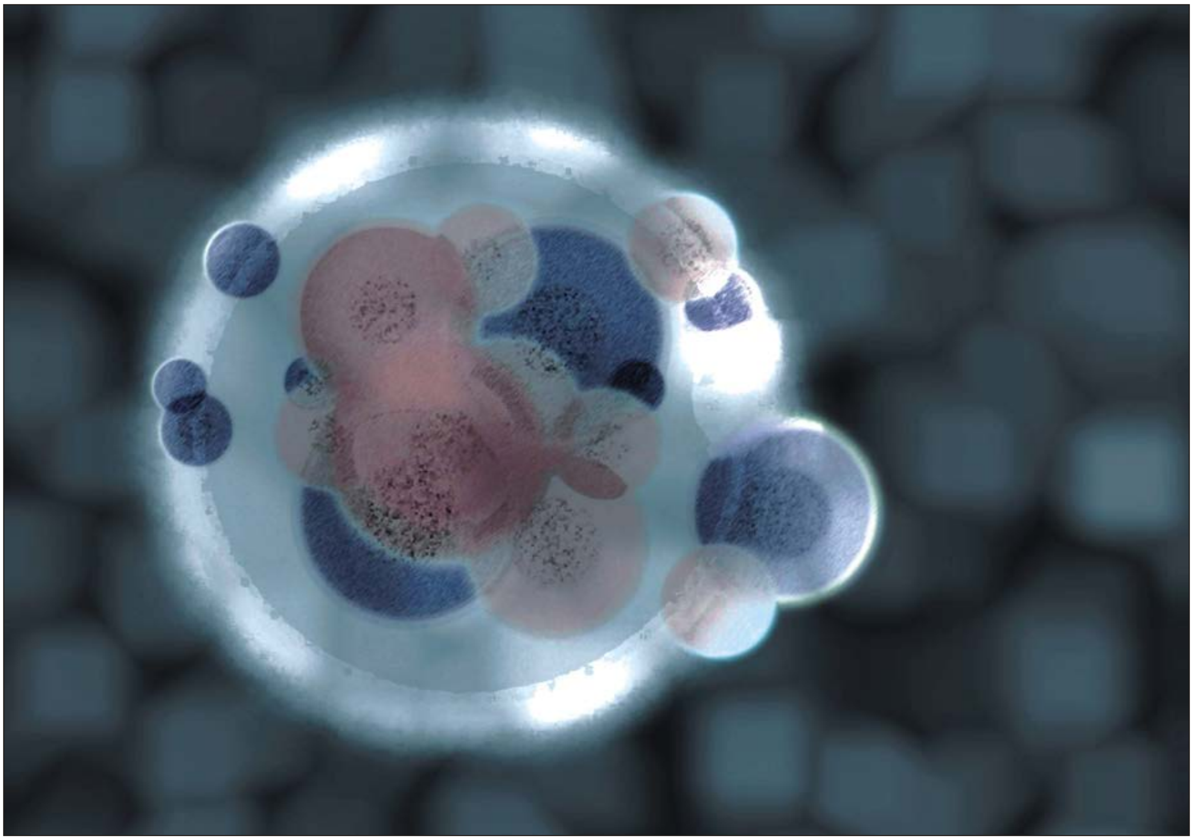

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Research Article
Efficiency and Applicability of Low Cost Home-based Water Treatment Strategies in a Rural Context

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Abstract

Background and Objective: Most African communities living in rural and peri-urban areas lack access to safe drinking water. As a result, they use surface waters or harvest tap or rain water in storage containers. Such waters are not safe for human consumption and present great health risks for the consumers. In this study, home-based water treatment strategies were directed for use at household level to disinfect the water at point of use. **Materials and Methods:** Household bleach, boiling pot and common fabrics available in households were used to study chlorination, boiling and cloth filtration for cost and effectiveness in removing bacteria from river and tank waters for application in rural communities. **Results:** Two minutes of rolling boil eliminated bacteria from contaminated water with same efficiency as 5 and 10 min of continuous boiling. Household chlorine bleach was applied to contaminate water at the recommended proportion of 5 mL: 20 L of water. Although residual chlorine was detectable up to 8 days of treatment, the germicidal effect of chlorine lasted beyond 3 weeks of treatment. This had a direct impact on re-dosing of stored water and probable formation of disinfection by-products. Cloth filtration improved the clarity and colour and not the microbiological quality of the surface waters. Entrapment of bacteria required filter material with pore sizes of 0.4 µ or less because of their small sizes. **Conclusion:** Home based water treatment strategies have become significant for management of the quality of available water for the water stressed communities. Cost, efficacy and longevity are empirical elements which determine their adoption and implementation.

