5-2022

Point of Use Technologies to Increase Access to Clean Water in Rural Communities

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Spring 2022 Thesis

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Abstract

Access to clean water is an issue that many communities around the world struggle with. While large-scale efforts such as piping infrastructure have been successful, these are less effective at reaching small, rural communities. To supplement these efforts, point of use (POU) methods for water treatment can be implemented. These include boiling, chemical treatment, filters, and several additional technologies. These have all shown effectiveness in a lab setting, but their implementation in the real world, specifically in rural communities, has not been nearly as effective. In this paper, several different POU methods are evaluated for their effectiveness on a small-scale, including associated costs. A locally specific education campaign for the proper use of these technologies would empower individuals to treat their own water and be responsible for their own health in a way that has never been seen before.

Introduction

Globally, 2.2 billion people do not have access to safely managed drinking water services, and 144 million people drink untreated surface water such as that from a lake or river (World Health Organization 2019). This can lead to many health issues, especially in young children. Issues such as "gastrointestinal illness, nervous system or reproductive effects, and chronic diseases" can be caused by biological, chemical, and physical contaminants in drinking water (Environmental Protection Agency 2021). One of the most fatal of these effects is diarrhea, which largely affects children in low-income countries (Clasen, Thao, et al. 2008). This is especially a problem in rural areas, where 8 in 10 people lack access to basic drinking water services (World Health Organization 2019).

The WHO recognizes several methods for treating water to make it safe for drinking. This includes central treatment and household treatment. Central treatment is performed in a large plant and includes several steps such as pretreatment, coagulation, flocculation, sedimentation, filtration, and primary disinfection. This is done on a large scale and is therefore most useful for large communities. Household treatment includes chemical disinfection using chlorine; membrane, porous ceramic, or composite filters; granular media filters; solar disinfection; UV light treatment; thermal technologies; and coagulation, precipitation, and sedimentation techniques (World Health Organization 2017). Each of these is explored in detail in this paper.

Large scale efforts around the world have been very successful in bringing clean water to communities (World Health Organization 2017). The goal of these efforts is to bring clean water to as many people as possible, and that can be done most effectively by targeting urban areas. As such, rural communities are often disregarded in these efforts. Rural populations, while far more dispersed and harder to reach, make up a large portion of the global population. As many as 3.4

billion people live in rural areas, and 92% of these people live in developing countries (Organisation for Economic Co-operation and Development 2016).

To reach this population, small scale efforts such as those discussed in this paper could be implemented. These techniques include ways that people can treat their own water on an individual basis, without relying on government programs. This empowers people to treat their own water and be self-reliant. Government programs are often corrupted, especially in the developing world, causing vulnerable communities to suffer if they do not receive the aid these programs promise (World Bank 2021). Additionally, small scale methods can be implemented much faster than large scale. While funding and infrastructure needed for piping and large programs may take a long time to procure, smaller scale methods can be used almost immediately (Clasen, Thao, et al. 2008).

POU Methods

The WHO recognizes biological, chemical, and radiological contaminants. The WHO defines 24 pathogens, including bacteria, viruses, protozoa, and helminths, that can live in and be transmitted through water, and an additional 22 that may cause waterborne disease. In addition, they define several chemical contaminants: 8 naturally occurring, 21 from industrial processes, and 33 from agricultural sources (World Health Organization 2017). Physical contaminants include all other possible contaminants including dirt, sediment, and radiological contaminants.

Point of use (POU) methods include several different techniques that treat water at the household scale. Each of these methods has different strengths, weaknesses, and circumstances where they are the most effective. Radiological contaminants are not considered here as their effects are more long-term and therefore of less immediate concern in the developing world. Physical contaminants are included in this discussion because they can affect the use of other methods such as chemical disinfection. Several methods are evaluated in terms of their effectiveness at remediating biological, chemical, and physical contaminants.

Various POU methods are summarized in Table 1 and are explained in more detail in subsequent sections. Thermal technologies are discussed first as they are the standard to which other techniques are compared (Rosa, Miller and Clasen 2010). This is followed by other water treatments, grouped by category: chemical treatment, filters, and additional technologies.

