Social Acceptance and Feasibility of Household Water Treatment Technologies: Implications for the MadiDrop in Rural, Low-Income Communities

(Technical Paper)

University of Virginia North Grounds Campus Rivanna Stream and Trail Restoration Project with Biohabitats, Inc.

(STS Paper)

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

The World Health Organization (2019) estimates that between 2 and 4 billion people do not have access to safe water for drinking and sanitation purposes. Large numbers such as these are hard to conceptualize, desensitizing humans to the physical and psychological stresses experienced by those lacking access to basic services and the collective needs all humanity shares: a habitable planet with sustainable freshwater resources. Water can be compromised with several different contaminants, including viral and bacterial pathogens that cause waterborne illnesses and lead to symptoms like diarrhea, which is the second leading cause of death in children under the age of five (World Health Organization, 2017). As the world population continues to increase (especially in regions with lower gross domestic product per capita), the number of individuals affected by insufficiently treated water increases as well (Roser et al., 2023).

Clean water access around the world varies for several reasons, such as affordability, accessibility, and quality of the water. In high-resource, urban regions, it is standard practice to implement centralized water treatment facilities; however, in under-resourced regions, particularly rural areas, centralized systems are less common due to a variety of factors. These factors include economy of scale, funding availability (including continued investment in infrastructure), and the strength of governance. Alternative decentralized water treatment methods suggested by the World Health Organization (2019), such as household water treatment (HWT) technology, play a crucial role in filling a gap in access to safe drinking water. In low resource regions without centralized water treatment systems, HWT technologies are an economic and user-friendly alternative and treat water at the household level directly before consumption. Chemical disinfection is one type of HWT that chemically reduces the number of smaller, harmful microorganisms in the drinking supply (*Chemical Disinfectants*, n.d.). The Water Quality Laboratory at the University of Virginia created the MadiDrop, a small ceramic tablet used in 10-20 liters of water that releases silver nanoparticles for disinfection (*MadiDrop*, n.d.). Chlorine is more commonly used for disinfection in low-cost settings, but it can change the odor and taste of the water and produce harmful byproducts, making it less desirable (Lantagne et al., 2010). Studies conducted in the lab have shown that the MadiDrop can function at a 3-4 log reduction of coliform bacteria, a bacterial pathogen, but has little effect in viral pathogen removal (Hill et al., 2020).

The STS project will be conducted using a method of Biography of Artifacts and Practices (BOAP), as well as some components of Ethnography by finding product reviews of the MadiDrop or speaking with community members who have used the product. The end goal of the project is to be able to make recommendations to the producers of the MadiDrop to advise any changes or developments in the technology to improve their acceptance in communities worldwide.

My technical project for this senior thesis is separate from the STS thesis topic. Our Capstone team, the University of Virginia (UVA) Stream Restoration Capstone Group, is working in conjunction with an environmental consulting firm called Biohabitats, Inc. to assess an unnamed tributary stream to Meadow Creek located in Albemarle County and the City of Charlottesville. This assessment will allow us to compose a design proposal to restore and remediate the erosion, pollution, and stress imposed by nearby human development on the stream. Our research and design will also provide insight into cost and pollution reduction credit opportunities for UVA.

Technical Topic

The UVA Stream Restoration Capstone Group is working in conjunction with Biohabitats to assess an unnamed tributary stream to Meadow Creek located in Albemarle County and the City of Charlottesville. This assessment will allow us to compose a design proposal to restore and remediate the erosion, pollution, and stress imposed by nearby human development on the stream. Our research and design will also provide insight into cost and pollution reduction credit opportunities for UVA. The stream itself is 5,000 feet long, running parallel to the US 250/Route 29 bypass, located near UVA's North Grounds, and contains a portion of the Rivanna Trail. These attributes make it an important waterway to protect.

The UVA Capstone group will focus on two specific reaches for their project: Reach 3 and Reach 5. These reaches were chosen for their large credit contributions, if addressed. Because the budget is reliant on external factors, such as receiving grant funding, the project will be broken into stages, with preliminary design as the first step. The design of these two reaches will be the task of the UVA team to analyze and create. Reaches 3 and 5 are tributaries to the stream fed by culverts running under the US 250/Route 29 Bypass. These reaches are of particular interest because we have concern about the influence of increased flow contributions on sediment load and phosphorus and nitrogen concentrations. Therefore, our research and design will be primarily centered around Reach 3 and Reach 5.

