Review Article

How are water treatment technologies used in developing countries and which are the most effective? An implication to improve global health

Caleb Zinn[1], Rachel Bailey[1], Noah Barkley[1], Mallory Rose Walsh[1], Ashlen Hynes[1], Tameka Coleman[1], Gordana Savic[1], Kacie Soltis[1], Sharmika Primm[1], Ubydul Haque[2]

[1]Department of Public Health & Prevention Sciences, Baldwin Wallace University, Berea, OH, USA; [2]Department of Biostatistics and Epidemiology, University of North Texas Health Science Center, Fort Worth, TX, USA

Contributions: (I) Conception and design: C Zinn, U Haque; (II) Administrative support: None; (III) Provision of study materials or patients: None; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: U Haque; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Ubydul Haque. Department of Biostatistics and Epidemiology, University of North Texas Health Science Center, Fort Worth, TX, USA. Email: mdubydul.haque@unthsc.edu.

Abstract: Worldwide, there are an estimated 2.3 billion people living in water-scarce and stressed areas. The water in these areas may contain harmful pathogens, such as bacteria, that can have a negative effect on human health. Poor sanitation, lack of hygiene, contaminated water sources, and the overall poor quality of drinking water leads to disease and death amongst people of all ages in underdeveloped and developing countries. In order to better the health of these communities and the quality of water, affordable water treatment technologies that can reduce harmful contamination to potable water standards must continue to be developed. The purpose of this study is to review the currently available techniques, such as solar water disinfection (SODIS), chlorination, ceramic and biosand water filtration and slow sand filtration, that can be utilized in developing countries. A number of peer-reviewed journal articles were reviewed to identify the strengths and weaknesses of each of water treatment technologies. This process is based on the quality/efficiency of the treatment process, the availability/accessibility of the treatment as well as its overall effectiveness. Based on our study, SODIS had the most positive impacts however, membrane filtration shows a potential to become the preferred water treatment method in the future. Affordable and effective water treatment is a vital step towards reducing morbidity, as well as reducing health complications for the present and the future in developing countries.

Keywords: Water; treatment; technologies

Received: 08 June 2018; Accepted: 21 June 2018; Published: 26 September 2018.
doi: 10.21037/jphe.2018.06.02
View this article at: http://dx.doi.org/10.21037/jphe.2018.06.02

Background

Water contamination has been a serious public health concern all over the world even in developed countries. According to the World Health Organization (WHO), improvements in drinking water, sanitation, hygiene, and water resource management may reduce the global disease burden by 10% (1). One of the Millennium Developed Goals is to decentralize drinking water (2), making it available globally, therefore reducing the risk of health complications and morbidity all across the globe. In developing countries, the most common form of contamination comes from water that has been stored in poor conditions (3), urging the need for better water treatment technologies. It is imperative to treat water for bacteria and other chemical/microbial components that may compromise public health safety. Advanced and affordable water treatment technologies are continue to be developed to provide assistance to those who cannot afford clean water. Prevention strategies such as treating water, educating guidelines for the safe storage of drinking water, and practicing improved sanitation techniques, can significantly reduce the risk of deadly waterborne diseases.

One common prevention strategy for treating water is chlorination. Chlorination method requires people to add one full bottle cap of sodium hypochlorite solution to clear water, or two bottle caps for turbid water, in a standard sized container, mixed thoroughly by agitating, and waiting approximately 30 minutes before consumption (4). This method effectively inactivates most bacteria and viruses that cause diarrheal disease however it is not as effective at removing protozoa, such as Cryptosporidium (4). Chlorination is inexpensive, generally easy to use and maintain, however there is a lower disinfection effectiveness in turbid waters, and it has potential for long-term health effects, such as some types of cancers such as Colorectal (4,5). This water treatment method has also been distributed free of charge in a number of disaster areas including Indonesia, India and Myanmar.

One of the widely used prevention strategies to treat water, Solar Water Disinfection (SODIS), is a safe and simple way to kill pathogens in water, making it safe to drink (6). Results have shown that exposing a filled water bottle to the sun for at least 6 hours reduces the number of pathogens in the water, and thus greatly reduces health complications (e.g., diarrhea) (7). SODIS uses the sun's ultraviolet radiation to improve the quality of the water. It is an inexpensive and easy method to improve the quality of drinking water in a household. Studies also investigated low-cost SODIS-based point-of-use (POU) household devices in Pakistan (7). The study concluded that SODIS were successful in treating contaminated water and can be used for people living in large cities facing shortage of potable water (7).

Another well-known prevention strategies are ceramic and biosand water filters (BSF). Biosand filtration is a slow-sand filter adapted for use in the home. The most widely used version of the BSF is a concrete container approximately 0.9 meters tall and 0.3 meters square filled with sand. The water level is maintained at 5–6 centimeters above sand layer to grow on top of sand which in turn helps reduce disease-causing organisms. A plate with holes is placed on top of the sand to prevent disruption of the bioactive layer when water is added to the system. The filters can be effective POUs due to their versatility and ability to be used easily in homes. These technologies thus make it easier for people to keep sanitary water in their own home (8). Studies also showed that the ceramic filters are 3–6 times more cost-effective than the centralized water system in place for reduction of waterborne diseases (e.g., diarrheal illness) among children under five (9). The filters are known to be environmentally friendly in terms of low energy use, water use, and particulate matter emissions (9,10).