Table 1: Summary of POU Methods' Effectiveness in Remediating Contaminants

Technique	Biological	Chemical	Physical
Thermal technologies	Yes	No*	No*
Chemical disinfection	Yes	Yes*	No
Filters	Yes	Yes	Yes
Coagulation, precipitation, and/or sedimentation	Yes	Yes	Yes
UV disinfection	Yes	No	No

*May increase concentration. See sections below for additional details.

Thermal Technologies (Boiling)

Boiling is commonly used across the world for treatment of drinking water, and as many as 1.1 billion people practice this (Rosa, Miller and Clasen 2010). This is in use not only in developing countries but also in developed countries during water crises including biological contaminants (Centers for Disease Control and Prevention 2021). In lab environments, boiling has been found to kill biological contaminants that may be pathogenic. Chemical contaminants, however, may be increased in concentration as water evaporates off, and physical contaminants are not addressed.

In situ, many people do not boil their water correctly. The CDC recommends "bring[ing] water to a full rolling boil for 1 minute (at elevations above 6,500 feet, boil for 3 minutes)" (Centers for Disease Control and Prevention 2021). In addition, many people do not store their boiled water correctly, leading to recontamination of the water. A 2010 study in Guatemala found that 71.2% of boiled water samples met WHO requirements for safe water, and 10.7% was in the low-risk category (Rosa, Miller and Clasen 2010). However, a 2008 study in India found that only 59.6% of boiled water samples were safe (Clasen, et al. 2008) and just 37% in Vietnam in 2008 (Clasen, Thao, et al. 2008).

Boiling is largely used due to its practicality, ease of use, and low cost to perform. A 2011 survey in Indonesia found that 83% of respondents thought boiling was practical, 73% thought it was easy, and 90% thought it was cheap, for example (Sodha, et al. 2011). It is commonly used in regions around the world that experience long or short-term needs for decontamination of water. It is very effective in removing biological contaminants, included that from fecal contamination and *E. coli*, which are very common contaminants in the developing world (Sodha, et al. 2011).

The main drawbacks of boiling are the cost associated with fueling, and the frequent errors in the process. In areas without electricity, wood or gas can be cost prohibitive. In addition, the use of boiling is largely over-reported. Brown and Sobsey found that 90% of households in Cambodia reported boiling as a water treatment technique they use, but only 31% had boiled water on hand at follow-up visits. In addition, many do not store their boiled water in a covered and small-mouthed container, thus making it more vulnerable to recontamination (Brown and Sobsey 2012).

A further problem relates to chemical and physical contaminants, which can be concentrated through the boiling process. The CDC only recommends boiling for biological contaminants, not for "harmful chemicals and toxins" (Centers for Disease Control and Prevention 2019) or "radioactive materials" (Centers for Disease Control and Prevention 2019).

Boiling is highly effective in areas with short-term water cleanliness problems such as following an environmental disaster or chemical spill. The CDC often issues boil water advisories if a community's water "has, or could have, germs that can make you sick" (Centers for Disease Control and Prevention 2021). Several governmental efforts that advocate for boiling have been effective, especially when there is adequate knowledge and understanding of the reasoning behind the advisory (Vedachalam, Spotte-Smtih and Riha 2016).

Chemical Disinfection

Chemical disinfection includes the use of chlorine, iodine, and other chemicals to decontaminate water. This is largely done to kill biological pathogens or neutralize other known chemical contaminants in a sample. In the developing world, chlorine is usually used as it is the cheapest. Iodine can also be used to disinfect water, but residual amounts of this over long periods can be harmful. The WHO has examined other chemicals for this use, but chlorine and iodine are the only ones that are recommended (World Health Organization 2017). For this paper, only chlorine will be examined as it is the most cost-effective, easy to access, and sustainable for long-term use.