Key words: Water quality, boiling treatment, chlorination, cloth filtration, home-based water treatment

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

South Africa is a drought stricken country, with millions of people living without a good and reliable source of potable water. The years 2015 and 2016 have been the driest and the water shortage has been worsened by the erratic weather conditions, as a result the dams are at half their capacities[1]. Water scarcity is a global problem. Almost half of Africans lack potable water for household use. In South Africa, peri-urban communities are experiencing sporadic interruptions in the supply of clean water whilst communities in the rural areas exist either without a reliable source of clean water or lack the infrastructure for provision of clean water. All these challenges regarding availability and consistent provision of potable water commonly lead to use of non-potable and unsavoury sources of water for drinking purposes. Rural communities commonly use surface water for household purposes without prior treatment and these water sources are often shared with livestock. The Limpopo province of South Africa generally has the highest percentage of residents that rely on surface waters for drinking purposes or use communal taps[2]. Peri-urban households usually store water in containers for lengthy periods when taps run dry. The health concerns were compounded by the fact that the tap water was often of poor quality[3-5]. On the other hand, many studies have reported on the poor quality of container-stored water for human consumption and the potential health risks due to the pathogens detected in such waters[6-8]. The impact of water borne diseases was significant in South Africa and it is still a major concern.

In 1996, 20% of diarrhoeal child deaths were reported by Borne and Coetzee[9] as a result of lack of safe water supply and proper sanitary facilities. High incidences of cholera and dysentery were reported in Limpopo, Mpumalanga and KwaZulu Natal provinces of South Africa by the Department of Health[10] and these were commonly due to contamination of water sources. The situation has not improved significantly wherein diarrhoea was still regarded as the third biggest killer in South Africa, with the children under 5 years and the elderly being the most affected[2], with the death toll estimated[11] at 20%. Globally, diarrhoea was the leading killer of children under age 5 in 2015 at a rate of 1400 deaths each day and it was envisaged that the rate of mortality can be reduced through improving the quality of unsafe drinking water, sanitation and hygienic practices[12].

Premised on lack of infrastructure and consistent supply of clean water in peri-urban and rural communities, the home-based water treatment strategies (HWTS) are currently gaining ground for treatment of water at the point of consumption. The efficacy of any treatment strategy is critical to prevent a false sense of safety. Current technologies for water disinfection are largely focused on filtration techniques that employ various materials such as ceramic, nano-membranes and slow sand filtration[13]. Although efficient, these methods have limitations that prevent broad application in rural communities which cannot afford the technology. Cost commonly outweighs safety for impoverished communities. This study sought to investigate the efficacy of the boiling, cloth filtration and the chlorination methods in the improvement of the potability of container-stored and surface waters for household use in water scarce communities. The purpose of this study was to explore the boiling, chlorination and membrane filtration methods as low-cost water treatment strategies to remove bacteria and improve the aesthetics and use of surface and stored water at household level.

MATERIALS AND METHODS

Study period: The study was conducted between April, 2016 and August, 2017. Purposive sampling was followed for analysis and treatment of waters used for domestic purposes.

Water sampling: Surface water samples were collected from Motse River and from a stream in Apel in the Sekhukhune district in the Limpopo Province of South Africa. These waters were used for household purposes without prior treatment. Stored plastic tank water samples were collected from Mentz village near University of Limpopo in the Limpopo province. The village receives an intermittent supply of potable water from the local municipality.

Water samples were collected into 2 L sterile bottles and transported on ice to the Microbiology laboratory at the University of Limpopo. The water samples were processed within 3 h of sampling.