A Hydrologic and Hydraulic (H&H) Analysis will be performed on these two reaches, which will involve the development of a HEC-HMS model and a HEC-RAS model. Furthermore, on-site cross sections will be taken for both reaches to augment the data necessary for the HEC-RAS model. The team will collect water quality grab samples (analyzing TSS, total phosphorus, and nitrate concentrations) in dry weather and wet weather to set a baseline for the site. Samples will be collected within each reach and upstream of each reach in the main stream. Furthermore, during the winter, we will analyze chloride concentrations to determine the influence of salting the roads for de-icing on this tributary stream.

We will address the results of the H&H analysis and the water quality levels by developing a restoration design for the degraded outfalls from the US 250/ Route 29 Bypass. The design components will address the sediment load, nutrient concentrations, salinity level, and embankment erosion concerns. Also included within our scope is a restoration design of the Rivanna Trail and rerouting the trail during the construction process. Lastly, our scope includes the calculation of VA Sediment and Nutrient Credits to be allocated to UVA as a result of the restoration of the stream. These credits are classified under MS4 and TMDL credits for the university. Along with this, we will perform a cost analysis for the work budget compared to the Sediment and Nutrient Credits attained.

STS Implication

The objective of this study is to answer the question of why HWT technologies, specifically the MadiDrop, are not readily welcomed by some communities, South Africa in particular, or "how does the design of HWT technologies impact their acceptance in high-risk communities?" Without direct access to the user population, this thesis will be conducted by reviewing published literature about social acceptance of other HWT technologies and evaluating how the community's reasons for their reservations about their usage can be applied to the MadiDrop. Another component to the thesis will be reviewing literature about chemical disinfection, HWT in general, and the usage of HWT in regions of South Africa.

HWT technologies aim to provide safe drinking water to populations globally. One of the main threats to safe drinking water is harmful contaminants that can impact the health of the consumer. Children under the age of five are at the most risk for severe health implications because of waterborne illness, as it is the second leading cause of death for that age group (World Health Organization, 2017). The hardest part to grasp is its easy prevention by maintaining good water treatment and storage practices. Creating a device that is effective in disinfecting pathogenic microorganisms is a difficult task that has already been achieved in multiple ways. There are chlorine tablets, silver-impregnated filters, the MadiDrop, activated carbon flocculation devices, etc. Each of these technologies holds a variety of characteristics that are either appealing or dissuading to high-risk communities. Therefore, the next step for researchers involved with HWT and global public health is to address community concerns regarding the properties of these technologies and adapting them to maintain their efficacy while becoming more acceptable to the user. Concerns like the change in taste and smell of water or even the color of the tablet have kept some consumers from using these life-saving devices.

Like most technologies, especially those with global implementations, there are politics associated with the device. The inherent politics associated with MadiDrop are in its very design. The shape of the MadiDrop is a simple white rectangular prism. In previous versions of the MadiDrop, it was circular, powdered, and/or brown in color. The motivation for changing the shape and color of the MadiDrop was social acceptance in and of itself. I spoke to Dr. Sydney Turner (researcher of the MadiDrop in the Water Quality lab at UVA) about the adaptation of the design throughout the years. She told me that community members using the product felt uncomfortable putting a brown tablet or clay powder into their clear, seemingly “clean” water. The MadiDrop is best used in clear or “clean” water because its purpose is to disinfect and inactive pathogenic microorganisms that are invisible to the naked eye. To gain trust and increase usage and acceptance, the design of the MadiDrop changed and became a crisp white color and simple rectangular shape. The design was much more welcomed in homes and the efficacy of the tablet was not sacrificed to do so. Testimonies from communities globally advocate for some acceptance of the device as well as its functionality: "The MadiDrop was well-received by the community and its price point is not a hurdle," (Dr. Barry Bialek, Doctors Without Borders (Ethiopia), MadiDrop)

This project is important for providing clean water to communities globally. The access to these treatment technologies has been addressed already, and they are made to be low-cost and user-friendly to accommodate this. However, unless the user accepts the technology and uses it properly, there will still be a gap in access to clean water. The project aims to help groups that live in rural or low-resource areas that lack a centralized water treatment infrastructure. However, certain regions with a centralized system are still consuming water that is not treated to WHO standards and could benefit from the use of these tablets. These tablets are low-cost, but not free, and those without the ability to purchase one could suffer without it.

The STS methodology of BOAP within the concept of theory-methods package will be extremely relevant for this project. Most of the analysis for the STS component of this project will be reading previous literature of other HWT technologies in other regions of the world, then taking the feedback provided by the paper and using it to influence the design proposal of the MadiDrop. BOAP methodology focuses on allowing the social implications influence the design of a technology. The goal of the study is to increase social acceptance of a technology as much as possible, and where it is feasible, receive direct consumer feedback. Therefore, the consumer evaluation of these products will directly contribute to the proposed improved design of the MadiDrop tablet.