One of the main strengths of this technique over all other techniques is that residual chlorine in the water protects against recontamination. The storage of water can often lead to recontamination if containers are wide-mouthed, uncovered, or near a contaminant source such as a bathroom (Sodha, et al. 2011). Residual chlorine left in treated water samples ensures that any recontamination is remedied.

While residual chlorine can be beneficial in neutralizing recontamination, it can be dangerous if at too high of a level (Centers for Disease Control and Prevention 2020). Because of this, the dosing and use of chlorination must be well-tracked within a household to make sure the chlorine itself does not become a harmful contaminant (World Health Organization 2017). In addition, excess chlorine may change the taste or smell of the water, which some people do not like (Centers for Disease Control and Prevention 2020).

Filters

Filters include any medium through which water flows. This separates large particles such as dirt, but it can also decrease concentrations of chemical and physical contaminants. The WHO recognizes two different categories of filters: membrane, porous ceramic, or composite filters and granular media filters such as sand (World Health Organization 2017).

Granular media filters include the use of any small substance through which water can flow. This can be done on an industrial scale using pumps and the addition of other methods, but it can also be useful on a small scale. One simple example of this is slow sand filtration. Several different global projects have already been successful in implementing this technique (Centers for Disease Control and Prevention 2022). One example of this is the BioSand Water Filter, which contains all of the necessary setup for sand filtration to increase access to clean water. They have millions of their products in use around the world (Manz Engineering n.d.).

This technique has proven to be very effective in reducing biological, chemical, and physical contaminants from water samples. Slow sand filtration is very simple to set up and use, so there is a low probability of user error as seen in other methods such as boiling. In addition, the same sand can be used several times without needing replacement, so it is very low cost.

Despite the low cost of maintenance, there is a high cost to initially set up a sand filtration system. Due to the heavy weight of sand and large size of the apparatus required for effective filtration, this method is not very portable. Because of this, people that move frequently or spend time in several different homes may find it difficult to use this technique.

Due to their high initial cost, this technique is best suited to households that do not move around a lot and can maintain the same system for a long time. This technique would also be a good candidate for aid programs that would have a long-lasting impact as it can be used for a long period of time after the initial cost of setup.

Membrane filters differ from granular media in that the medium the water passes through is a single substance, not granular like sand. There are many different types of membrane, porous ceramic, and composite filters. This includes "carbon block filters, porous ceramics containing colloidal silver, reactive membranes, polymeric membranes and fibre/cloth filters" (World Health Organization 2017). Only carbon block filters, also known as biochar, will be examined in this section as the other methods are more expensive to obtain and use. Cloth filters, while inexpensive, have only been found to be effective in removing large contaminants as small contaminants can still pass through the cloth.

Biochar is a form of carbon produced from a variety of biomass sources that can be used as a membrane filter to disinfect water (Spokas 2020). It is particularly useful as a filter as it effectively removes chemical, biological, and physical contaminants, compared to other methods that only remove biological contaminants (Gwenzi, et al. 2017).

The main strength of biochar is its extremely low cost. Because it comes from organic materials, many people can make biochar themselves at home with only the cost of fuel to facilitate the process. In addition, biochar is already in use in many rural areas in developing countries as it is used for fuel. As many as 90% of households in poor and vulnerable communities in developing countries rely on biomass fuels such as wood or coal (Gwenzi, et al. 2017), so the materials are already readily available. In addition, biochar can still be used as fuel after it has been used as a filter, maximizing the return of the cost of biochar.

It also maintains organoleptic properties (taste, smell, color) of the water, which some other techniques do not. Secondary water characteristics like this play a big part in how "clean" and "safe" people think their water is (Sodha, et al. 2011), so maintaining these properties would make the technique easier to implement successfully. More research into how people's perceptions of their water affect their acceptance of the source is needed to solidify these results.

One of the main weaknesses of this technique is its contribution to a community's carbon footprint. In addition, biomass is an abundant resource that is present in relative abundance in many rural areas, but this may not be the case in urban areas. This also makes it more difficult to use on a larger scale. As such, the use of biochar as water treatment fills a very specific niche, mostly in rural areas. The main factors that make this a good treatment for a community are reliance on biomass for fuel and agriculture. Both require biochar already, making the process cheaper as the material can be reused.