Bacterial analysis: The membrane filtration technique was used to enumerate heterotrophic bacteria (HPC), total (TCC) and faecal (FCC) coliforms. Selective media were used for the screening of pathogenic bacteria. A volume of 100 mL of undiluted or diluted water samples were vacuum filtered through a 0 and 45 μm hydrophilic mixed cellulose esters filter membranes. The R2A agar medium (Sigma) was used for enumeration of heterotrophs, m-Endo (Sigma) and m-FC (Sigma) were used for selectively growing total and faecal coliforms, respectively. The tests were performed in triplicates and averages of the observations were presented.

Turbidity and colour: Turbidity and colour of surface water samples were determined with the Formazine method (DIN EN ISO 7027-C2) and Hazen method (APHA 2120), respectively using a UV Nanocolor® spectrophotometer (Macherey-Nagel).

Total suspended solids: A gravimetric method (Standard methods for the examination of water and wastewater, 2540 D) was used for the determination of suspended solids in surface water samples. A volume of 100 mL of water was filtered through a pre-weighed glass fibre filter membrane. The filter was dried at 105°C, allowed to cool at room temperature and weighed again. The TSS was calculated in mg L^{-1} as in Eq. 1:

$$TSS = \frac{A\text{-}B}{C} \times 1000 \quad (1)$$

where, A is the final weight of membrane after filtration, B is the initial weight of membrane before filtration and C is the volume of water sample filtered.

Water treatment: Cloth filtration was used for surface water and the boiling and chlorination methods were used for container-stored water. The treatment strategies were evaluated for efficiency and cost-effectiveness noting that cost was a critical factor for adoption by financially strained households in the rural communities. Bacterial analysis for surface and container stored waters was performed prior to treatment to establish the bacterial load.

Boiling method: A 5 L of container-stored water was brought to a rolling boil. About 200 mL samples were collected sequentially at times 0, 1, 2, 5 and 10 min. The water samples were cooled down and processed for bacterial enumeration.

Chlorination: Commercial household bleach was used as a source of sodium hypochlorite (NaOCl). About 5 mL of bleach solution was added to 20 L of container stored water and allowed to stand for 30 min before first sample collection. Efficiency of chlorine disinfection was determined for reduction in bacterial load in 2 days intervals over a 22 day period as described for bacterial analysis above.

Trihalomethane (THM) content following bleach treatment was investigated with 2, 5 and 8 months old household bleach. Three of 1 L container-stored water samples were treated with household bleach at a ratio of 5 mL: 20 L (bleach: water). The 500 mL aliquots of the treated water samples were sent to Waterlab in Pretoria (RSA) for analysis of trihalomethanes.

Cloth filtration method: Different types of fabrics were used to filter the surface water, namely, cotton, suede and silk. The method of Colwell *et al.*[14] was followed with modifications. The filter was placed and fastened over the mouth of a plastic bucket and the surface water was allowed to pass through at a gravitational speed. Water was filtered through a single, double and four layers of the cloths to increase surface area for bacterial entrapment. The treated water was analysed for reduction in bacterial load.

Statistical Analysis: The bacterial and physico-chemical parameters experiments were performed in triplicates and the average of these readings were presented. A pair size t-test method was performed to test for significant difference during evaluation of the efficacy of filters to improve turbidity, colour and total suspended solids in water. A $p<0.05$ was considered statistically significant.

RESULTS

The three point-of-use water treatment strategies tested in this study showed varying degrees of efficiency for removal of contaminating bacteria and improvement of other water quality parameters such as turbidity, apparent colour and suspended solids.

Two minutes of rolling boil was the minimum time for elimination of the coliform and heterotrophic bacteria from the container stored water (Fig. 1). Resurgence of bacteria in treated water was investigated following minimal handling through scooping of water using jugs.

Acceptable bacterial quality of boiled water was maintained for 2 days for water which was stored in clean, disinfected plastic containers contrary to storage in a plastic container rinsed with hot water with and without detergent only. Coliform bacteria re-emerged at a slower rate compared to heterotrophs for water which was stored in a disinfected plastic container.