Slow sand filtration (SSF) is another simple method that can remove pathogens and particles in drinking water (11). When sand surface area increases, it leads to an increase in possible adsorption spaces on sand and biofilm attached to the sand grains. It was reported that an increase of 0.25 to 0.63 mm in *d* 10 of filter sand ended up decreasing the total coliform bacteria removal from 98.6% to 96%, which shows the high efficiency (11).

Membrane filters are typically manufactured as flat sheet stock or as hollow fibers then formed into membrane modules. Modules typically involve potting or sealing the membrane material into an assembly which are designed for long-term use. Some examples of modules used include, hollow-fiber modules and spiral-wound modules.

In this study, we will investigate the strengths and weaknesses of various water treatment technologies. Our study will be based on published pee-reviewed journal articles as well as our observations of drinking water industry trends. It is noted that our study is specifically designed for applications in developing countries. We will also provide recommendations to promote drinking water treatment technology guidelines and suggestions, so that many people in developing countries can access safe drinking water. We do believe that this work will be beneficial to local communities in developing countries, Engineers without Borders (EWB), and other stakeholders who need substantial understanding of available water treatment technologies for well-informed decision-making.

Methods

We searched literature through PubMed, Google Scholars, and Medline (EBSCO) using the key words "water treatment technology", "world", "disease"," drinking water", "public health and drinking water", "public health drinking water and disease". Initially we retrieved 56 papers however, after reviewing them, only 38 were considered for this study (*Box 1*).

These articles were selected based off of multiple factors including a discussion regarding various water treatment

Box 1 Literature search for water treatment in developing countries

Period searched: from 2000 to September 2017

Source: PubMed, Google Scholars, Medline (EBSCO)

Search terms: "Water Treatment Technology" AND "Developing Countries" AND "Water Disease" AND "Drinking Water" AND "Public Health and Drinking Water" AND "Public Health and Drinking Water Disease"

Inclusion criterion: any mention of water treatment or water treatment efficiency

Articles found =56, articles included =38

Exclusion material: having no reference to any human disease and no reference to preventing disease through water treatment

methods, their impacts on global health, strengths and weaknesses of specific water treatment technologies and the level of filtration or treatment capacities. We chose to analyze papers that discussed if the specific treatment effectively inactivated pathogens and removed chemicals such as arsenic, or if they only filtered pathogens. Each paper was analyzed according to cost, consistency/reliability of filtration capacities/efficiency, accessibility to filtration, cultural integration of filtration technique, ease of use, feasibility of instruction regarding operation and management, and overall effectiveness of the filtration.

We collected information regarding each water treatment method and combined this information in a matrix. Information collected included, cost, maintenance, installation, materials, operation, the efficiency of the system killing microbes or filtering out substances such as chemicals, necessary training required, strengths and weaknesses, requirements to operate (such as environmental requirements), filtration method use in developing countries and Risks, Attitudes, Norms, Abilities, and Self-regulation (RANAS) comments regarding the filtration method. Literature search keywords included, "household water treatment" OR "developing countries" OR "RANAS" during the period 2000–2018.

Results

Study characteristics

Table 1 shows the characteristics of the articles utilized in review (n=24), which were conducted over a vast region including China, Bangladesh, Cameroon, and several other countries (12-16). The total sample size from all the studies cannot be addressed since multiple studies only focused on the effectiveness in the removal of contaminants, while others focused on usage by those in developing countries. All of the studies focused on the removal of a particular contaminant presented the specific implementations.

Quality of reporting

Only 11 of the 24 studies gave a sample size. The 13 that did not provide the sample size focused on the effectiveness of removing a specific contaminant. The studies that included a sample size often focused on how the water treatment was integrated into a community. Sources of bias as well as how methodological efforts reduce the bias, were rarely discussed.

Results of literature searches regarding water treatment methods such as chlorination and SODIS, varied and each method had benefits and drawbacks. According to information collected, SODIS proves to be the most efficient method for treating water due to its low cost, ease of use, ability to kill most viruses and bacteria, and the absence of installation/maintenance. Other treatment methods such as chlorination, are also effective and may be preferred over SODIS due to the immediate access to clean water. Membrane filtration, such as reverse osmosis, is not used often in developing countries due to their complexity, however membrane filtration may be used more often in the future due to the efficiency of the particular filtration system. In the following, the core reviews for each treatment technologies are presented (*Tables 2-5*).

SODIS (solar disinfection)

As mentioned earlier, SODIS is a simple and inexpensive method that has been proven to be effective in removing pathogens and bacteria in contaminated water. A study in Cameroon presented two-cross sectional surveys and intervention regarding SODIS (23). Prior to the intervention, diarrhea was found amongst 34.3% of children. After the intervention, the risk of diarrhea was reduced by 42.5% (23). Another study in Pakistan consisted of 24 experiments that used 1.5-liter Polyethylene terephthalate (PET) bottles filled with water from water sources in Karachi, Pakistan (23). In these experiments, it was shown that SODIS reduced 100% of pathogens when used correctly. In order to optimize performance, specific types of backings on bottles must be used to further positive performances. Backings that were absorptive and

