Practical Paper

Implementation of point-of-use water treatment methods in a rural Tanzanian community: a case study

T. M. Ngasala, S. J. Masten, C. Cohen, D. Ravitz and E. J. Mwita

ABSTRACT

This study was conducted in an agro-pastoral community in Northern Tanzania, where water sources are contaminated, and point-of-use water treatment is rarely used. The objectives of the study were to determine the quality of drinking water at the household level and to assess the perception and attitude towards the treatment methods that were introduced to community members. The three treatment methods evaluated were chlorine tablets, silver-infused ceramic tablets, and solar water disinfection (SODIS). These methods were selected due to their availability, ease of use, cost, and effectiveness in water with high levels of coliform bacteria. Each home within the study area was provided with one of three treatment methods. The use, performance, and acceptability of the new water treatment methods were assessed over a three-week period. Prior to the introduction of the methods, 40% of households reported that they treated water regularly. However, 80% of the household water samples tested positive for *Escherichia coli*. After introducing the new methods, 60% of households increased their water consumption, and all water samples tested negative for *E. coli* during the final week of testing. The work demonstrates the need to provide access to cost-effective household water treatment methods, especially in rural communities that lack access to potable water.

Key words | *Escherichia coli*, household water treatment methods, rural areas, solar disinfection, Tanzania, water quality

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HIGHLIGHTS

- 40% of households surveyed treated their water with either boiling or filtration clay pots.
- Three treatment methods were introduced and resulted in increased water consumption and improved attitudes towards treatment.
- The treatments effectively eliminated *E. coli* and significantly reduced faecal coliform bacteria levels.
- Households were able to integrate all three treatment methods during the study period.

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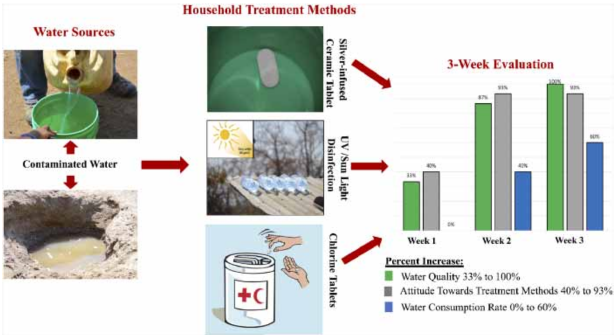
GRAPHICAL ABSTRACT



INTRODUCTION

In the study area in rural northeastern Tanzania (see Figure S1 in Supplementary Material), access to clean water is limited, and both surface and shallow groundwater is highly contaminated due to poor management of livestock operations (Ngasala *et al.* 2018). Residents in this area experience water scarcity due to the semi-arid climate and unpredictable rainfall (Pearson *et al.* 2016). The community relies on three main water sources: surface water, shallow wells, and deep wells as shown in Supplementary Material, Figure S1. Their use depends on access and seasonal availability. In many rural areas, traditional household point-of-use water treatment involves either boiling or the use of clay filtration pots (Makutsa *et al.* 2001; Zereffa & Bekalo 2017). However, disinfection by boiling is often limited due to the limited availability of wood, time constraints, and the cost of fuel (McGuigan *et al.* 1999; Ravindra *et al.* 2019). Ceramic (clay) filters require daily washing, which some may find to be tedious and, as a result, may not follow proper cleaning guidelines, which contributes to compromised water quality. Alternate treatment methods include chlorine tablets, silver-infused ceramic tablets, and the solar water disinfection (SODIS) method.

Chlorine tablets are effective, inexpensive, and readily available. In Tanzania, one chlorine tablet costs between Tshs. 100–500 (~$0.04–0.22 USD) and can treat a 20 L bucket of water. The cost of chlorine is about five times cheaper than using the boiling method (McGuigan *et al.* 1999; Aquatabs/Medentech 2007; PATH 2012).

Silver-infused ceramic tablets (also known as MadiDrop) release silver ions at non-toxic levels into the water. The silver ions have been shown effectively to achieve 4 log reduction in the total coliform bacteria and *Escherichia coli* (Ehdaie *et al.* 2017). The MadiDrop is a microporous, water permeable ceramic tablet that is infused with microscopic silver clusters. The base is made of clay (MadiDrop 2020). One silver-infused ceramic tablet costs about Tshs. 20,000 (~$8.63 USD). This tablet can be used for up to 6 months, and it is significantly cheaper than boiling at an approximate cost of Tshs. 30 per 20 L (assumed 20 L treated per day for 6 months).

