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

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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

It is estimated that two billion people (26% of the world) lack access to a source of safe drinking water, and even more are threatened by waterborne illnesses. Pathogens from contaminated sources of drinking water can cause a wide range of health effects, including diarrheal disease that can be especially fatal for children (WHO/UNICEF, 2021). Household Water Treatment (HWT) technologies are a game-changing solution to provide affordable clean water. These technologies aim to purify water sources at the household level and provide safe water for families and communities (WHO, 2019). Depending on the product, HWT works by disinfecting or filtering a water source. It can safely reduce the load of pathogenic microorganisms and other contaminants, improve the turbidity of the water, and alter the aesthetics of the drinking water to be more appealing. Most HWT technologies only do one or two of these things, which can lead to the pairing of multiple technologies together for the same source of water (Albert et al., 2010). Bleach solutions, chlorine dissolving tablets, ceramic water filters, and the MadiDrop tablet are just a few examples of HWT technologies that are currently used. This paper focuses on the design and improvement of the MadiDrop, which is a ceramic tablet embedded with silver nitrate for disinfection. It treats between 10 and 20 liters of water per day, suitable for a family of four (*madidrop.com*).

There are several HWT technologies on the market. Despite their effectiveness, HWT technologies are not as easily accepted by communities as one would think. Some factors that lead to the rejection of HWT technologies include a change of taste or smell of the water (often associated with chlorine), affordability of the technology, and a lack of support from community leadership (Figueroa & Kincaid, 2010). These factors come from a variety of levels, including community, household, and individual. There are also more culture-specific factors that can cause certain HWT technologies to be rejected. This paper explores how influence from every level can impact the practice of safe HWT.

In this paper, I will provide recommendations for the improvement of the MadiDrop tablet in order to optimize the social acceptance of the technology in communities. The paper will explore the background of HWT technologies around the world, analyze older case studies investigating the acceptance of these technologies, give a brief description of the qualities of the MadiDrop tablet, analyze more recent studies about newer HWT technologies, and use the literature review to recommend improvements to the design of the MadiDrop. The current design of the MadiDrop can be seen below in Figure 1.

Figure 1. MadiDrop tablet

Biography of Artifacts and Practices (BOAP) is the framework used to analyze the sociotechnical implications of this study. Studying social acceptance of these devices in different regions can help bridge the gap between innovation and implementation.

Methods and Frameworks

This STS project is conducted using the STS framework of Biographies of Artifacts and Practices (BOAP). With BOAP framework, this paper explores how the evolution of society impacts the design of a technology used in that society or how the implementation of a certain technological design can impact a society. BOAP analyzes a technology that is up-in-coming or in the process of development by comparing it to previous developments of similar technologies. BOAP also evaluates the development of a technology over an extended time period and analyzes how society has impact the changes in design and vice versa (Hyysalo et al., 2019).

Household Water Treatment (HWT) technologies have been used in societies for over 4,000 years (Angel Water Inc, 2017). Societal desires and needs for water quality directly resulted in their development over the years. As a result, there is significant literature published about the evolution of HWT technology, as well as consumer preference feedback for several technologies used. A simple search on Google Scholar with key words such as "household water treatment," "user preference," and "point-of-use water treatment," as well as reviewing other sources cited in papers read, made gathering literature a simple process.

I performed a literature review of HWT technologies for this research paper. Most of the analysis for the STS component of this project is reading this literature and then taking the feedback provided by the paper and using it to influence the design proposal of the MadiDrop. Evaluated technologies include ceramic water filters, chlorine solutions, flocculant tablets, and combinations thereof. BOAP methodology focuses on allowing the social implications influence the design of a technology. A secondary component to this research is reviewing feedback about the MadiDrop from previous users. Consumer evaluations of these products directly contribute to the proposed improved design of the MadiDrop. This is crucial to achieve the overarching goal of improving the social acceptance of the MadiDrop among communities worldwide.