Table 1 Strengths and weakness of water treatment technologies

Study area	Study	Sample size	Treatment type	Disease prevented	Removes	Strength	Weakness
Yaoundé, Cameroon	Graf *et al.* 2010	2,193	SODIS	Diarrhea, cholera, waterborne pathogens, etc.	Kills bacteria such as *E. Coli*	(I) Requires money and energy to use the SODIS containers and treat the water. (II) With full compliance diarrhea was reduced by 42.5%	Turbidity can prevent these treatments from being effective and creating drinkable water
Southern Spain	Gomez-Couso *et al.* 2012	N/A	SODIS	Diarrhea, cholera, waterborne pathogens, etc.	Cryptosporidium parvum	(I) System is highly resistant to environmental changes, (II) Maintenance required is minimal	The higher the levels of turbidity reduce the effectiveness
Nicaragua	Altherr *et al.* 2008	81	SODIS	Diarrhea, cholera, waterborne pathogens, etc.	Kills bacteria such as *E. Coli*	Requires little money and little energy to use the SODIS containers and treat the water	Turbidity can prevent these treatments from being effective and creating drinkable water
NED University of Engineering and Technology	Mustafa *et al.* 2013	24 experiments	SODIS	Diarrhea, cholera, waterborne pathogens, etc.	Fecal coliforms and total coliforms	Easy to use, not energy intensive, safe to store if necessary	Turbidity of water can prevent the killing of microorganisms
University of North Carolina	Sobsey *et al.* 2009	N/A	SODIS, Point of Use (Ceramic Filter), Chlorination, Biosand Filter	Diarrhea, cholera, waterborne pathogens, etc.	Bacteria	Between these 5 treatments there can be local production of one to meet the areas need	All of these have trouble being continually and regularly used in the long run. The lack of education and cultural acceptance leads to a waning over time
N/A	Thompson *et al.* 2003	N/A	SODIS	Diarrhea, cholera, waterborne pathogens, etc.	Bacteria	Any of these 4 methods can be used in a developing country effectively	None of these treat turbid water
North Carolina	Abebe *et al.* 2016	3 types of Chitosans	Ceramic Water Filter	Diarrhea, cholera, waterborne pathogens, etc.	Virus, bacteria, non-living compounds that lend to turbidity	Extremely effective and cost efficient	Doesn't always get rid of Virus
University of Missouri	Salvinelli *et al.* 2016	12 filters used	Ceramic Water Filters	Diarrhea, cholera, waterborne pathogens, etc.	None	Made from local resources, cheap	(I) Turbidity clogs the filters over long term and (II) they need to be cleaned often to keep the flow rate high
Computer software/Lab	Ren *et al.* 2013	100,000	Silver Impregnated Ceramic Point of Use Filters	Diarrhea, cholera, waterborne pathogens, etc.	*E. coli*, total coliforms, protozoan oocyst, and turbidity	Culturally accepted, can be made locally and are sustainable	These cannot filter out substances such as arsenic and fluoride

Table 1 (*continued*)

Table 1 (*continued*)

Study area	Study	Sample size	Treatment type	Disease prevented	Removes	Strength	Weakness
University of Karlsruhe, Germany	Frimmel *et al.* 2003	N/A	Membrane Filtration	Diarrhea, cholera, waterborne pathogens, etc.	Organic matter, micro pollutants, and microorganisms	These three processes eliminate most if not all microorganism	Turbidity can prevent these treatments from being effective, these can also be expensive
Beijing China	Qia *et al.* 2015	5 waste water treatment plants	Detection	N/A	Organic micropollutants	Allow for detection of pharmaceuticals, caffeine, and pesticides	These detections were in large water filtration plants which third world countries don't have access to
Perth, Western Australia	Nair *et al.* 2001	121 rainwater samples (500 mL)	Detection of Escherichia coli and Salmonella spp.	Diarrhea, cholera, waterborne pathogens, etc.	N/A	This is preventative measure so no one gets sick in the first place	There can be false negative and false positive results. 4.1% and 2.0% respectively
CRDT, IIT, India	Meenakshi *et al.* 2006	N/A	Membrane Filtration, Better Nutrition, Ion Exchange, Coagulation-Precipitation	Dental and skeletal fluorosis	Fluoride	Check paper each has its own advantage	Expensive and it leaves a byproduct that is hazardous and hard to get rid of
NED University of Engineering and Technology (Water from Pakistan)	Haider *et al.* 2009	N/A	Membrane Filtration, Adsorbents, Precipitation/ Coagulation, Ion Exchange, Point of use methods	Arsenic poisoning	Arsenic	Between these 5 methods Arsenic can be removed cheaply from anywhere	During weak and moderate sunlight conditions the performance and pathogen removal may not be achieved
Bangladesh	Jiang *et al.* 2013	N/A	Co-Precipitation/ Coagulation/Filtration, Precipitation/Filtration, Adsorption, Activated Alumina, Layered Double Hydroxide, Natural and Modified Zeolites and Clays, and Sorption by Laterite and Limonite with Oxidation	Arsenic poisoning	Arsenic	Some of these technologies can be slightly changed to address other problems like fluoride removal	This method only addresses arsenic and no other possible contaminates in the water supply
Saxonia, Germany	Langenback *et al.* 2009	6 PVC pipe filters	Slow Sand Filtration	Diarrhea, cholera, waterborne pathogens, etc.	*E. Coli*, solids found in the water, intestinal	Requires no energy and filters both pathogens and particles that make water turbid. Simple and easy to learn	Requires regular maintenance

Table 1 (*continued*)

Table 1 (*continued*)