The SODIS, also known as UV light disinfection, uses sunlight (McGuigan *et al.* 1999; Gómez-Couso *et al.* 2012; Mustafa *et al.* 2013) to achieve disinfection. It requires little maintenance and no chemical addition. However, there is a one-time cost of clear plastic bottles that are used to store water. A 0.5 L water bottle, commonly used for this method and readily available in rural Tanzania, costs Tshs. 500 ($0.22 USD). The one-time cost to buy enough water bottles to treat 20 L is Tshs. 20,000 (~$8.63 USD). Additionally, the use of SODIS will help produce a sustainable form of recycling in a society that would otherwise have burned the bottles as trash. A disadvantage of this method is the potential leaching of organic chemicals from the plastic bottles; however, Schmid *et al.* (2008) demonstrated that the carcinogenic risk due to the leaching of di(2-ethylhexyl)adipate (DEHA) and di(2-ethylhexyl)phthalate (DEHP) from polyethylene terephthalate (PET) bottles is negligible. While, the waters tested in this study had sufficiently low turbidity that pre-treatment was unnecessary, if the water is very turbid, filtration or sedimentation would be required prior to disinfection with all three methods tested.

METHODS

Our study uniquely linked household water quality and the attitude of residents towards household water treatment methods. We focused on how randomly selected households in the community respond to the implementation of new and more effective water treatment methods while monitoring the quality of water. Two main objectives of this study were to determine the quality of drinking water at the household level before and after implementation of the new method and to assess the perception and attitude towards the three treatment methods introduced. Three water treatment methods were selected due to their low cost, ease of use, and ability to inactivate coliform bacteria. To our knowledge, this is the first study to report on the technological performance of the MadiDrop tablets in comparison with other household water treatment methods.

Field visits, household surveys (see Supplementary Materials), and water samples from homes and original water sources were obtained over a three-week period, as described in detail in Appendix B in the Supplementary Material. The source water was sampled once at the start of the study, while one water sample from each home was collected from storage containers and analysed each week. Fifteen families were randomly selected within the study area. Each family was provided with one of the three water treatment methods: chlorine tablets (four households), silver-infused ceramic tablets (six households), and clear plastic bottles for solar disinfection (five households) (see Figure S2 in the Supplementary Material). Water samples were tested for *E. coli* immediately upon collection using the Coliform Presence/Absence incubation method with UV light *E. coli* confirmation (P/A Broth with MUG, Method 8364) (HACH 2013) (see Figure S3 in the Supplementary Material). The survey responses were analysed using the Mann–Whitney U test method, a nonparametric test that is optimal for small sample sizes and non-uniform distributed data (MacFarland & Yates 2016). Details regarding analytical methods and statistical analyses are provided in Appendix C in the Supplementary Material.

RESULTS

Water quality

Field observation and water testing revealed that the water sources used by the community were not safe for consumption. These findings are consistent with the findings of Ngasala *et al.* (2018), where water sources in the same area were extensively analysed. As shown in Table S1 in the Supplementary Material, seven out of nine water samples tested from three sources identified in Figure S1 in the Supplemental Material were found to be contaminated by *E. coli.* Only two samples from deep well tested negative for *E. coli*. Figure 1 summarises water quality results for

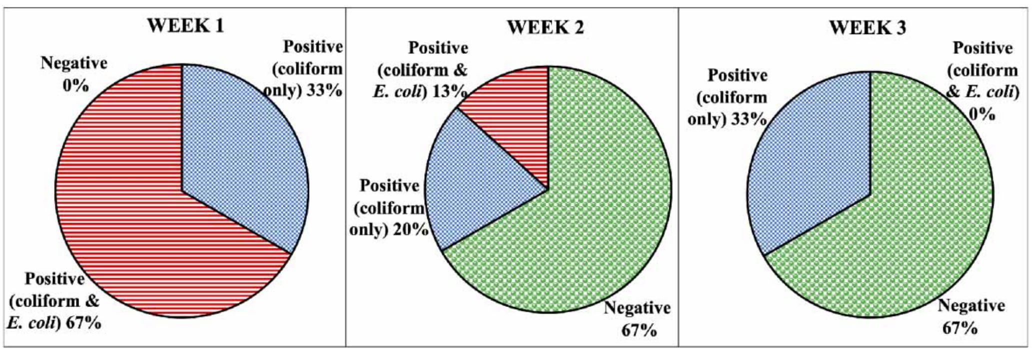


Figure 1 | Water quality results of the three-week evaluation period. Week 1 shows the highest level of contamination and Week 3 shows a significant improvement in water quality with an absence of *E. coli.*

all 3 weeks from households surveyed. Week 1 represents test results from the 15 households before the new water treatment method was introduced. Weeks 2 and 3 represent water testing results after the introduction of new household water treatment method. For the first week, four out of 15 samples tested were from shallow wells, and 11 were deep wells. During Week 2, 14 water samples reported were from deep wells and only one was from a shallow well. During Week 3, 12 water samples reported were from deep wells and only one was from a shallow well. The improvement in water quality can be observed in Figure 1.