The final component of my research using BOAP framework is proposing a new design for the MadiDrop. The proposed design does not majorly change the current design, but rather finds minor ways of improving the technology's social acceptance. In order to determine improvements from a technological standpoint, I reviewed literature published about the benefits of silver nitrate versus silver nanoparticles for pathogenic microorganism disinfection, as well as the feasibility of seeding each tablet with more silver to extend its active lifetime. All of these contributions impact the final design of the MadiDrop and theoretically improves one or more aspects of social acceptance of the tablet.

Global Background of HWT Technologies

Treating drinking water has been a practice for centuries, starting with basic boiling and simple filtration and evolving to high functioning, multistage, centralized water treatment facilities (Angel Water Inc, 2017). These practices help to prevent the spread of waterborne diseases and make clean water easily accessible. However, a sizeable portion of the world (26%) lacks access to the resources or knowledge of treating their drinking water. To address this gap, the United Nations included "Clean Water and Sanitation" as Goal 6 of their 17 Sustainable Development Goals to improve quality of life on Earth (*Sustainable Development*). The United Nations reviews their progress towards each of these goals and publishes a report every year. According to the 2023 report, there has been notable progress towards the goal of universal access to clean drinking water and hygienic sanitation systems due to small achievements like a 9% improvement of water use efficiency (United Nations Department of Economic and Social Affairs, 2023, pg. 24). Despite great efforts made, we are still behind in our targeted timeline for this goal (achieve universal access by 2030). One of the strategies the United Nations recommends for a path to getting back on track for the goal is to "adopt a more integrated and holistic approach to water management," (United Nations, 2023, pg. 24). HWT technologies are one of these approaches that can bridge the gap in access to clean water.

There are several types of HWT technologies. They range from chemical disinfection to physical filtration to solar distillation. Depending on the quality of source water meant to be treated, different options are more suitable than others. For example, areas where water is treated enough to remove turbidity, but no disinfectant is added, chemical disinfection will be a sufficient technology to make the source water potable and remove pathogenic microorganisms that can cause illnesses. For a different region where the water is not treated at all, filtration is likely the best option to remove as much turbidity from the water and improve its quality. Within each type of technology, there are already several products on the market for consumers to purchase. Each product has a special recipe to make it desirable for different audiences. However, studies have shown that promoting the technology's effectiveness is not enough to convince consumers to use the product. Manufacturers must promote these technologies at a smaller scale level until the technology's usage becomes a habit in the consumer's life.

The MadiDrop Tablet: Structure, Performance, and Prevalence

The MadiDrop is a HWT technology. It is a ceramic tablet seeded with silver nitrate meant to treat 10 to 20 liters of water and continuously release silver for disinfection at safe concentrations for consumption. Each tablet is made of clay, water, and silver nitrate and fired in a kiln to incorporate it all into one piece. The tablet is wrapped in an easy-to-understand instructional paper. The process of using the MadiDrop is a simple, three-step process that involves an initial three-minute pre-rinse of the tablet, putting it in the water basin, and keeping water in it between 8 and 48 hours before use. The MadiDrop performs at a 4-log reduction of pathogens found in water sources that cause common waterborne illnesses, such as *Escherichia coliform* (*E. coli*) bacteria and *MS2 bacteriophage* virus, and a 1-log reduction of *Cryptosporidium parvum* and *Giardia lamblia* (*Third Party Testing and Verification*).

The MadiDrop works when the silver nitrate ($AgNO_3$) separates into free silver ions (Ag^+) and free nitrate ions (NO_3^-) as the tablet is submerged in water. The free silver ions are released into the water source and begin working to disinfect the microorganisms. The mode of antibacterial action for free silver ions is the accumulation of silver into the envelope of the bacteria proceeded by the splitting of the cytoplasmic membrane from the cell wall of the bacteria. In summary, this causes oxidation stress to the bacteria, damage to the DNA strands, and, ultimately, death of the bacteria cell. A figure demonstrating silver ions' mode of antibacterial action is included below in Figure 2.