Study area	Study	Sample size	Treatment type	Disease prevented	Removes	Strength	Weakness
Eawag, SFIAST and CSWUE	Peter-Varbanets	N/A	Membrane Filtration	Diarrhea, cholera, waterborne pathogens, etc.	Bad chemicals from water	Low cost and low maintained	Research is not sufficient enough to implement this method
Culiacan, Mexico	Chaidez *et al.* 2016	25 households from two communities	Biosand Filtration	Diarrhea, cholera, waterborne pathogens, etc.	Heterotrophic bacteria, total coliforms, fecal coliforms, *E. coli*, and Giardia spp.	Treats water with high turbidity and filters out bacteria	Requires constant maintenance
N/A	Lantange *et al.* 2006	N/A	Biosand Filtration, Ceramic Filtration, Solar Disinfection	Can filter out most water borne pathogens, prevent cholera and diarrhea	Virus, bacteria, non-living compounds, and protozoa	One of these can be applied in almost any circumstance	Often times these processes aren't used regularly and used in the long term
Bangladesh	Mahmud *et al.* 2007	3 communities	Water Safety Plans	Diarrhea, cholera, waterborne pathogens, etc.	N/A	These plans can enhance other water filtration systems due to better management of water	Requires training of communities which can be time intensive and expensive
WHO, Bangladesh and Cranfield University, UK	Trevett AF *et al.* 2008	N/A	Disease Risk Index (DRI)	N/A	Consuming decontaminated drinking- water	Easy to implement and use for the daily household	Has not been adequately tested in conjunction with physical interventions
Ethiopian Rift Valley	Huber *et al.* 2012	211	Risk, Attitude, Norm, Ability, Self-Regulation (RANAS) model of behavior change	Dental and skeletal fluorosis	N/A	Helps increase the effectiveness treatments that filter out fluoride	To gather this data, requires a lot of time and several translators
Chad	Lilje *et al.* 2015	1,017	RANAS	Diarrhea, cholera, waterborne pathogens, etc.	N/A	Very effective at predicting who will use water treatment	Time consuming and can be expensive to hire people to take questionnaires to people

CRDT, IIT (Centre for Rural Development and Technology, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi, India); Eawag, SFIAST and CSWUE (Swiss Federal Institue of Aquatic Science and Technology, and Chris Swartz Water Utilization Engineers); WHO, World Health Organization.

Table 2 Cost—installation, materials, operations, and maintenances

Technology	Operations and maintenances
Chlorination (17-24)	Proven to be a low-cost intervention
	Chlorine, the 250-milliliter bottle of sodium hypochlorite solution used to treat water
	Requires no maintenance or installation except for using the bottle and solution regularly
Solar disinfection (23,25,26)	SODIS is a low cost, effective water treatment method
	Does not require installation or maintenance of filtration system
	SODIS was initially developed to disinfect water inexpensively for oral rehydration solutions
	Users fill 0.3–2-liter plastic soda bottles with low-turbidity water, shake them, and place the bottles on a roof or rack for six hours (weather permitting if sunny), or two days if it is cloudy
	SODIS only requires a bottle for the water to go in and sunlight or at least partial sunlight
Biosand filtration (23,25,26)	One-time cost of US$3 to family
	Materials needed include a container, lid, diffuser box, standpipe and media (sand and gravel) bed
	Users pour water into the BSF and collect finished water from the outlet pipe in a bucket
	Requires one-time installation
Ceramic filters (9,23,27,28)	Typically holds 8.2 liters of water and sits inside a 20 to 30-liter plastic or ceramic receptacle with a spigot
	Range in cost from approximately $7–$30 and some countries may have financial assistance making it zero-cost
	The filter contains colloidal silver which are tiny silver particles suspended in liquid that are used as a disinfectant to prevent bacterial growth in the ceramic filter and assists with inactivating the bacteria in the filter. This silver does not leave a residual in drinking water
Slow sand filters (9,27-29)	Cost ranges between US$12–US$16.76
	Materials include buckets or box/bed, bag of fine sand (50 lbs.), spigot, gravel, matrix of mesh and cheesecloth to serve as biofilm
	Once installation is completed, the operation does not cost money
	The sand is the primary cleansing agent and must be cleaned periodically since the top layers become clogged with algae, debris and plant life. It mechanically filters bacteria through grains of sand and the absorption of bacteria to a biofilm layer
Membrane filtration (30-32)	Higher cost method, depending on the specific filtration
	Can include microfiltration (MF), ultrafiltration (UF), Nano filtration (NF), or reverse osmosis (RO)
	Cost depends on the type of membrane filtration as well as the power used (if any) to use the filtration method.
	Normally, membrane material is manufactured from a synthetic polymer
	Chlorine doses of 0.5 mg/L or less may be added

reflective were able to show the bacteria growing back after a week of keeping the bottles at room temperature (7,23). Another study in Indonesia introduced an episode of training 144 villages, 70 elementary schools, and a total of 130,000 people within 14 months on how to use SODIS. By integrating hygiene education and SODIS into the community, bacteria contamination of household drinking water was reduced by 97% (23). However, one drawback to SODIS, is limited capability of filtering out only pathogens, not chemical components.

Membrane filtration

A major advantage of membrane filtration is that it is versatile. This water treatment can be produced and adapted to filter out almost any substance ranging from pathogens,

Table 3 What's the requirement to use these treatment methods?

