Effectiveness of Point-of-Use Technologies on Water Quality in Limpopo, South Africa

By Merly Konathapally and Olivia Jones

Household in the Dzimauli Region

Abstract

Point-of-use (POU) water treatment is a valuable solution to improve drinking water quality and to reduce pathogen exposure in children by using minimal resources in a household setting. The MadiTrial Project examined the effectiveness of ceramic water filters in reducing childhood pathogen exposure from drinking water. This study was a randomized, controlled trial in Dzimauli, Limpopo, South Africa that tested two POU water treatment technologies, a ceramic water filter and a MadiDrop silver tablet. Results were obtained by (1) measuring the performance of the interventions in reducing bacterial presence in water; (2) examining the potential association between pathogen prevalence in stool and intervention access; and (3) comparing filter performance with and without silver. Analysis at both the University of Virginia and the University of Venda in South Africa found a significant reduction of the *Giardia* parasite in stool samples from the ceramic water filter intervention group. A lack of silver in ceramic water filters showed significant reduction of their ability to treat water effectively. Most other stool pathogen prevalences across water treatment intervention groups showed little difference, possibly due to other exposures. The importance of silver in addition to the mechanical filtration of the interventions shows that safe methods of chemical filtration can be further researched to increase water filter effectiveness. Ongoing studies are examining various forms of silver addition in ceramic water filters. Current analysis is also examining the impact of the filters on growth and other anthropometric characteristics.

Introduction

Lack of access to safe water in low-resource settings potentially contributes to stunted growth in children. Current research indicates that nearly 162 million children under 5 years are affected by stunted growth, which can lead to diminished cognitive and physical growth.[1] A 2013 study in countries including South Africa determined that interventions to increase birth weight and linear growth in children during the first two years of life are beneficial to gains in height and education, as well as reducing risk in multiple adult chronic diseases.[2] Enteric infections and malnutrition can have compounding effects on early childhood development.[3] The development of water filtration to prevent enteric diseases in children continues to be an important area of research, particularly in the Dzimauli region of South Africa.

The Dzimauli region has a rural landscape and is generally classified as a lower-resource setting. The Mutale River, a primary water source in many households, was tested prior to the study and showed significant contamination from various pathogens that cause waterborne diseases, particularly diarrhea. Diarrheal disease in young children can be extremely dangerous due to disruptions in intestinal absorption which can cause up to 43% of stunted growth in children.[3] The MadiDrop, a silver tablet that chemically filters water, showed potential to reduce pathogen exposure addition to the mechanical filtration done by a ceramic water filter.[4] This study aimed to examine the reduction in exposure to several key pathogens in enteric diseases: *E. coli*, *Giardia*, *Cryptosporidium, Shigella*, and *Adenovirus*. These pathogens have been shown to cause diarrheal diseases and have the potential for transmission through contaminated water. POU technologies have been shown as an effective method for filtration in a low-resource, household

setting, and can be promising technologies to reduce pathogen exposure.[5]

The MadiTrial project began after extensive research on water filtration methods, as well as development of a factory for creation of the filters and distribution. A partnership between the University of Virginia and the University of Venda in Thohoyandou, Limpopo, South Africa permitted researchers to establish a project in the Dzimauli region of Limpopo. Beginning in 2016, this current study was a continuation of the MadiTrial project and analyzed data from summer 2018 to compare with previously collected data. The project aimed to measure the impact of these POU water treatment technologies on long-term health consequences, particularly linear growth and childhood stunting, in children under the age of 5 years.

Methods

This study originally tested two POU water treatment technologies: a ceramic water filter and a MadiDrop silver tablet. Initially, 416 families were enrolled in the study and divided evenly among four groups, as shown in Table 1. The four groups consisted of the ceramic water filter (A), MadiDrop (B), bucket (C), and no intervention (D). The ceramic water filters (Group A) were utilized to mechanically remove pathogens directly. The MadiDrop silver tablet (Group B) provides chemical filtration through the use of silver in the stored water. The bucket (Group C) was used to determine if protection from the outside environment alone could impact the water quality. No intervention (Group D) was used as the control. Following the first year, the MadiDrop intervention was removed from the study due to concerns about the concentration of silver in the filtered water. These participants were then given a ceramic water filter, similar to Group A.