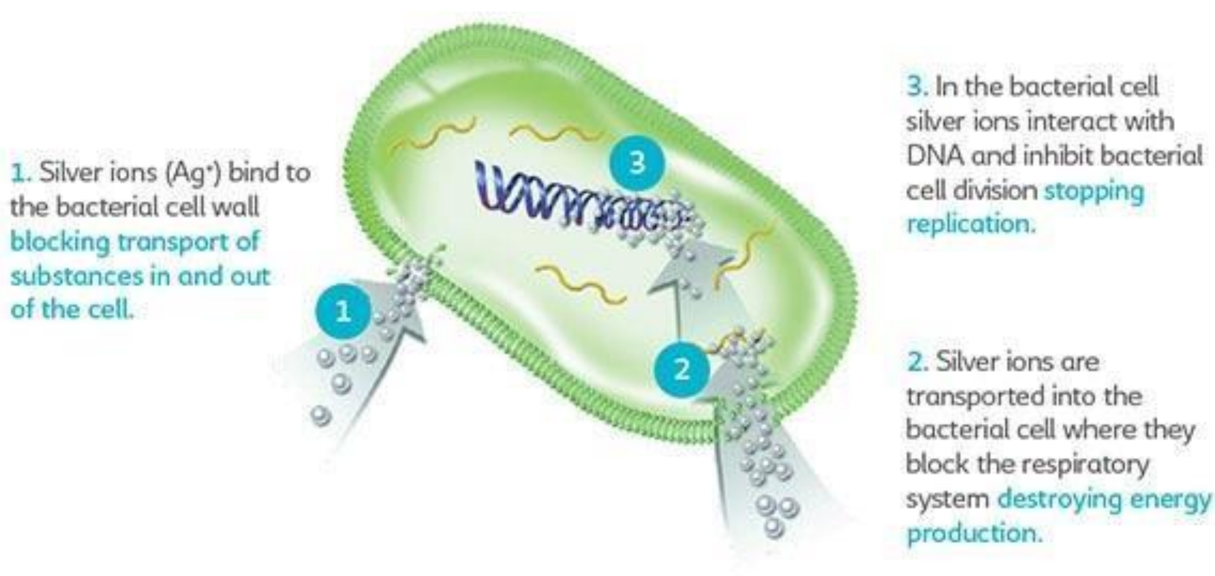

Figure 2: Mode of Action of Silver Ions Against a Bacterial Cell (Nielsen)

The efficacy of silver as a disinfectant is directly proportional to the amount of silver in the environment, meaning higher doses of silver are more effective (Kedziora et al., 2018). However, the drinking water limit set by the World Health Organization must be observed at 100 ppb (0.1 mg/L), as this water is intended to be consumed (2021). The amount of silver released by the current design of the MadiDrop is safely below this design limit and depends on how much water is being treated and how long the MadiDrop is submerged in the water.

Users from over 40 countries around the world have testified about the MadiDrop's lifesaving potential (*madidrop.com/success-stories*). Brent Buttermore, a Global Missions Pastor from Zambia, stated that "the MadiDrops we brought to this village provided close to 1.5 years' worth of clean water. As a result, 1200 people in this village are experiencing clean water for the first time! Truly amazing!" Lakshmi D. from India stated that "in Venkata Reddy Palli, we do not have good water to drink. We always fall sick from diarrhea. As soon as I received [a MadiDrop], my family started to feel better. Now we are all healthy." Even Daniel Lian, who works with a village in Nepal, discovered that,

> "The villagers generally know that they should boil or chlorinate their water, but have stubbornly refused because of the taste, temperature and/or effort needed. After 1.5 months [of using the MadiDrop], the reports are that chronic diarrhea has stopped, and the latest report yesterday is that households are now sharing with their neighbors. This is significant because it is the monsoon when there is usually greater contamination and incidence of diarrhea. It also means that the 'taste, temperature and/or effort' obstacles are being broken down, and they are spreading the word."