Chlorination and longevity of germicidal effect: This study sought to investigate the germicidal longevity of chlorination as a strategy for point of use water treatment. Coliforms were completely removed while 99% reduction in heterotrophs was achieved within the first day of treatment. This coincided with the highest activity of free residual chlorine in the treated water (Fig. 2, 3). The level of free residual chlorine declined gradually to undetectable at day 10, however, the germicidal effect was maintained over a 3 week study period without any resurgence of heterotrophs and coliforms.

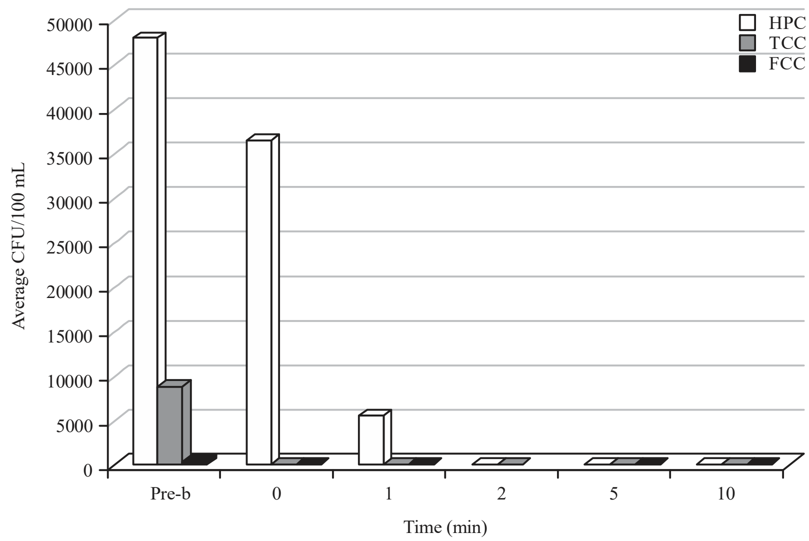

Fig. 1: Effect of time as a factor of disinfection of container stored water by boiling
Pre-b refers to initial microbial load before boiling treatment

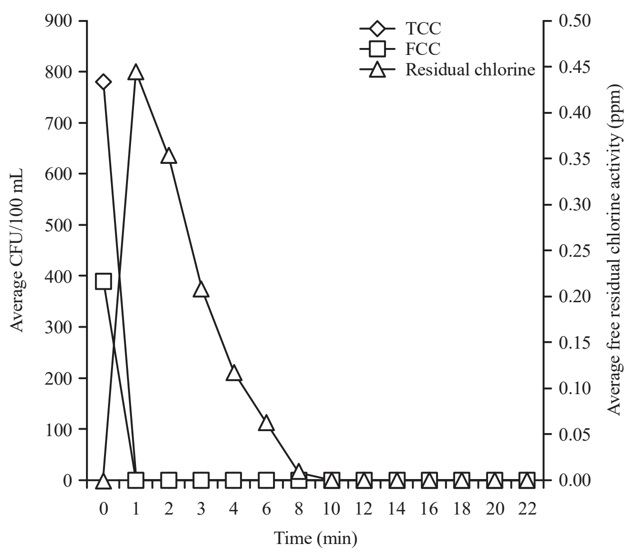

Fig. 2: Microbial load of coliform bacteria and residual chlorine contents during chlorination

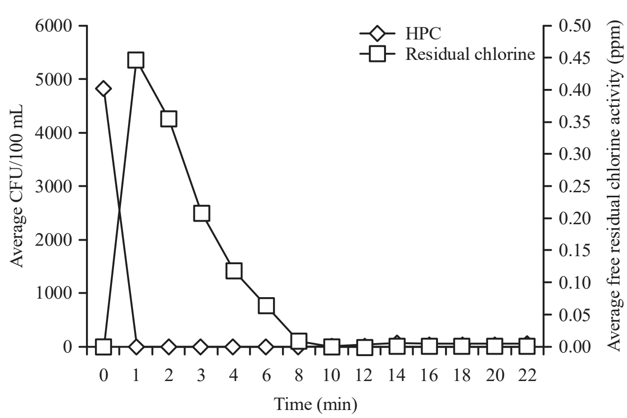

Fig. 3: Microbial load of heterotrophic bacteria and residual chlorine contents during chlorination