Technology	Requirement
Chlorination (17-24)	Water from improved/low turbidity should be dosed at 1.88 mg/L of water and used within 24 hours whereas water from unimproved /higher turbidity should be dosed at 3.75 mg/L of water and consumed within 8 hours of chlorination
	Can be used in any climate condition
Solar disinfection (23,25,26)	Direct sunlight for at least six hours, or two days of being cloudy
	Works best with direct sunlight, but low-cost additives are able to accelerate the process in cloudy and sunny weather.
	No specific temperature is required even though sunlight is required
	Water amount should not exceed 2.0 liters and water must be kept in a clear plastic soda bottle to ensure sunlight is hitting water
Biosand filtration (23,25,26)	Necessary to know turbidity readings on the water source where biosand filtration is being proposed
	Not recommended to be used if water source is contaminated with organic/inorganic industrial and agricultural toxins, or regions where ambient air reaches freezing temperatures
	Water level must be maintained 5–6 centimeters above the sand layer, therefore if this filtration method is kept outdoors, increased rainfall could be a potential issue
Ceramic filters (9,23,27,28)	No specific requirements regarding weather
	Can only filter at a flow rate of 1–2 liters per hour
	Cleaning the system must be practiced regularly to prevent recontamination of water
Slow sand filters (9,25,26,33)	Water must be emptied at the bottom to allow new water to be filtered, typically four liters of water fit below the filter
	Filter must be cleaned and maintained regularly to prevent further contamination
	Filters should be installed in a location that is protected from damaging sunlight, wind, rain, animals and children
	The filter needs enough water flowing in to keep the sand layer covered in water
	Water must run through the layers of sand for three weeks prior to first use
Membrane filtration (30-32)	NF/RO systems require pre-treatment of the influent, increased electrical supply and high level of technical expertise
	Requires backwashing (process designed to remove contaminants accumulated on the membrane)
	Chemical cleaning is necessary also to prevent the membrane from fouling
	Membrane integrity testing must be performed testing the turbidity of water, particle counting or monitoring, air pressure testing of the system, bubble point testing, sonic wave sensing and biological monitoring
	Training is required for every type of membrane filtration

bacteria, arsenic, and other harmful chemical pollutants (27,33). It also requires no chemicals, little maintenance, and has a long lifespan (33). However, this is not always suitable for use in developing countries due to costs. Most of the available membranes in markets are relatively expensive in comparison with other treatment options such as solar disinfection. However, many researchers/scientists are working on creating the membranes for a cheaper price (34). The other disadvantage of the membrane filtration systems is that they can waste a lot of the water as brine which can be difficult to get rid of (33).

Biosand filtration

Biosand is one of the simplest filtration systems to use since it requires little knowledge to prepare/install/use. The only requirements are to change the top layer of sand periodically and know how to pour the water over the sand. The products needed for biosand filtration can be made locally, at a low cost and they have a long life span (11). The biosand filtration filters out not only pathogens such as bacteria and protozoa, but can also filter out inorganic materials that can make water turbid (35). About 81–100% of bacteria and protozoa are filtered out on average (23).

Table 4 What's the known strength in general?

Technology	Strength
Chlorination (17-24)	Proven reduction of bacteria and most viruses and highly effective to treat drinking water
	Readily available and easy to use
	Residual protection against contamination
	Proven health impact in multiple randomized/controlled studies
	Widespread use of this treatment has the potential to dramatically reduce the global burden of waterborne diarrheal disease
	Can be used on non-piped domestic water
	Can work in turbid water
	Does not require installation
Solar disinfection (23,25,26)	One of the water treatment methods known to kill bacteria, viruses and protozoa
	Minimal change in water taste
	Recontamination is unlikely since water is consumed directly from the bottle that has a cap on it to protect the water
	Does not require chemicals, improving human health
	Does not require installation
	If water bottles are reused, there is no additional cost for the actual treatment method
	Can be used anywhere with sunlight
	Integrated very easily into societies
Biosand filtration (23,25,26)	Proven removal of protozoa and about 90 percent of bacteria
	One-time installation with low maintenance
	There is an improved look and taste of the water
	The installation process uses locally available materials
	Long lasting
Ceramic filters (9,23,27,28)	Proven reduction of bacteria and protozoa
	Generally, has long life providing the filter remains intact
	Filter can be produced locally
	Natural disasters are unlikely to disrupt water filtration
	Filters can be reused after scrubbing and new filters can be bought without having to completely replace the whole structure
Slow sand filters (9,27-29)	Filters remove most bacteria, some viruses and some parasites/protozoa
	They do not require chemicals
	Easy to maintain once properly educated on correct cleaning procedures
Membrane filtration (30-32)	Can filter out most bacteria and some membrane filtration systems can filter out viruses and most compounds found in water such as metals
	Membrane processes are increasingly becoming considered as an alternative to conventional water and wastewater treatment methods
	Higher standards than conventional water and waste water treatment processes
	Potential for mobile treatment units

Table 5 What's the known weakness?

Technology	Weakness
Chlorination (17-24)	Lower effectiveness in water contaminated with organic and certain inorganic compounds
	Potential objections due to off taste or odor
	Concerns about the potential long-term carcinogenic effects of chlorination by-products
	The presence of biofilms may cause the depletion of chlorine and the formation of non-negligible levels of toxic disinfection
	Metagenomic analysis confirmed that drinking water chlorination could concentrate various antibiotic resistance genes, the results highlighted prevalence of antibiotic resistant bacteria and antibiotic resistance genes in chlorinated drinking water showing the effect chlorination has on microbial antibiotic resistance in drinking water
Solar disinfection (23,25,26)	SODIS relies on sunlight and takes time for the water to be treated, especially if cloudy
	Specific environmental conditions are uncontrollable and not always reliable
	There is still a need to pretreat water that appears very turbid
	Limited volume of water that can be treated at one time
	Requires a large supply of intact, clean and properly sized plastic bottles which may not always be available.
Biosand filtration (23,25,26)	Must be maintained and stored safely
	Lower rate of virus and bacteria inactivation
	It is difficult to transport
	Requires materials and time to install as well as maintain changing the sand
	Possibility of recontamination if not all bacteria are killed or if sand is not changed after a while
Ceramic filters (9,23,27,28)	Unknown effectiveness at inactivating viruses
	Potential of recontamination of water if filter is not kept clean
	Necessity to educate and train users thoroughly, especially teaching how to clean filter correctly
	Low flow rate of 1–2 liters per hour which may mean users are not getting enough water they need
	Large amounts of turbidity can slow the filtration process
Slow sand filters (9,27-29)	May not be as effective as other water treatment methods with disinfecting water and protecting against bacteria, viruses and protozoa
	Difficult to transport
	They do not filter out most industrial chemicals
	Requires an abundance of materials, installation and regular maintenance
	If filter is not cleaned, recontamination is possibility resulting in further health complications
	Requires a lot of training and education to use correctly
Membrane filtration (30-32)	Higher level of technical expertise
	Higher production/operation/maintenance cost of Nano filtration/Reverse osmosis systems
	Membranes are currently not widely used in water industry due to the perceived poor economics compared with conventional systems and widespread use of membrane filtration will depend on the ability to produce significantly cheaper membranes or tightening regulatory standards