Aside from Zambia, India, and Nepal, the MadiDrop has been used in Nicaragua, South Africa, Tanzania, Brazil, Haiti, Guatemala, and others, extending its reach from North, Central, and South America to Europe, Africa, and even Asia (*madidrop.com*).

Previously Identified Factors to Acceptance

HWT technology manufacturers identified multiple factors that contribute to their usage at the individual level. Maria Elena Figueroa and D. Lawrence Kincaid published a manuscript titled "Social, Cultural and Behavioral Correlates of Household Water Treatment and Storage" that compiled data from several studies about factors impacting the safe practices of HWT (2010). The first factor regarding acceptance is the use of these technologies by the broader community. Multiple studies found that Bounded Normative Influence Theory can explain one way in which a practice can become a norm, meaning entire communities need to buy into the HWT practices for it to be effective and functional (Kincaid, 2004). It is necessary for these communities to overcome the preconceived notion that water safety and hygienic habits are personal and private issues managed by each household, and "are not a common concern," (Yeager, et al. 1999, p. 538). Similarly, promotional advertisements have been shown to improve the usage of HWT technologies. Effective platforms include mass media, educational entertainment, and even word of mouth (Waterkeyn & Cairncross, 2005; Ahmed, 1998.; Thevos et al. 2000). With these advertisements communicating the effectiveness of HWT, the acceptance of the technology improves drastically. Finally, global advocacy groups (such as the International Network for Household Water Treatment and Safe Storage) publishing papers about the importance of treating drinking water is one way to reach local leaders and improve usage rates within a community (*The HWTS Network*). However, improving usage rates is easier said than done. Obstacles to a HWT technology's acceptance come from a range of sources at various authoritative levels.

Individual

Personal factors can lead to the acceptance or rejection of the usage of the HWT technology. One factor is the level of education in the household (Underhill, 2006). Knowledge – or lack thereof – of how the technology functions can lead to rejection of the technology. Some preconceptions about HWT are that chlorine is harmful or that clear water is always safe. With proper education, consumers would know that neither of these statements is necessarily true. Chlorine in regulated doses is safe to consumers and clear water can still be contaminated with pathogenic microorganisms. Another factor at the individual level is personal beliefs about certain technologies, expectations, and societal norms (Fishbein & Ajzen, 1975). Personal beliefs and preconceptions are difficult to change, even if it is for the improvement of health. Similarly, personal preferences and initial reactions to changed behaviors impact the usage of HWT technology (Zajonc, 1984). Finally, personal trust with the entity advocating for the change of behavior and the associated credibility with that entity can lead to a technology's acceptance or rejection (Rogers, 1959; Batson, 1994; Slater and Rouner, 1996; Hovland et al., 1953)

Household

The next level of factors is at the household level, where all family members are considered. At this level, factors that are considered include the amount of time required to perform the same function with a changed behavior (Acton, 1975; Grossman, 1972). An example of this would be a ceramic water filter that takes up to 8 hours to filter 10 liters of water. Experts recommend this over just boiling the water, though boiling is much faster. An advantage of using a ceramic water filter is the removal of turbidity and often disinfection, as most ceramic filters contain disinfectant components such as silver. Boiling only reduces the microorganism load in the water and does not address turbidity. However, time intensive activities can prevent some practices from being a feasible option in some households. Another household factor is the beliefs and preferences of the other household members (Grossman, 1972; Figueroa, 1996). Finally, the income and resources available per household, as well as the discretion of the authoritative figure of the home, impact the usage of HWT technologies (Haddad & Hoddinott, 1991; Haddad, et al., 1992).

Community

The final level is community, and factors could be equal access to informational, educational, and health resources to its population (Carnegie, et al., 2000; McKee, et al., 2000). This factor impacts factors at the smaller levels, such as education at the individual level or affordability at the household level. Community support can make a huge difference in the usage of HWT technologies. Another impact of acceptance that is at the community level is managing the social capital in deciding which external authorities or experts to trust (Lin, 1999). The allegiance of local community leaders to external figures heavily influences the trust and perceived credibility of those external figures with the rest of the community.