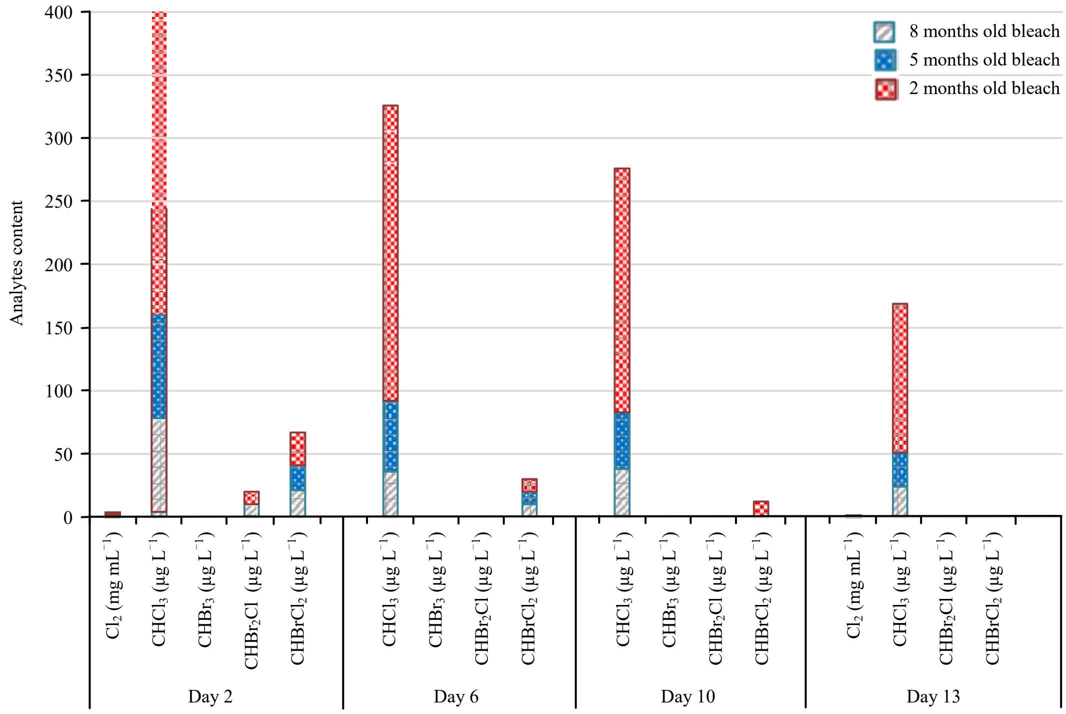

Fig. 4: Concentrations of trihalomethanes present in treated drinking water

Trihalomethanes were associated with chlorination and the content of the 4 analytes was investigated over a 2 week period following treatment of water with chlorine. The chloroform content in the treated water was high over the 2 week period. Although a decrease was observed from 78-24 µg L^{-1} for the 8 month old bleach solution, 82-27 µg L^{-1} for the 5 month old bleach solution and 396-118 µg L^{-1} for the 2 month old bleach solution (Fig. 4). This was followed by bromodichloromethane content which was lower at 22 µg L^{-1} for day 2 and 10 µg L^{-1} for day 6 to undetectable levels at days 10 and 13. The levels of bromoform and dibromochloromethane were generally lower than 10 µg L^{-1}. It was noteworthy that the levels of the THMs in the chlorinated water remained low to undetectable at micro-scale measures throughout.

Cloth filtration: There was no significant reduction in the levels of heterotrophs and coliform bacteria in water samples following filtration with all the different fabrics. The bacterial load decreased from 64×103 CFU mL^{-1} to an average of 38×103 CFU mL^{-1} for heterotrophs, 13×103 to 9×103 CFU/100 mL for total coliforms and 9×103 to 5×103 CFU/100 mL for faecal coliforms. Nonetheless, clarity of the water improved through reduction of turbidity, soluble solids and colour (Fig. 5). Suede cloth was better at clarifying the turbid river water than cotton and silk.