Field workers in the Dzimauli region conducted quarterly visits to participant's

homes, and counseled on topics including water health, sanitation, and hygiene practices. In the initial visit, a baseline questionnaire recorded demographics, socioeconomic status, water sources, and sanitation/hygiene practices. During the quarterly visits, height, weight, behavioral surveys and stool samples were collected for later analysis at the University of Venda.

The effectiveness of the water filters was measured through membrane filtration conducted in the science laboratories at the University of Venda. In the summer of 2017 and 2018, inflow and outflow water samples were collected from 100 random households in each intervention group. The samples were run through membrane filtration using a vacuum pump and the filters were placed in m-Coli blue cultures to incubate overnight. Bacterial counts were recorded and analyzed the following day. Distilled water was used as the control comparison.

SmartSpout spigots were also installed in summer 2017 on Groups A, B, and C interventions to quantitatively measure usage. The SmartSpout spigots recorded each time an intervention was used for over 5 seconds, and this data was retrieved through a smartphone from field workers. The main purpose of this measurement was to compare adherence to the study to reported adherence from the quarterly surveys.

Stool samples were collected from the primary child of the households every three months, and the 6, 12, 18, and 24 months samples were analyzed for pathogen prevalence. Samples were stored at -70°C until DNA extraction analysis during summer 2018. The QIAamp Fast Stool Minikit DNA extraction tool was utilized to extract the DNA from each samples. Distilled water was also used as the control sample. Following DNA extraction, quantitative real-time multiplex polymerase chain reaction (qPCR) was conducted to examine pathogen

prevalence. The qPCR amplified bacterial DNA which was visualized by primer-probe fluorescent signals with the LightCycler 480 program. A positive template was used as a positive control in each qPCR and distilled water was used as a negative control. Results were considered positive with a threshold cycle (Ct) below 35.00 and an acceptable, exponential-like amplification curve. The three panels studied and target genes are summarized in Table 2. These forms of data collection permitted analysis of the effectiveness of POU technologies in various aspects.

Outcomes

The results from the various forms of data collection were able to provide a better picture in how to improve water quality in the region and ultimately reduce child stunting in Limpopo. The data from 356 total households was used to measure the effectiveness of the interventions.

The membrane filtration data was compared among the inflow and outflow samples of the three main interventions: ceramic water filter (Groups A and B), bucket (Group C), and no intervention (Group D). The total coliform bacteria per 100 mL of water was determined and plotted, and then the log reduction in coliform bacteria was calculated to compare inflow and outflow. The ceramic water filter samples showed a slight decrease in total coliform bacteria, while the bucket and no intervention groups did not see significant changes. These results represented the 24 month period of the study, and were then compared to the 6 month membrane filtration results to determine the impact of silver and chemical filtration in water treatment. The 6 month membrane filtration results from the summer of 2017 saw a much more significant reduction in coliform bacteria with use of the MadiDrop, as depicted in Figure 1. The MadiDrop was able to produce a 5-log-reduction in total

coliform, which is the desired result for water treatment. These results revealed the importance of chemical filtration in POU technologies. Prior to this study, the mechanical filtration of the ceramic water filter was believed to sufficiently treat water samples, but these results confirmed the ability of silver to treat water.

The SmartSpout data was collected from 267 households with the ceramic water filter or bucket interventions. The instances of intervention usage over 5 seconds were recorded and displayed in Figure 2. Interestingly, Group C with the bucket intervention showed the highest adherence throughout the course of the study. At the beginning of the study, the MadiDrop intervention (Group B) also showed similar levels of adherence as Group C. During summer 2017, the MadiDrop filters were removed from Group B, and following this change, their intervention adherence levels significantly decreased, reaching the levels of Group A. Highlighting the actual versus theoretical adherence during participant meetings hopefully encouraged higher levels of usage and promote water sanitation practices.