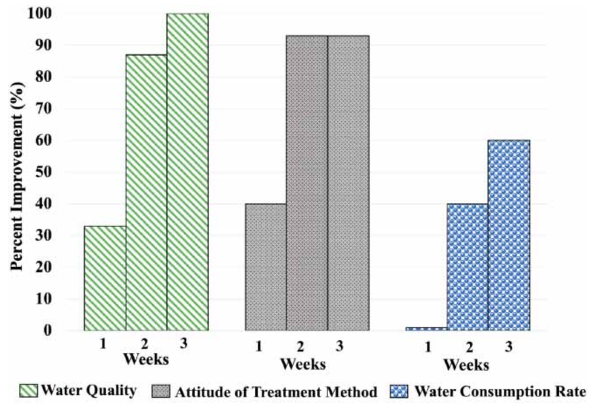


Figure 2 | The weekly evaluation results from survey responses showing the influence on water quality, the participants' attitude towards drinking water treatment and the household water consumption rate.

Overall weekly evaluation responses

Tables S2, S3, and S4 in the Supplementary Material show a summary of household survey responses of weekly evaluations. Prior to the implementation of the three water treatment methods, 60% of the surveyed residents reported to not treat their drinking water (see Figure S4 in the Supplementary Material). Further questioning revealed that it is partly due to factors such as lack of time and access to wood and charcoal that is used to boil water. The reported average water consumption rate per person before the implementation of the three water treatment methods was 1.4 L, which is much lower than the WHO recommended amounts of 3.7 L/day for men and 2.7 L/day for women (Grandjean 2004). After implementation of the new treatment methods, the drinking water consumption rate increased by 60% and the bacterial water quality improved by 67%. The willingness of the participants to continue these methods also increased significantly (53%) but levelled off by the end of Week 2 (Figure 2). The water consumption rate is compared against that in Week 1 (which is artificially set at 0% as a baseline for comparative purposes).

The improvement in water quality, along with an increase in the attitude to treating water and water consumption rate between Weeks 1–2 and 1–3, was significantly different at the 95% confidence level (see Table S5 in the Supplementary Material). However, the differences between Weeks 2 and 3 were not statistically significant at the 95% confidence interval. There was a significant improvement in water quality, treatment attitude, and water consumption rate after using the new water treatment method when it was compared to Weeks 1 and 2. Comparison between Weeks 2 and 3 showed an improvement in water quality, treatment attitude, and water consumption rate although the improvement was not statistically significant. The improvement was obvious between Weeks 3 and 1 for all three variables.

Effectiveness of water treatment methods

Weekly evaluations also revealed the effectiveness, along with the advantages and disadvantages of each water treatment method used. Overall, the participants reported that all three methods were easy to use and improved taste (see Table S6 in the Supplementary Material). The silver-infused ceramic tablet was particularly popular among the residents in the community, due to its simplicity and the knowledge that it was helping to improve their health. However, two families commented that the waiting time of 12 h was too long. Households that used the chlorine tablets were satisfied with the treatment method and the taste of the treated water, although two women from two households reported that, initially, the taste was different from what they were accustomed. Solar disinfection method users commented that the water tasted better, the method was easy to use, and they were happy to learn that using treated water would help to improve their health. One limitation mentioned was the availability of clear plastic bottles and remembering to refill water for future use. None of the users voiced concern regarding the safety of the treatment methods.

DISCUSSION

Field observation and water testing results showed that the water sources used by the community were not safe for consumption. This is mainly due to sharing of water sources with animals and poor sewage management which leads to water contamination with bacteria, including faecal coliform and *E. coli* as measured in this study and other contaminants that originate from animal and human wastes such as ammonia, nitrate, and phosphorus that cause illness (Ngasala *et al.* 2018, 2019a). It was also observed that all of the water samples collected from households were from shallow wells and deep wells (see Table S1 and Figure S5 in the Supplementary Material). This is not surprising. As this study was done during the dry season and surface water sources are very seasonal, most of them were dry (Ngasala *et al.* 2018).