DISCUSSION

Developing countries, including South Africa, are greatly challenged by the lack of access to safe drinking water. This is mainly due to limited financial resources and lack of infrastructure. Rural communities in developing countries rarely have an adequate supply of microbiologically safe drinking water, while provision of safe water is an ideal solution to getting rid of waterborne diseases.

Household water treatment strategies such as boiling, chlorination and filtration provide an immediate and temporary solution[15] when the safety of water cannot be guaranteed for drinking purposes. Boiling is universally accepted for household treatment of water; it kills all pathogens of concern. Its adoption is limited by the availability and the cost of fuel notwithstanding its restricted application for only clarified water. This study showed that the same level of microbiological treatment efficacy was achieved with 2 min of boiling time in comparison with 5-10 min and more that have been reported in literature[16,17]. This finding has a marked financial saving for the poor communities while achieving the desirable level of water safety. Boiling has a protective effect but shows bias toward non-helminth organisms[18]. The inherent challenge of boiling was compliance due to the nature of the actual task of boiling or remembering to boil. However, the benefit can be realised only when the

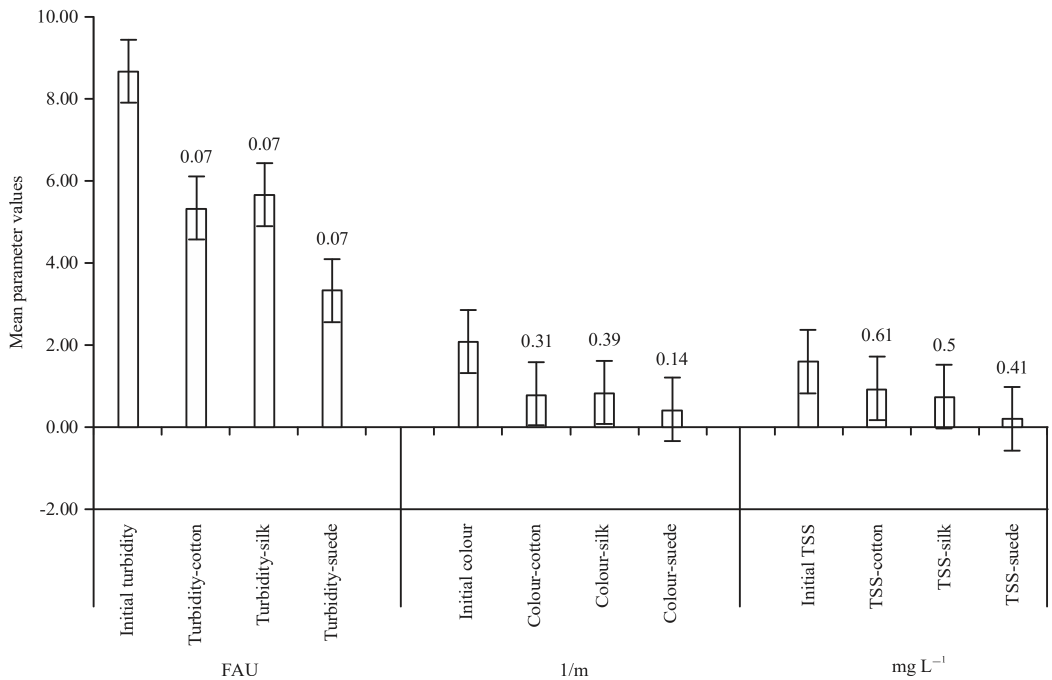

Fig. 5: Measures of physical water quality parameters following filtration of surface water samples with quadruple folded fabrics
p-values at 95% confidence interval are shown on the graph bars