The results for pathogen prevalence in stool samples were also analyzed to determine the ability of the water filters to reduce pathogen exposure. The prevalence ratio between each intervention group (Groups A, B, C) and the control (Group D) were compared with a 95% confidence interval. The prevalence of positive findings in each group was compared to compute the ratio. Table 3 presents the relative *Giardia* prevalence among each intervention group. Of the eight pathogens that were tested, only *Giardia* presented significant decreases in prevalence with the ceramic water filter (Group A) compared to the control. The p-value of 0.02 revealed the significance of the result and also confirmed that mechanical filtration alone is insufficient in water

purification for pathogens. The prevalence of other pathogens varied but all showed insignificant change in prevalence, as shown in Table 3.

The questionnaires and surveys from the longitudinal study are currently being analyzed to determine additional outcomes, and answer the primary goal of the study, which was to reduce stunting in the Limpopo region through decreased pathogen exposure from water sources.

Discussion

This study examined water quality and its public health outcomes in multiple different facets. As the MadiTrial Project concludes in the months following this study, the results will provide a more defined approach to improving water quality in the Limpopo region and improving child growth. The currently analyzed results show the importance of considering the environment while constructing interventions and study design.

The results from membrane filtration revealed the importance of silver in reducing total coliform bacteria. Prior research shown the relevance of mechanical filtration in water purification, but the chemical filtration component was more debated in low-resource, POU settings. The effectiveness of the MadiDrop in comparison to the ceramic water filter alone shows the necessity of silver or another form of chemical filtration in water purification. Additionally, the removal of the MadiDrop from the study shows the importance of considering the study population and local practices when designing studies. In the laboratory setting, the MadiDrop had performed exceptionally in reducing pathogen prevalence without concern for silver concentration in the filtered water. However, in practice the silver concentration in the filtered water showed that the usage of the MadiDrop differed in households compared to the laboratory testing. One possible explanation for this

difference could be in the volume and usage of water in the Dzimauli region. Compared to water usage in the United States, households in the Dzimauli region use water less frequently and generally had a lower volume of water constantly going through the ceramic water filters. As a result, the sitting water in these filters could have been exposed to increased silver release by the MadiDrop. This difference creates an important discussion about approaching public health from a global standpoint. Due to the interpretive flexibility of technology, a more effective method of silver or other chemical filtration must be researched for implementation in this region. Current research at the University of Venda and by other groups at the University of Virginia are exploring the effectiveness of a silver nitrate coating on the ceramic water filters in providing a form of chemical filtration. These ongoing studies and continued development of interventions show how science and global health can intersect to create lasting changes.

The results from the stool samples and the qPCR reveal information about the water filter interventions as well. There was no significant decrease found in pathogen prevalence in the stool samples of young children, except for *Giardia*. This parasite is relatively large at 8-14 μm compared to the other pathogens such as *E. coli* which is around 2 μm in length.[6] As a result, the pores in the ceramic water filters are much more likely to prevent the passage of parasites like *Giardia*, rather than smaller pathogens. These results show that the mechanical filtration of the filters is effective but only to a certain extent. It is able to reduce the impact of larger pathogens, which have the potential to cause severe water-related illnesses, but is limited in ability to reduce smaller pathogens. Chemical filtration has the potential to resolve the pathogen size limitation by targeting smaller pathogens that mechanical

filtration cannot. The presence of silver in addition to traditional mechanical filtration presents as an ideal combination for future water treatment.

Households in the Dzimauli region have various water sources and methods of storage. Many homes have access to a tap system that provides filtered water from the government; however, these taps are often dry during many days of the week. During one of the field visits, the team spoke with a mother who explained that the water from the tap source was unavailable during weekends, and often was dry throughout the week as well. She was unsure as to when the water would return, and had to rely on rationing her remaining water and finding alternative sources. This situation was common among many households in this study, leaving participants to find additional sources of water or efficient methods of storage. One water source is delivery by outside sources of large quantities of water in plastic jugs. This water is often stored for long periods of time and has the potential to be contaminated after delivery. Thus, there exists a need for POU treatment that filters the water directly prior to use.

