Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Modeling the sustainability of a ceramic water filter intervention

Jonathan Mellor [a,*], *Lydia Abebe* [a], *Beeta Ehdaie* [a], *Rebecca Dillingham* [b], *James Smith* [a]

[a] *Department of Civil and Environmental Engineering, University of Virginia, Thornton Hall, P.O. Box 400742, Charlottesville, VA 22904, USA*

[b] *The Center for Global Health, Carter-Harrison Research Building, MR-6, Room 2526, 345 Crispell Drive, P.O. Box 801379, University of Virginia Health System, Charlottesville, VA 22908-1379, USA*

ARTICLE INFO

Article history:
Received 22 August 2013
Received in revised form
21 November 2013
Accepted 22 November 2013
Available online 3 December 2013

Keywords:
Agent-based modeling
ABM
Diarrhea
Ceramic water filters
Africa
Point-of-use
WASH
Water quality
Household water treatment
POU
HWT
Complex systems
Developing country
ECD

ABSTRACT

Ceramic water filters (CWFs) are a point-of-use water treatment technology that has shown promise in preventing early childhood diarrhea (ECD) in resource-limited settings. Despite this promise, some researchers have questioned their ability to reduce ECD incidences over the long term since most effectiveness trials conducted to date are less than one year in duration limiting their ability to assess long-term sustainability factors. Most trials also suffer from lack of blinding making them potentially biased. This study uses an agent-based model (ABM) to explore factors related to the long-term sustainability of CWFs in preventing ECD and was based on a three year longitudinal field study. Factors such as filter user compliance, microbial removal effectiveness, filter cleaning and compliance declines were explored. Modeled results indicate that broadly defined human behaviors like compliance and declining microbial effectiveness due to improper maintenance are primary drivers of the outcome metrics of household drinking water quality and ECD rates. The model predicts that a ceramic filter intervention can reduce ECD incidence amongst under two year old children by 41.3%. However, after three years, the average filter is almost entirely ineffective at reducing ECD incidence due to declining filter microbial removal effectiveness resulting from improper maintenance. The model predicts very low ECD rates are possible if compliance rates are 80–90%, filter log reduction efficiency is 3 or greater and there are minimal long-term compliance declines. Cleaning filters at least once every 4 months makes it more likely to achieve very low ECD rates as does the availability of replacement filters for purchase. These results help to understand the heterogeneity seen in previous intervention-control trials and reemphasize the need for researchers to accurately measure confounding variables and ensure that field trials are at least 2–3 years in duration. In summary, the CWF can be a highly effective tool in the fight against ECD, but every effort should be made by implementing agencies to ensure consistent use and maintenance.

* *Corresponding author*. Current address: Department of Chemical & Environmental Engineering, Yale University, P.O. Box 208286, New Haven, CT 06520-8286.
E-mail address: jem3w@virginia.edu (J. Mellor).

0043-1354/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.watres.2013.11.035

1. Introduction

Early childhood diarrhea (ECD) is a scourge that kills an estimated 1.6 million children worldwide each year and is a problem that is largely due to poor access to water, sanitation and hygiene (WASH) infrastructure (WHO, 2006). This problem is further exacerbated by the fact that water frequently becomes contaminated after collection but before consumption in many developing world countries (Wright et al., 2004) limiting the ability of community safe water sources to prevent ECD. This is a particular problem for households who must travel long distances to collect water (Mellor et al., 2012b). This is why many have advocated for the use of point-of-use water treatment devices as a means of improving health (Clasen, 2010). Biosand filtration (Tiwari et al., 2009), solar disinfection, and chlorination (Arnold and Colford, 2007) have all shown promise as means of improving household drinking water quality. Ceramic water filters (CWFs) are one such technology that can be produced in local communities using methods and materials that do not need to be imported and are an environmentally sound technology (Ren et al., 2013). They have been shown to be a highly effective means of removing *Escherichia coli* and other pathogens in controlled environments (Brown and Sobsey, 2010) and are typically impregnated with colloidal silver (Oyanedel-Craver and Smith, 2008). They have been shown to be effective at removing *E. coli* and total coliform in the field (Kallman et al., 2011) and at reducing ECD incidence (Fewtrell et al., 2005).