communities comprehend the benefits over the health risks associated with contaminated water. The health risks of waterborne infections that were associated with contaminated water were greatly reduced when boiling disinfection was consistently and continuously practised[17]. Germicidal efficacy of chlorination treatment of water lasted for 3 weeks and continuing. The challenge with chlorination is the development of by-products. This threatened the adoption of the method due to its potential health risks. With the levels and longevity of microbiological treatment efficiency observed in this study, the frequency for re-dosing of water was reduced and this further minimised the potential risks from trihalomethanes. Nonetheless, the concentrations of the trihalomethane compounds, namely, bromoform, dibromochloromethane and bromodichloromethane which were detected in the treated water were low to be of concern wherein the threshold was 100 μg L^{-1} for bromoform, 100 μg L^{-1} for dibromochloromethane and 60 μg L^{-1} for bromodichloromethane[19]. Chloroform was detected in higher concentrations in water treated with 2 months old bleach during the first 2-10 days of treatment. The concentration exceeded the maximum acceptable limit of 200 μg L^{-1} as stated by WHO[20]. Chloroform was the most dominant species found in chlorinated water and long-term exposure may lead to cancer. Chlorination was generally known to be an effective strategy for household treatment of unsafe water, often better than the boiling method because of its residual germicidal activity[21].

Solar water disinfection (SODIS) is often an alternative option to boiling, cloth filtration and chlorination. The SODIS showed to be efficient in reducing microbial contaminants[22] through exposure of the water to direct sunlight[23] for 6 h. This treatment requires a clear sky and less turbid water to be effective. The primary specific shortcoming of SODIS was the limitation of the volume of water that can be treated at one time due to lack of penetrative power of the UV rays. A specific irradiation dose was required to disinfect the water[24] and this could be a challenge during cloudy days. Furthermore, SODIS was not time efficient for production of large volumes of safe water in comparison to the water treatment methods under study.

Aesthetics is one of the primary factors that determine the acceptability of water. While chlorination and boiling methods are applicable to clear water, filtration can be used to improve clarity of water in addition to its microbiological quality. However, with cloth filtration, porosity is a key element of the fabric which determines its entrapment efficiency. The fabrics could reduce hue and improve clarity of the water, nevertheless they were not effective in improving the microbiological quality as shown in this study. Filtration, with any material, is essentially employed to remove suspended solids and particulate matter from the water. Cloth fabrics had shown some success in removing bigger pathogenic organisms[14,25,26] from contaminated water. Cost proved to be a critical factor for adoption of any safety strategy for home based water disinfection. Geremew *et al.*[27] additionally reported education status of the head of the household and access to transmission media such as radio and television as aggravating factors to the wide adoption of home-based treatment strategies. The HWTS are important for point of use intervention and were initially directed for interventions when advisories were issued on compromised water quality. However, for communities that lack infrastructure or utilities for continuous water provision often use unsafe water resources. Hence, HWTS has become important for continuous treatment of water at household level, considering the increasing challenge of provision of safe water in developing countries.

The importance of this study was to highlight the most cost effective strategy of using the well- known home-based water treatment methods in order to produce safe drinking water. Most households were surviving with <$1.00 a day, which was below the international poverty line of[28] $1.90. Cost generally outweighed safety in most impoverished communities. It was important to determine the minimum requirements for water safety of the water treatment strategies while limiting the cost for implementation and operation.

CONCLUSION

The boiling, chlorination and filtration methods were cost effective methods which any household could easily adopt for treatment of contaminated water. Importantly, these methods were simple to implement for continuous use in water scarce communities where surface waters were common sources of household water. Like any other method, none of these strategies could assure complete safety and production of good quality potable water. Each had advantages and shortcomings, however, these can be circumvented when combination treatment is employed for treatment of contaminated water. Home-based water treatment strategies are important in developing countries where safe drinking water is often not available. Hence, knowledge of their efficiency, in addition to cost effectiveness and longevity, is important for adoption and routine use.

SIGNIFICANCE STATEMENT

This study discovered that not any one method is efficient for home based water treatment. Boiling and chlorination methods showed efficiency in removing microbial contaminants, with both residual activities during water storage, whereas, cloth filtration showed importance in improving the aesthetics of the contaminated water. Combination treatment of contaminated water using different strategies can be beneficial for communities which depend on unsavoury water resources for their household needs. This study will help the researchers to consider the longevity and residual effect of a water purification method when investigating the water treatment strategies for home-based and community use. Thus a novel theory on combinatorial home-based water treatment strategy may be arrived at and advocated to communities that are affected by shortage of potable water to curb the risk of water-borne infections.

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