Thesis Timeline

Technical Project:

- October 2023 – begin testing MadiDrop (silver release rate), compile data and research published about the MadiDrop.
- November 2023 – write first draft of technical topic report for prospectus.
- December 2023 – review and submit technical topic report for prospectus.
- January – continue testing and researching the MadiDrop, wet lab experiments and literature reviews.
- February – write up synopsis of MadiDrop and determine correlation to other HWT technologies that have been reviewed for social acceptance.
- March – analyze literature and start thinking of recommendations for MadiDrop to be more accepted into communities, begin creating prototype.
- April – first draft of sociotechnical report, peer review and edit, finish prototype.
- May – submit and publish sociotechnical thesis, present findings to MadiDrop board.

STS Project:

- October 2023 – first draft of the prospectus, get it reviewed, peer edited.
- November 2023 – revise prospectus, continue research on other HWT technologies and their social acceptance.
- December 2023 – submit prospectus.
- January – compile resources used for history of HWT, the MadiDrop, South Africa water situation, and case studies on user preference on HWT technologies.
- February – begin sociotechnical thesis draft.
- March – finish first draft of sociotechnical thesis.
- April – peer review of sociotechnical thesis and final edits.
- May – submit and publish sociotechnical thesis, present findings to MadiDrop board.

Key Texts

A preliminary review of publications that would contribute to the literary review of HWT technologies and their acceptance was conducted. Below are some of the key citations that will be utilized for the project:

- Albert, Jeff, Jill Luoto, and David Levine. "End-User Preferences for and Performance of Competing POU Water Treatment Technologies among the Rural Poor of Kenya." *Environmental Science & Technology* 44, no. 12 (June 15, 2010): 4426–32. https://doi.org/10.1021/es1000566.

This study will be extremely helpful for analyzing reasons for why certain HWT treatment technologies are not accepted by all communities. The survey study is conducted in Kenya, another African country. The study explores three different types of water treatment technologies: chemical disinfection, flocculant disinfection, and filtration and chemical disinfection combination. At the end of the study, it was reported that subjects prefer filtration and chemical disinfection combination, even though it had the worst log reduction performance of the three technologies. Reasons for this could include the change in taste because of the chemical disinfection alone (the chemical chosen for this was a hypochlorite as opposed to silver in the filters). Chlorine is known for changing the taste and smell of water, while silver does not. Additionally, the filter can produce water that has a much lower turbidity than any of the other technologies. Aesthetics play a large role in user preference for water treatment technologies.

- Bhardwaj, A. K., Sundaram, S., Yadav, K. K., & Srivastav, A. L. (2021). An overview of silver nano-particles as promising materials for water disinfection. *Environmental Technology & Innovation*, *23*, 101721. https://doi.org/10.1016/j.eti.2021.101721

In this study, authors prove the efficacy of silver-nanoparticles in their disinfection capabilities. It will be a good study to use in my capstone to show the functionality of the chemical in water treatment technologies. Additionally, it provides a comprehensive review of the feasibility of silver nanoparticles as a mechanism for water disinfection. Household water treatment technologies could feasibly use this mechanism to ensure it provides safe water that remains safe for consumption.

- Chen, Baiyang, Jingyi Jiang, Xin Yang, Xiangru Zhang, and Paul Westerhoff. “Roles and Knowledge Gaps of Point-of-Use Technologies for Mitigating Health Risks from Disinfection Byproducts in Tap Water: A Critical Review.” *Water Research* 200 (July 15, 2021): 117265. https://doi.org/10.1016/j.watres.2021.117265.

This will be an interesting study to provide ulterior reasons for the lack of preference for HWT technologies. Disinfection byproducts are a huge topic of concern for global public health leaders, as they are unintended compounds produced by disinfection chemicals. Most HWT technologies incorporate some kind of chemical for disinfection, whether it be chlorine, silver, copper, etc. The MadiDrop uses silver nitrate to release silver ions into the water to disinfect the microorganisms present. Evaluating the health risks associated with the release of silver will be another aspect to explore to make the MadiDrop the most desirable, both by community members as well as public health scientists.