Field Studies Reviewing Specific HWT Technologies and User Preferences

The first study was conducted in Kenya and evaluated both the performance and user preference of three HWT technologies: a ceramic water filter, a hypochlorite solution (WaterGuard), and a powdered disinfectant flocculant (PUR). The study found that users preferred ceramic water filters because they were easy to use, cleared turbidity, made the water taste and smell better. In addition, the lifetime of the filters was much longer compared to the other two technologies; The WaterGuard and PUR have a 6-month lifetime. Users also mentioned disliking PUR and WaterGuard because of the questionable taste and odor from the chlorine addition to the water, their difficulty to use, their inability to remove turbidity, and the length of time they require to treat the water. Despite all of these things, the WaterGuard had higher usage rates and performed superiorly against *E. coli* (Albert et al., 2010). Key takeaways from this study are that aesthetics of the water, simplicity of the technology, and the lifetime of the HWT technology are significant factors for the consumer.

The second study was conducted in Ethiopia. It evaluated the specific influences that impact the choices in practicing safe water treatment with HWT technologies. The study revealed there are several misconceptions regarding water safety and human health that are preventing consumers from using the water treatment devices properly (Tamene, 2021). These statements were:

- Filters are too slow to support the family's water needs
- After the age of two, it is safe enough and the children are old enough to drink untreated water.
- The number of illiterate community members makes communication very difficult.
- The only protection they need is God.
- Strong folks are safe from 'unclean water.'
- There are herbaceous medicines that cure any diseases. There's no need to worry.
- Shame comes from neighbors on households that treat their water.
- Chlorinated water tastes and smells wrong and doesn't quench thirst.
- Boiled water tastes flat.
- There is a severe lack of trust in the government for good reasons after decades of deceit and conflict.
- The cost of fuel for constantly boiling water is incredibly high and unaffordable.
- The control of household money is held by one person, and they can choose not to invest in treating water, despite what other household members would prefer.
- The treatment devices are hard to get a hold of, often located in bigger superstores, not out in rural areas where they are needed most.
- Free samples of products made the community dependent on handouts.

The standard for clean water was very low for this village in Ethiopia. If the water didn't make you sick and there was nothing floating in the cup, the community would drink it. This misconception resulted from individual, household, and community factors. The primary reasons were the lack education (resulting in a lack of awareness of waterborne diseases and their causes), personal beliefs about the product or water treatment practices, lack of trust in authority, affordability, and minimal public advocacy (Tamene, 2021). This study demonstrated that community acceptance is crucial for individual usage, affordability is a huge factor in accessibility, and correcting beliefs about water safety can bring in more users of HWT technologies.

The final paper was written by Maria Elena Figueroa and D. Lawrence Kincaid in 2010. The paper was a literature review that summarized the HWT perceptions of other studies. One study concluded that people did not think there were always health benefits with water treatment. Another stated that some believe other motivations to treat water were to help with digestion, help after illness was contracted, warm the water, or establish a higher status in the community. A third community believed that diarrhea was not necessarily a bad thing, was not related to hygienic practices, and could even be beneficial for children growing up. A final study concluded that most water treatment is not adequate enough anyways (Figueroa & Kincaid, 2010). This last statement is not entirely incorrect, and actually supports the notion to practice HWT treatment is a secondary safety measure to ensure clean drinking water.

Taking these insights, Figueroa and Kincaid provided a summary of recommendations to improve the acceptance and proper usage of HWT technologies around the world. They believe that promotional advertisement of water treatment is crucial, as changing water treatment habits is difficult to convince the consumer to do. Along with this, water treatment programs and community resources have to work in conjunction to make the behavioral change become a new norm. Additionally, intervention studies are not conducive to producing sustainable habits to maintain the desired health outcomes of the changed treatment behavior. The length of an intervention study is too short to establish a new routine, and there is a high risk of improper or terminated usage once the study concludes. It is also important not to isolate water as the only source of pathogenic microorganisms that threaten public health (Figueroa & Kincaid, 2010). It would be devastating to convince a community that clean water correlates to the elimination of disease. Without safe hygiene, sanitation, and storage practices, the risk of contracting a disease is still high. These are all recommendations taken into consideration for the proposed design of the MadiDrop tablet.