The major drawback to biosand filtration, is that it requires constant maintenance since the sand must be replaced often. If the sand on the top of the filter is not replaced, not only will the filtration be ineffective, the water that is being filtered can become even more contaminated (23,25,26).

Ceramic filters

Ceramic water filters (CWF) have been proven to be one of the most effective and sustainable methods for improving household water quality in reducing waterborne diseases and related death. These filters are widely used in developing countries where water quality is poor. It can remove turbidity, organic matter, and microbes (14). Other advantages include simple cleaning, improved environmental performance in terms of energy use, potential to impact global warming, turbidity, and particulate matter emissions. Ceramic filters are 3–6 times more cost effective than a centralized water system (9). Filter units can last for long periods but will need a supply of replacement parts due to breakage. The major weakness to ceramic filters are the ineffectiveness in removing viruses since viruses are smaller than the porous sizes of CWFs and therefore, are not effectively removed from water (14). The use of chitosan coagulation as a pretreatment for ceramic filtration has been shown to increase virus and bacteria reductions (14).

Chlorination

Chlorination is presently a commonly used, effective method for removing bacteria and viruses from drinking water. Numerous studies have shown the complete removal of bacteria in drinking water. In seven randomized, controlled trials, chlorination has resulted in reductions of diarrheal disease incidence among users ranging from 22–84% (4). These studies were conducted in urban and rural regions and have included a wide range of users, both adults and children, living in poor regions, and users drinking highly turbid, contaminated water (4). A bottle of hypochlorite solution that treats 1,000 liters of water typically costs approximately 10 cents when using refillable bottles and 11–50 cents for disposable bottles (4). Water bottles can increase this price therefore refillable bottles are recommended. A major drawback to this method is the risk of potential long-term health issues, such as colorectal cancers (5), as well as the lower disinfection effectiveness in turbid waters and the lower protection against protozoa.

Arsenic treatment

In many part of the developing countries, arsenic contamination is becoming a serious and emerging critical concern. To address that, we analyzed various techniques regarding arsenic removal technologies (36). One of the technologies that is designed to remove arsenic from drinking water, oxidation filtration, removes arsenic from iron and manganese containing groundwater (16). This process requires less investment and has a low operating cost which is why this technology is widely accepted by developing countries (16). However, other technique such as precipitation/co-precipitation, which are used to treat both drinking water and wastewater, has a higher cost but is very effective at treating arsenic and other pollutants (16). There are other low cost technologies such as ion exchange, filtration, and adsorption, as well as bioremediation which require training and education for proper maintenance and operations (16).

Discussion

SODIS can be used in any developing countries or areas as long as there is a regular access to sunlight. Since this method can only treat waterborne pathogens, areas that have high chemical contaminations would not be able to use SODIS. Based on authors' experiences, some of the prime areas that can adopt SODIS include, but not limited to, Chad, Kenya, Bangladesh, Botswana, and Pakistan. This method can be used almost anywhere ranging from rural villages to urban centers. This can also be used during floods and droughts to store and purify water. Overall, SODIS is an inexpensive and effective method that is constantly available for developing countries. There is still a need to pretreat water that appears turbid. In addition, there is a lower user acceptability of this method due to the limited amount of water that can be treated at a time, especially when the climate conditions are not suitable for the method to work. SODIS also requires a large supply of intact, clean, and properly sized plastic water bottles. It is clear that SODIS can be used in Asian and African countries, where there is enough sunlight and where water scarcity is an issue (16).

Biosand can work on turbid water however, it is more expensive than SODIS and requires that someone be present nearby to regularly change the top layer of sand. It improves the microbiological quality of drinking water. In laboratory testing, this method consistently reduces bacteria by about

81–100 percent and protozoa by 99.98–100 percent. It removes less than 90 percent of indicator viruses (23). Biosand may pose a threat for further contamination if the sand is not changed regularly. This may not be an ideal method for treating water since water can become more contaminated resulting in an increase in health complications and deaths.

Due to involved cost, membrane technology can be difficult to integrate culturally into a community in developing countries even though their proven effectiveness in treatment. Ceramic Filtration, however, has an advantage over SODIS and membrane technology in the fact that it can be integrated with the cultural aspects of numerous countries. Laboratory testing has shown bacteria is mostly filtered through the filter's small pores however colloidal silver is necessary to inactivate 100 percent of the bacteria (28). However, it is unknown if the filter inactivates viruses or removes them. For instance, ceramic pots are already used in Chad, where the ceramic filters fit well with the culture. Ceramic filters cost more on average than SODIS, but this cost could potentially decrease over time. These ceramic filters may also have the potential to be produced locally, which may provide and stimulate the local community to decrease the cost.