Additional Technologies

Coagulation, Precipitation, and/or Sedimentation

Coagulation is the process by which contaminants are removed from water through the addition of a coagulant such as aluminum sulfate. This causes contaminants to precipitate out of solution and settle on the bottom through sedimentation. However, this process is rarely used by individual households due to the high specificity of skills required to perform this technique (Pooi and Ng 2018). Because this method is not a good candidate for household use, it will not be discussed further.

UV Light Technologies

UV light has been shown to be effective at killing pathogens in water sources. This can be done either with a UV lamp or by using the sun's energy. The cost of equipment and electricity makes a lamp much more costly than solar disinfection (SODIS).

SODIS is a very simple way to treat water and has been proven effective in the laboratory setting (Mausezahl, et al. 2009). The CDC recommends filling small (< 2 liter) bottles with the water to be treated, shaking them to oxygenate the water, and then leaving the bottles in the sun for 6 hours in sunny conditions or 2 days in cloudy conditions (Centers for Disease Control and Prevention 2022). This is a very easy technique with virtually no material or labor costs. This makes it a good candidate to deploy in rural communities. It has also proven to be very effective at removing pathogens in water (Mausezahl, et al. 2009).

The main drawback to this technique is that it takes time to prepare the treated water. Even in sunny conditions, it takes 6 hours for solar disinfection to be effective. This means that people must plan for how much water they will need in the next day or even several days. Treating too much water at once and then storing it improperly can also lead to recontamination, as discussed with other techniques.

In summary, SODIS is a very cheap and easy way to treat water, but it only affects biological contaminants, not chemical or physical. Because of this, it may need to be used in addition to another technique such as chemical treatment that will completely treat the water to a drinkable standard.

Discussion and Conclusion

Although many of the techniques discussed in this paper have proven highly effective in a lab setting, their implementation in situ is not nearly as effective. From improper technique (Sodha, et al. 2011) to overreporting (Brown and Sobsey 2012) to lack of knowledge about the technique as a whole (Rosa, Miller and Clasen 2010), there are several factors that separate the lab setting from actual community implementation.

One of the main factors affecting implementation is the cost of these techniques. There are many techniques that are not discussed in this paper due to their high cost, such as forward and reverse osmosis, desalination, and large-scale wastewater treatment. Of those discussed in this paper, many can be relatively high cost based on regional factors. For example, boiling requires fuel to heat the water samples; chemical treatment requires the purchase of chlorine or another chemical. Even the techniques that have little to no monetary cost hold a burden of time. SODIS and filtration are good examples of this as they require the user to set up the treatment and wait for some time. This requires them to plan how much water they will need on a scale of days to weeks depending on the technique. The cost of the water treatment technique must therefore be weighed against its cost. Techniques that are too high cost, either monetarily or timewise, will likely not be practiced.

Another barrier to implementation of these techniques is the method to spread knowledge about the technique. For example, many people don’t know how long they should boil their water or how to properly store it to prevent recontamination. Education campaigns in the past have mainly come from governments or NGOs (Sodha, et al. 2011). Learning how to disseminate this knowledge to rural and remote communities effectively is vital in the successful implementation of these techniques.

Additionally, it is important to recognize that there are different water contaminants and costs in different regions. For example, the cost of fuel in India is much lower than it is in sub-Saharan Africa, indicating that boiling may be more or less appropriate in different regions. Similarly, the availability of chemicals for water treatment varies. Because of this, an education campaign should be highly specific and oriented to small geographic regions. In some cases, a combination of treatments may be more effective (World Health Organization 2017).

Despite the large variety of effective water treatment methods, their implementation has been largely unsuccessful to date due to cost and education (Sodha, et al. 2011). A highly localized education campaign would help with both, as the best treatment for each community can be found and taught to be used effectively. This would help bring water to rural communities that are harder to reach by large-scale efforts such as piping. By giving people the ability to treat their own water, they become empowered to control their own health regardless of state intervention or aid.

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