These POU technologies have the potential to remove harmful pathogens that cause waterborne disease, which can severely impact the health of young children. These technologies are only effective, however, if they are used frequently in households and are efficient in their delivery of filtered water. The SmartSpout data showed that adherence to the interventions could be improved to increase effectiveness of the filtration. Adherance with the bucket intervention (Group C) was highest. One possible explanation for this result was that the ceramic water filters (Groups A, B) required additional time and planning to filter the water for use. The gradual release of water would increase the time taken to receive water, possibly discouraging use.

Meanwhile, the water stored in the buckets was available immediately. Convenience and efficiency of the filters should also be considered to encourage continued usage of the interventions.

An additional application of the SmartSpout data was its use in participant meetings. During summer 2018, three participant meetings were held at different locations in the Dzimauli region to inform participants about preliminary results and encourage continued filter use after the conclusion of the study. During these meetings, which primarily took place in local community centers and churches, the water quality of the Mutale River, a local water source, was discussed as well as the results of membrane filtration in reducing bacterial presence in the water. These presentations allowed for increased awareness of the purpose of the study and its potential impact on the health of children. The meetings were heavily attended by mothers and their children, showing strong investment in the project and improving water quality in the region.

The findings of this study show the importance of addressing water quality in order to make community-wide changes in public health. There were also key limitations in the study that led to these results. The removal of the MadiDrop significantly changed the study progress and outcome, showing that further research in chemical filtration is needed. The lack of differences in many stool pathogen prevalences across water treatment intervention groups can also be attributed to other exposures, such as through food, other water sources, and more. Since work was conducted in households, it would not be possible to control for all external variables, making the results more realistic, but also difficult to control for situational factors. An additional limitation was the short amount of time available to spend in the field and laboratory at the

University of Venda. Regardless of these limitations, the PureMadi Project continues to be a source of change in the Limpopo region and a method of addressing water quality and health at the local level.

Conclusion

The key findings in this study confirm the importance of water treatment to impact children's health outcomes. As the anthropometric components of this study are analyzed, further research and development will also address silver's role in treating water and other methods of providing this chemical filtration, such as silver nitrate coatings. Additionally, this study demonstrates the importance of working within a community and addressing concerns through a direct approach. These direct involvements as well as continued collaboration between the University of Virginia and the University of Venda, will prove essential to addressing water quality and public health.

References

1. Weise AS. WHA Global Nutrition Target 2025: Stunting Policy Brief. :10.
2. Adair LS, Fall CHD, Osmond C, et al. Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: findings from five birth cohort studies. *Lancet Lond Engl*. 2013;382(9891):525-534. doi:10.1016/S0140-6736(13)60103-8
3. Guerrant RL, DeBoer MD, Moore SR, Scharf RJ, Lima AAM. The impoverished gut—a triple burden of diarrhoea, stunting and chronic disease. *Nat Rev Gastroenterol Hepatol*. 2013;10(4):220-229. doi:10.1038/nrgastro.2012.239
4. Kahler DM, Koermer NT, Reichl AR, Samie A, Smith JA. Performance and Acceptance of Novel Silver-Impregnated Ceramic Cubes for Drinking Water Treatment in Two Field Sites: Limpopo Province, South Africa and Dodoma Region, Tanzania. *Water*. 2016;8(95). doi:10.3390/w8030095
5. Levy K, Nelson KL, Hubbard A, Eisenberg JNS. Following the water: a controlled study of drinking water storage in northern coastal Ecuador. *Environ Health Perspect*. 2008;116(11):1533-1540. doi:10.1289/ehp.11296
6. Water Research Center - Giardia, Pathogenic Organisms, and Waterborne Disease impact on drinking water. https://www.water-research.net/index.php/reports/giardia-crytosporidium-and-waterborne-disease. Accessed March 24, 2019.

Acknowledgements

The project was funded by the Center for Global Health at the University of Virginia through the Center for Global Health University Scholar Award (IRB-HSR # 18662). The research was supported and mentored by Dr. Elizabeth McQuade and Dr. Darwin Operario of the University of Virginia and Dr. Bessong and Dr. Samie at the University of Venda. Also special thanks to other team members: Courtney Hill, Kelly McCain, LaChrisha Hill, Chad Brown, Masilo Maponya, and Ntwanano Mutileni.