Slow sand filters may not completely remove (can remove 99% of bacteria) all of the infection-causing bacteria in contaminated water, but they will often remove enough pathogens to a level that is safe enough to drink and will be tolerated (28).

Although chlorination is typically used to filter drinking water, it can have potential long-term effects on health due to the chlorination by-products (e.g., trihalomethane). Some drawbacks of this method include lower protection against protozoa, lower disinfection effectiveness in turbid waters, potential taste and odor objections, and ensure the quality control of the hypochlorite solution (37). Some benefits include, proven reduction of most bacteria and viruses in water, residual protection against recontamination, general ease-of-use and acceptability, proven reduction of diarrheal incidence, and it is a cost-effective method. Even though chlorination is usually the most widely accepted method for treating drinking water, it may not the most ideal method since there are other complications, such as the cost of disposable water bottles, the risk of over chlorinated water, and the risk of potential long-term health effects.

Arsenic contamination is a well-known problem in many developing countries. Not all of these countries have centralized water to treat the arsenic therefore other measures, such as ion exchange and adsorption, need to be educated at the local-levels. These countries can use mainstream and social media to train their citizens. This also may not be the ideal method for treating water due to the amount of training needed and specific guidelines that need to be followed in order to ensure proper usage.

In developing countries, budget is certainly a limiting factor for adopting specific water treatment methods. For instance, membrane filtration can be the universal filter, but membrane filtration can be quite expensive. A way to make the membrane filtration more cost-effective, is to create a membrane using locally available resources in the area (38). This can significantly reduce the cost of membranes because they would not have to be made/imported from another country. Presently, SODIS appears to be the most practical method of treating water however, membrane filtration is becoming a more practical method than SODIS. As time progresses, membrane filtration will likely become the most effective means of water filtration. Membranes can be designed to filter not only waterborne pathogens but also arsenic, fluoride, and other chemicals as well. The knowledge required to create membranes cheaply is the major obstacle holding back membrane filtration from becoming more widespread. Membrane filtration will likely become more prevalent in third world countries if membranes will be created at a lower cost and knowledge is spread regarding the impact it will have on improving health.

Conclusions

Waterborne diseases are one of the top public health/safety concerns, urging a necessity for advanced/affordable water treatment technologies in developing countries. There are several water treatment technologies such as biosand filtration, membrane filtration, chlorination, SODIS, and ceramic filtration. Each of these, as well as many other methods, have had a positive impact on treating water and decreasing health complications however, they also have drawbacks. Based on our review, the most versatile and cost-effective method for treating water at this time is SODIS. It requires little technical knowledge to operate and can be utilized easily. It is also very cost-effective because the only resources required are plastic bottles. SODIS also has a long lifespan due to the nature of the plastic bottles. Currently, SODIS, as well as chlorination, is widespread, therefore continued use prevents having to redistribute a new type of filtration. However, as time progresses, membrane filtration will likely become the most effective means of water filtration. Membranes can be designed to filter not only waterborne pathogens but arsenic, fluoride, and other chemicals as well, which is an attribute that SODIS may achieve as it only filters pathogens and not chemicals. All of the water treatment technologies discussed have an impact on improving global public health. We must continue improving these water treatment technologies to ensure that everyone has access to clean water. This will have a major impact on reducing the number of people worldwide who are affected with water-borne illness and morbidity.

Acknowledgments

Funding: None.

Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/jphe.2018.06.02). UH serves as an unpaid editorial board member of *Journal of Public Health and Emergency* from Jan 2017 to Dec 2019. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Prüss-Üstün A, Bos R, Gore F, et al. Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health. Geneva, Switzerland, 2008.
2. UN, 2006. The Millenium Development Goals Report 2006. United Nations Department of Economic and Social Affairs DESA.
3. WHO. Global Water Supply and Sanitation Assessment. World Health Organization. Geneva, 2000.
4. CDC. Safe Water System. Available online: https://www.cdc.gov/safewater/chlorination.html, last accessed 09.18.2018.
5. El-Tawil AM. Colorectal cancers and chlorinated water. World J Gastrointest Oncol 2016;8:402-9.
6. Gómez-Couso H, Fontan-Sainz M, Navntoft C, et al. Comparison of different solar reactors for household disinfection of drinking water in developing countries: evaluation of their efficacy in relation to the waterborne enteropathogen Cryptosporidium parvum. Trans R Soc Trop Med Hyg 2012;106:645-52.
7. Mustafa A, Scholz M, Khan S, et al. Application of solar disinfection for treatment of contaminated public water supply in a developing country: field observations. J Water Health 2013;11:135-45.
8. Sobsey MD, Stauber CE, Casanova LM, et al. Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world. Environ Sci Technol 2008;42:4261-7.
9. Ren D, Colosi LM, Smith JA. Evaluating the sustainability of ceramic filters for point-of-use drinking water treatment. Environ Sci Technol 2013;47:11206-13.
10. Salvinelli C, Elmore AC, Reidmeyer MR, et al. Characterization of the relationship between ceramic pot filter water production and turbidity in source water. Water Res 2016;104:28-33.
11. Langenbach K, Kuschk P, Horn H, et al. Slow sand filtration of secondary clarifier effluent for wastewater reuse. Environ Sci Technol 2009;43:5896-901.
12. Jiang JQ, Ashekuzzaman SM, Jiang A, et al. Arsenic contaminated groundwater and its treatment options in Bangladesh. Int J Environ Res Public Health 2012;10:18-46.
13. Malik AH, Khan ZM, Mahmood Q, et al. Perspectives of low cost arsenic remediation of drinking water in Pakistan and other countries. J Hazard Mater 2009;168:1-12.
14. Abebe LS, Chen X, Sobsey MD. Chitosan Coagulation to Improve Microbial and Turbidity Removal by Ceramic Water Filtration for Household Drinking Water Treatment. Int J Environ Res Public Health 2016;13(3).
15. Qi W, Singer H, Berg M, et al. Elimination of polar micropollutants and anthropogenic markers by wastewater treatment in Beijing, China. Chemosphere 2015;119:1054-61.
16. Graf J, Zebaze Togouet S, Kemka N, et al. Health gains