Current MadiDrop Design and Field Study Findings

The MadiDrop is just one example of a HWT technology that can improve by taking this feedback. It has even been tested in a field study in South Africa. The study explored user preferences of the MadiDrop compared to a ceramic water filter and a ceramic filter and MadiDrop combination. Feedback from consumers showed that ceramic devices (both the MadiDrop and the filters) were preferable over other HWT technologies consumers had used in the past. They improved the taste and smell of the water due to the natural aesthetic of the ceramic. Despite their efforts, users often failed to practice safe storage. Over 30% of households never cleaned their water storage containers, which put the water supply at risk for recontamination. Failing to clean storage containers can also lead to odd smells and tastes of the water. Users even provided some critiques about the MadiDrop tablets. The volume of water that the tablet is able to treat (10 to 20 liters) was too small to be desirable. Due to the limited quantity of treatable water, consumers were not willing to pay more than $4.25 USD per year for a tablet (Ehdaie et al., 2017). The current cost for a single MadiDrop on the official website is $14.95 plus shipping (*Buy MadiDrops Now*).

The benefits of the current design of the MadiDrop are numerous. For starters, silver does not change the smell or taste of the water like chlorine does. Almost every study that evaluated chlorine-incorporating technologies mentioned user dislike of the change in taste and smell of the water. Also, silver is particularly effective against bacteria and good against viruses. A 4-log reduction of *E. coli* bacteria and *MS2 bacteriophage* virus equates to 99.99% elimination of the pathogenic microorganism (*Third Party Testing and Verification*). The simple design of the tablet is appealing to consumers. Previous designs of the MadiDrop were a reddish, orange color or circular in shape and consumer feedback described aversion to using the tablets because they did not look clean. An illustration of the progression of the MadiDrop design is shown in Figure 3 below.

Figure 3. Evolution of the MadiDrop's Design (Wren, 2017)

When the MadiDrop is shipped, it is wrapped in an informational paper with pictographs to make the instructions of use easy to understand. The MadiDrop is also nonperishable, meaning it has an unlimited shelf life that allows for indefinite storage until usage (*Inventive Water Disinfection Tablet*). This helps the product to be shipped in large quantities around the world without worrying about it going bad before it can be used.

The current design of the MadiDrop does have limitations that could be improved. It cannot address turbidity issues in a water supply, as it does not incorporate a filtering component. Turbidity is one of the main reasons for people not to trust water because of how dirty it makes the water look. Additionally, the MadiDrop is made of natural materials, but with that comes a margin of error built into the design. This causes some unpredictability of silver release rates, implying that on a day-to-day basis, the silver levels could be slightly higher or lower than expected. However, the manufacturers of the MadiDrop aim to account for this in order to protect the consumer from high levels of silver. The MadiDrop is also less effective against viruses than bacteria, but the option to add a copper mesh is being explored now and has shown positive results. Finally, as mentioned in consumer feedback from the South Africa field study, the MadiDrop is limited to treating 20 liters of water per tablet per day. This is enough to sustain a small family, but it is unable to accommodate higher demands alone. Consumers with a higher water quantity demand can use multiple MadiDrop tablets, but that increases the cost of use.

Recommendations to Improve MadiDrop Design

For starters, the board of MadiDrop must take more drastic measures of outreaching to communities directly. Advocating for the product and spreading information to these smaller groups will improve their acceptance on a large scale. This could be done by employing local workers, providing advertising resources to these regions, as well as fiscal support for their public advocacy efforts. For specific product adjustments, the following recommendations are taken directly from consumer feedback about the MadiDrop, aiming to improve aspects of the tablet that are currently of concern for users. The hope with these alterations is to improve the MadiDrop's usage and acceptance by making the tablets more to the liking of the consumers who will actually be using them.