The respondents in our study who reported that they treated their water were aware of the dangers of untreated water and had been educated by schoolteachers or doctors. Despite their attempts to decontaminate their water, water tested still had faecal contamination in Week 1. As shown in Figure 1, prior to treatment, all samples were contaminated with *E. coli* and faecal coliform bacteria. The water quality of the original sources was also found to be contaminated (see Table S1 in the Supplementary Material). During the second week, there was a significant decrease in the percentage of samples that tested positive, which is most likely due to the deployment of the alternative household water treatment methods. The presence of faecal coliforms in some samples may be due to contamination during storage from placing treated water into ineffectively cleaned storage containers or by mixing treated with untreated water in the storage containers. Also, some participants may not have followed instructions for the proper use of the treatment method, resulting in poor treatment efficacy. As shown by Ngasala *et al.* (2019b) in a study conducted in a peri-urban community in Dar es Salaam, Tanzania, proper storage after treatment is critical to avoiding recontamination. Mintz *et al.* (1995) suggest that poorly designed storage containers can contribute to contamination of already treated drinking water during storage. The results presented by Ngasala *et al.* (2019b) and Mintz *et al.* (1995) demonstrate the importance of educating the community about proper water sanitation, storage, and management.

During the third week, the presence of *E. coli* was likely eliminated from all the samples because the families whose water had *E. coli* present in the second week were instructed to make sure that their containers were clean. These results suggest that all the treatment methods were effective in eliminating *E. coli* and significantly reducing faecal coliform bacteria. Due to the small sample size, it was not statistically possible to analyse each of the treatment methods separately for effectiveness. It is unknown whether extending the treatment and testing beyond the 3-week mark would have resulted in further reduction in faecal coliform bacteria. Overall, participants reported that all three methods were easy to use, and they were happy that their health and well-being will be improved. Also, these results demonstrate that each of the households were able to integrate the treatment method that was provided to them daily throughout the study period.

Some of the constraints during this case study included a small sample size. Similar constraints were found in the CHINS (Community Housing and Infrastructure Needs Surveys) developed by the Australian Bureau of Statistics where surveys lacked data quality and that they did not incorporate a significant proportion of their participants (Bailie *et al.* 2004). Moreover, the short test period prevented the study from looking at the long-term impact that the alternative treatment methods would have on all of the families. One of these considerations was that the three-week period is insufficient to determine if the benefits of treating the water are sufficient to sustain motivation to employ the methods and to use their limited financial resources. Although 93% of participants mentioned they would buy their given method after this brief study, it is unclear if the same percentage would be observed if the test period was longer and a longitudinal study of the residents over a longer period of time is necessary as noted by Casanova *et al.* (2012), to promote continued use of disinfection treatment, distribution and education must be joined with capacity building for long-term water monitoring, supply chains, and local production.

CONCLUSION

The limited study demonstrated that, over a three-week time period, significant improvement was made in water consumption, water quality, and attitude towards the treatment. The introduction of the alternative household water treatment methods proved to be successful in eliminating the presence of *E. coli* bacteria. In future studies, different techniques similar to that of a gravity-fed ultrafilter, which has been proved to be an effective, low-cost water treatment technology (Chaidez *et al.* 2016), could be implemented to see if the willingness of the subjects to treat drinking water would increase even more than already observed. Contaminants other than those that stem from faecal matter should also be tested. Additionally, the study could be expanded to cover more households over a longer period for a better representation of the long-term effectiveness of the alternative household water treatment methods. As this study was conducted during the dry season, the expanded study should be conducted during the wet season to assess how deteriorated source water quality and increased availability (Elisante & Muzuka 2016) might affect the efficacy and acceptance of these treatment methods. It would also be beneficial for the area to find a distributor to sell the silver-infused ceramic tablets and to create an educational programme to help the rural Tanzanians learn about solar disinfection and how easy it is to integrate these methods into their daily lives in order to increase their awareness of the importance of treating water easily, cheaply, and effectively. A few of the households reported to have taught their neighbours and friends how to use solar disinfection method. By sharing knowledge with others, these households demonstrated that this particular method can be easily integrated into the community lifestyle. From this, the implementation of a simple and cost-effective treatment method into the community would greatly increase the number of people with clean water in their homes.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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