Despite this promise, most recent research has suggested that the evidence in support of point-of-use treatment technologies might be subject to recall bias since few studies have been blinded (Schmidt and Cairncross, 2009). Other researchers have found that factors including duration of follow-up and blinding were significant predictors of intervention effectiveness and that point-of-use water treatment device interventions would decline in effectiveness over time (Hunter, 2009). Blinding is important because of the courtesy bias that can be associated with the provisioning of useful products to research participants which can bias their reported disease rates. Enger et al. (2012) used a quantitative microbial risk assessment (QMRA) model to find that there are diminishing returns for improved log reduction efficiency in point-of-use water treatment devices when they are not used consistently, and that log reduction values above 2 generally prevented little additional diarrhea assuming 80% compliance. Other researchers have seen microbial effectiveness declines over time (Kallman et al., 2011) and that there can be contamination problems in the lower reservoir of CWFs due too poor maintenance (Lantagne, 2001).

Two studies have been conducted recently to understand realistic water filter compliance in the field. In the first paper Brown et al. (2009) found a linear decrease in use of the filters of approximately 2 percentage points each month. They also found that the odds ratio for using a filter was 1.7 when study participants were collecting surface water compared to 0.56 when using ground water which is of presumably better quality. A second study by Casanova et al. (2012) found that study participants were almost twice as likely to use their CWF when *E. coli* were present in the water. They likewise found that those with tap water were less likely to use the filters compared to those who used well water exclusively.

A final component essential for long-term sustainability is a willingness to pay (WTP) for new water filters after a filter breaks. Given that more than ~12% of filters can break over the course of a year (Brown et al., 2009), it would be desirable to have replacement filters available for purchase. However, it is unclear how much households might be willing-to-pay for new filters (especially if they were free initially) and how the availability of filters for purchase might affect ECD incidences.

A novel means of studying WASH interventions in resource limited-settings are agent-based models (ABMs) (An, 2008). ABMs are models that can be useful for understanding *complex* systems. They have previously been used to study schistosomiasis transmission (Hu et al., 2010), water usage in U.S. and Dutch households (Linkola et al., 2013), the impact of upstream water management on downstream agriculture in Thailand (Becu et al., 2003) and domestic water management in Spain (Galán et al., 2009). Coupled approaches have also been used to study subsistence farming, land cover and hydrology (Bithell and Brasington, 2009). The ABM technique is therefore an ideal tool to study the complex WASH system found in many developing world communities. This sort of analysis compliments intervention-control trials because such trials look at interventions in isolation, are susceptible to differences in intervention quality and are subject to large heterogeneities due to the difficulties of using self-reported ECD as an indicator of poor drinking water quality (Schmidt et al., 2011). Furthermore, it is clear that ECD is due to multiple technological, environmental and behavioral factors (Ezzati et al., 2005) leading some to suggest that systems approaches are preferable (Eisenberg et al., 2012).

Given the questions surrounding the ability of CWFs or any other point-of-use water treatment technology to effectively reduce ECD rates in the long term, there is a clear need to better understand the complexities of point-of-use water treatment technologies in a realistic setting. Therefore, the goal of this project is to investigate the role of factors affecting the imperfect use of CWFs in preventing early childhood diarrhea using an extension of an ABM described previously (Mellor et al., 2012a). This extension is based on three years of follow-up field data about filter microbial removal effectiveness, compliance and breakage. Specifically, the following factors were investigated to understand their relation to the outcome metrics of household drinking water quality and ECD rates:

- Filter prevalence
- Filter compliance
- Effects of measured declines in microbial removal effectiveness over time
- Filter breakage percent
- Filter breakage date
- Filter cleaning interval
- Filter microbial removal effectiveness
- Linear decreases in compliance over time
- WTP for new filters
- Perceptions of water quality and filter compliance

This study therefore helps implementing agencies improve CWF interventions, attempts to answer open research