- Daniel, D., Marks, S. J., Pande, S., & Rietveld, L. (2018). *Socio-environmental drivers of sustainable adoption of household water treatment in developing countries*. *1*(12). https://doi.org/10.1038/s41545-018-0012-z

This study provides the opportunity to explore other drivers for social acceptance of household water treatment technologies. One of the other motivators for their adaptation into communities is their economic feasibility and sustainability. As mentioned previously, one of the main motivators for household water treatment is providing safe drinking water at a relatively low cost compared to that of water distributed from municipalities. Another component of the economic analysis that can be performed on the MadiDrop is the economic benefits it provides at the avoidance of expensive medical care as a result of a consumer contracting a waterborne illness. Untreated water can cause serious illness in a consumer, especially younger children with weaker immune systems, and the price of consulting a physician to treat the symptoms (if available) can be costly.

- Figueroa, M. E., & Kincaid, D. L. (2010). Social, Cultural and Behavioral Correlates of Household Water Treatment and Storage. *The Johns Hopkins Bloomberg School of Public Health Center for Communication Programs*.

This publication from Johns Hopkins University evaluated the social, cultural, and behavioral components that play into HWT and storage. This will be crucial information to know when considering any adjustments in the design elements. Right now, the MadiDrop is simple to use, compact, and inexpensive. Adjusting any of these elements at the expense of another could impact the acceptance of the product, especially if it affects the social or cultural norm of the user.

- Hill, Courtney L., Kelly McCain, Mzwakhe E. Nyathi, Joshua N. Edokpayi, David M. Kahler, Darwin J. Operario, David D. J. Taylor, et al. "Impact of Low-Cost Point-of-Use Water Treatment Technologies on Enteric Infections and Growth among Children in Limpopo, South Africa." *The American Journal of Tropical Medicine and Hygiene* 103, no. 4 (October 7, 2020): 1405–15. https://doi.org/10.4269/ajtmh.20-0228.

This study focuses specifically on the impact HWT technologies have impacted communities in one province in South Africa. This will be another key component to my prospectus, as it focuses specifically on the region I am studying: South Africa. The study reviews the health impacts that these technologies have on enteric infections and the reduction of them in children. Disease prevention and the improvement of global health are two of the main goals of these water treatment technologies and it will be useful to be able to evaluate just how much it is doing. However, advertising and promoting these technologies for their scientific soundness will be more difficult than just stating it. This plays into the social acceptance and the STS component of the thesis project.

- Tamene, Aiggan. "A Qualitative Analysis of Factors Influencing Household Water Treatment Practices Among Consumers of Self-Supplied Water in Rural Ethiopia." *Risk Management and Healthcare Policy* 14 (March 16, 2021): 1129–39. https://doi.org/10.2147/RMHP.S299671.

This study will be a great foundation for understanding user tendencies. User trends are a huge component in the design of HWT technologies. A technology can be designed to be used in one way, but users (for various reasons) might not follow the instructions perfectly. Whether it is misunderstanding, miscommunication, or laziness, a certain degree of safety must be incorporated into the design to protect the user at all costs. Additionally, creating a product that is as user friendly as possible without compromising effectiveness is the overarching goal of HWT. The above study assesses how households in rural Ethiopia treat their water before consumption or usage. These practices will give us a better understanding of how some people go about treating their water. This is not a comprehensive study of all users globally, but it does provide some real information about some consumers in the world, more specifically Africa.

- Tamene, A., Habte, A., Woldeyohannes, D., Tamrat, H., Endale, F., Eajo, T., & Afework, A. (2022). Water treatment at the point-of-use and treatment preferences among households in Ethiopia: A contemporaneous systematic review and meta-analysis. *PLOS ONE*, *17*(10), e0276186. https://doi.org/10.1371/journal.pone.0276186

This study was led by the same author as the study above, giving more insight to some preferences and practices of water consumers using household water treatment technologies. Rather than common practices of treating water in households, this paper provides information of preferences for treatment. However, this paper did not evaluate chemical disinfection in its compilatory review of treatment techniques. It can still provide valuable information for preferences of other types of treatment technologies and why some were not welcomed and why others were.

- World Health Organization. (2018). *Alternative drinking-water disinfectants: Bromine, iodine and silver*. World Health Organization. https://iris.who.int/handle/10665/260545

This last resource is from the World Health Organization (WHO), and it discusses other chemicals that can safely and feasibly be used for water treatment purposes. The mainstream, most common chemical used for treatment is chlorine, but chlorine alters a lot of the aesthetics of the water. Additionally, it can be quite hazardous if not used properly. The WHO provided a lengthy report on other chemicals that can be used for disinfection, at which quantities, and characteristics of the chemical and water after treatment.

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