from solar water disinfection (SODIS): evaluation of a water quality intervention in Yaounde, Cameroon. J Water Health 2010;8:779-96.

17. Wilhelm N, Kaufmann A, Blanton E, et al. Sodium hypochlorite dosage for household and emergency water treatment: updated recommendations. J Water Health. 2018;16:112-25.
18. Clasen T. Household Water Treatment and Safe Storage to Prevent Diarrheal Disease in Developing Countries. Curr Environ Health Rep 2015;2:69-74.
19. Xu J, Huang C, Shi X, et al. Role of drinking water biofilms on residual chlorine decay and trihalomethane formation: An experimental and modeling study. Sci Total Environ 2018;642:516-25.
20. Shi P, Jia SY, Zhang XX, et al. Metagenomic insights into chlorination effects on microbial antibiotic resistance in drinking water. Water Res 2013;47:111-20.
21. Miranda AC, Lepretti M, Rizzo L, et al. Surface water disinfection by chlorination and advanced oxidation processes: Inactivation of an antibiotic resistant E-coli strain and cytotoxicity evaluation. Sci Total Environ 2016;554-555:1-6.
22. Sobsey MD, Handzel T, Venczel L. Chlorination and safe storage of household drinking water in developing countries to reduce waterborne disease. Water Sci Technol. 2003;47:221-8.
23. Lantagne SD, Quick R, Mintz ED. Household Water Treatment and Safe Storage Options in Developing Countires: A Review of Current Implementation Practices. Available online: https://www.wilsoncenter.org/sites/default/files/WaterStoriesHousehold.pdf, last accessed 09.18.2018.
24. Imanishi M, Kweza PF, Slayton RB, et al. Household water treatment uptake during a public health response to a large typhoid fever outbreak in Harare, Zimbabwe. Am J Trop Med Hyg 2014;90:945-54.
25. Mosler HJ, Kraemer SM, Johnston RB. Achieving long-term use of solar water disinfection in Zimbabwe. Public Health 2013;127:92-8.
26. Lea M. Biological sand filters: low-cost bioremediation technique for production of clean drinking water. Curr Protoc Microbiol 2014;33:1G.1.1-26.
27. Clark PA, Pinedo CA, Fadus M, et al. Slow-sand water filter: design, implementation, accessibility and sustainability in developing countries. Med Sci Monit 2012;18:RA105-17.
28. D'Alessio M, Yoneyama B, Kirs M, et al. Pharmaceutically active compounds: Their removal during slow sand filtration and their impact on slow sand filtration bacterial removal. Sci Total Environ 2015;524-525:124-35.
29. US4911831A. Slow sand filters. Available online: https://patents.google.com/patent/US4911831A/en, last accessed 09.18.2018.
30. Hoslett J, Massara TM, Malamis S, et al. Surface water filtration using granular media and membranes: A review. Sci Total Environ 2018;639:1268-82.
31. Membrane Filtration. Available online: https://www.mrwa.com/WaterWorksMnl/Chapter%2019%20Membrane%20Filtration.pdf, last accessed 09.18.2018.
32. Owen G, Bandi M, Howell JA, et al. Economic-Assessment of Membrane Processes for Water and Waste-Water Treatment. J Membrane Sci 1995;102:77-91.
33. Frimmel FH. Water Chemistry: Science and Technology (Ed.: Fritz H. Frimmel) Part III: Therapy of Aquatic Systems when they Need Help: Water Technology for Specific Water Usage. Environ Sci Pollut Res 2003;10:408-13.
34. Meenakshi, Maheshwari RC. Fluoride in drinking water and its removal. J Hazard Mater 2006;137:456-63.
35. Chaidez C, Ibarra-Rodriguez JR, Valdez-Torres JB, et al. Point-of-use Unit Based on Gravity Ultrafiltration Removes Waterborne Gastrointestinal Pathogens from Untreated Water Sources in Rural Communities. Wilderness Environ Med 2016;27:379-85.
36. Archer AR, Elmore AC, Bell E, et al. Field investigation of arsenic in ceramic pot filter-treated drinking water. Water Sci Technol 2011;63:2193-8.
37. Nair J, Gibbs R, Mathew K, et al. Suitability of the H2S method for testing untreated and chlorinated water supplies. Water Sci Technol 2001;44:119-26.
38. Peter-Varbanets M, Zurbrugg C, Swartz C, et al. Decentralized systems for potable water and the potential of membrane technology. Water Res 2009;43:245-65.

doi: 10.21037/jphe.2018.06.02
Cite this article as: Zinn C, Bailey R, Barkley N, Walsh MR, Hynes A, Coleman T, Savic G, Soltis K, Primm S, Haque U. How are water treatment technologies used in developing countries and which are the most effective? An implication to improve global health. J Public Health Emerg 2018;2:25.