A potential improvement to the MadiDrop could be switching from silver nitrate ($AgNO_3$) to silver nanoparticles for disinfection. For one, silver ions react with chlorine ions to create an insoluble precipitate ($AgCl$) that decreases disinfection performance (Kedziora et al., 2018). Chlorine is not the only chemical that reacts with free silver ions. Carbon trioxide, hydroxide, bromine, and iodine all react to create precipitates that can reduce disinfection performance (*Silver Precipitates*). This presents a problem for any water that contains traces of these elements, which can happen in areas with any degree of primary water treatment. Silver nanoparticles do not react the same way to free ions of other chemicals. If a silver nanoparticle solution could be made and painted onto the tablet and allow the tablet to sit at the bottom of the basin, there could still be a high level of disinfection without the risk of reaction with other constituents in the water. Silver nanoparticles work most effectively by increasing the exposed surface area of the compounds as much as possible (Kedziora et al., 2018). The greater surface area of silver nanoparticles allows for more interaction with microorganisms and can improve disinfection rates (Almatroudi, 2020). There is no literature published that compiles data about the relative costs of silver nitrate versus silver nanoparticles and exploration into the cost benefit is an important consideration. If there is a cost reduction in the use of silver nanoparticles over silver nitrate, the price per tablet could be reduced and allow for more accessibility worldwide.

Another idea that could improve the acceptance and usage of the MadiDrop globally is exploring a way to embed more silver in each tablet, either to treat bigger quantities of water or to increase the active lifetime of the tablets. Applying more silver into the tablet could either release more silver on a daily basis or extend the number of days the MadiDrop could effectively function. I do not know which it would do, and without testing I will not know, but I think it could be a worthwhile study to explore. If it raised silver concentrations on a daily basis, the MadiDrop manufacturers could produce two types of MadiDrops: one that treats 10 to 20 liters of water and another that treats 20 to 50 liters of water. If the other outcome occurs, where it releases the same rate of silver on a daily basis, they could calculate the average grams of silver released into the water daily and calculate the number of extra days the water could be treated.

My final recommendation for the improvement of the MadiDrop is more advocacy and advertising. Public advocacy in local communities goes a long way in the acceptance of a technology. If the MadiDrop could outreach to local leaders and provide content to put in mass media (i.e. ads in newspapers or posters in convenience stores). This could have the greatest impact in communities that need HWT technologies the most. Similarly, collaboration with local governments and revered community organizations or leaders would establish credibility within the community. Simply donating MadiDrops or performing short-term intervention studies does not establish a routine to use the HWT technology properly. Without proper and continuous usage, the MadiDrop cannot function to its full potential.

Conclusion

HWT technologies save lives, but getting people to use them is difficult. Factors like personal education levels, household beliefs, preconceptions, and community norms all play roles in whether or not a technology is adopted by a community. In order to improve the proper and continual usage of HWT technologies (particularly the MadiDrop), a bond of trust must be established between the local leadership, the user, and the manufacturer. Certain design parameters can ensure consumer satisfaction with the product. Parameters like the smell and taste of the water product, cost of the technology, and simplicity to use matter in the long run. The MadiDrop is a HWT technology that has been developing for over a decade. The manufacturers of the tablet have taken in feedback from consumers about the design and improved the tablet to the best of their ability. Improving aspects like the cost per unit, method of antimicrobial treatment, concentrations of silver, maximum quantity treated, active lifetime of the tablet, and the partnerships within local communities are just a few other recommendations that could take this product to the next level in its global footprint. There are two future studies that I think could be notable and result in important findings. The first future study is observing the impact on silver release if the silver concentration of the MadiDrop were to increase during the seeding process. The second study would be to identify the comparative performances of silver nitrate and silver nanoparticles as well as a cost analysis between the two.

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