Journal of Environmental Science and Technology

ISSN 1994-7887

Journal of Environmental Science and Technology 4 (1): 18-30, 2011
ISSN 1994-7887 / DOI: 10.3923/jest.2011.18.30

An Overview of Water Disinfection in Developing Countries and Potentials of Renewable Energy

C.G. Okpara, N.F. Oparaku and C.N. Ibeto
National Centre for Energy Research and Development, University of Nigeria, Nsukka, Nigeria

Corresponding Author: C.G. Okpara, National Centre for Energy Research and Development, University of Nigeria, Nsukka, Nigeria

ABSTRACT

Although, three-quarters of the earth's surface is water, only one percent of that water is available for human consumption; and that one percent often contains microorganisms that can cause life threatening waterborne diseases. Water-related diseases are a growing human tragedy, killing more than 5 million people each year-10 times the number of people killed in wars. About 2.3 billion people suffer from diseases linked to dirty water. Some 60% of all infant mortality worldwide is linked to infectious and parasitic diseases, most of them water-related. Renewable energy finds application in disinfection such as solar water disinfection. Disinfection methods include; UV disinfection, boiling, chlorination and use of deep tube wells. Water can also be disinfected with bromine, iodine and ozone. The advantages of UV disinfection over the other methods of disinfection are significant. It is recommended that developing countries inculcate the various outlined disinfection methods as convenient and appropriate. The methods should be adapted to their local conditions inorder to abate health diseases, thereby ensuring the health safety of the populace.

Key words: Disinfection, water, renewable energy, boiling, chlorination

INTRODUCTION

Water is a chemical substance that is essential to all forms of life. It is the most important natural resources on our planet. Water is the medium in which the reactions necessary for living functions take place. It is an active participant in many biological processes; water acts as the carrier of nutrients in the bodies of living organisms and it serves as temperature regulator.

Water is employed by man for several purposes such as in the industry as solvent, in agriculture for irrigation, for recreation, travel, commerce and as regards this study-domestic uses. To meet the above needs, it must satisfy certain requirements. For instance, there are stipulated standards for drinking water by several organizations such as WHO (2004) EU, UK and US EPA as shown in Table 1. The major sources of water in developing countries are rain, streams, well, boreholes etc. Even in Canada, over four million people depend on private wells for their drinking water. In addition, lakes, rivers and other sources of surface water often serve as the sole water supply for cottagers, campers, boaters and hikers (Health Canada, 2008).

Sources of water contamination could be from natural and/or anthropogenic sources. Private wells can become contaminated if they have been poorly constructed or improperly sited or if they have been infiltrated by contaminated surface water. In fact, the aquifer itself can even be the source of contamination. Surface waters and unprotected groundwaters are susceptible to faecal contamination from humans, livestock, wild animals and even house pets.

Water quality is the composition of water as affected by natural processes and human activities. Many different diseases are spread by contaminated drinking water, including Campylobacter, Cholera, Amoebic dysentery, Giardia (beaver fever) and Cryptosporidia. Other pathogenic microorganisms that can be found in drinking water are Caliciviruses, Heliobacter bacteria, Mycobacteria and Giardia Lambia. In the future more pathogenic microorganisms will emerge and spread through water, because of agricultural magnification, increased population growth, increased migration and climate change. Pathogenic microorganisms can also emerge because they built up resistance to disinfectants. These organisms usually get into drinking water supplies when source waters such as lakes or streams, community water supply pipes or storage reservoirs are contaminated by animal wastes or human sewage.

Water disinfection means the removal, deactivation or killing of pathogenic microorganisms. Microorganisms are destroyed or deactivated, resulting in termination of growth and reproduction. When microorganisms are not removed from drinking water, drinking water usage will cause people to fall ill (Lenntech, 1998-2009).

Infectious diseases caused by pathogenic bacteria, viruses and protozoan parasites are among the most common and widespread health risk of drinking water. Drinking water standards shown in Table 1. People are introduced to these microorganisms through contaminated drinking water, water drops, aerosols and washing or bathing. Some waterborne pathogenic microorganisms spread by water can cause severe, life-threatening diseases. Examples are typhoid fever, cholera and hepatitis A or E. Other microorganisms induce less dangerous diseases. Often, diarrhea is the main symptom. People with low resistance, mainly elderly people and young children are vulnerable to these diseases as well (Lenntech, 1998-2009).

Table 1: Drinking water standards

Category/variable	Units	WHO (2004)	Lenntech (1998-2004)	US Environmental Protection Egency (2007)	UK (1992)
Microbial criteria					
Total coliform	Per 100 mL		0	<1	
E. coli	Per 100 mL		0		
Pollution indicators					
Hardness	$CaCO_3$ mg L^{-1}	150-500			
pH range	pH	6.5-8.5		6.5-8.5	5.5-9.5
Conductivity	µS cm^{-1}	250	250		1500
Phosphate	mg L^{-1}				
Total dissolved solids	mg L^{-1}			500	
Inorganic pollutants					
Cadmium	mg L^{-1}	0.003	0.005	0.005	
Chloride	mg L^{-1}	250	250	250	250
Copper	mg L^{-1}	2.0	2.0	1.3	3.0
Iron	mg L^{-1}	0.2	0.2	0.3	0.2
Lead	mg L^{-1}	0.01	0.01	0.015	0.05
Nitrate	mg L^{-1}	50	50	45	50
Sodium	mg L^{-1}	200	200		150
Sulfate	mg L^{-1}	500	250	250	250
Zinc	mg L^{-1}	3		5	5

Sources: Lenntech (1998); WHO (2004); Lenntech (1998-2004); Dale Dorman (1998); US Environmental Protection Egency (2007)

The lack of money needed to develop the elaborate drinking water infrastructure favored in the developed world in addition to the difficulty or impossibility associated with importing materials and expertise necessary for sustainable operation of such facilities demand another solution. Different approaches must therefore be developed and undertaken in the developing world if safe drinking water is to be supplied indefinitely into the future. The following review will provide an overview of techniques capable of eliminating or neutralizing water-borne pathogens using little or no external input (capital, material, expertise, etc.). For instance, studies on the reduction of diarrhea among Solar Disinfection (SODIS) users show reduction values of 30-80% (Rose *et al.*, 2006; Hobbins, 2003).

NEED FOR DISINFECTION

It is estimated that in Latin America more than 40% of the population is utilizing water of dubious quality for human consumption. This value is probably even higher in Africa and areas of Southeast Asia. The cholera pandemic which struck Latin America in January 1991 and has become endemic in many of the countries, continues to exemplify the public health significance of contaminated drinking water (Reiff *et al.*, 1996). Worldwide, 1.2 billion people do not have access to clean and safe drinking water and 2.4 billion people lack sanitation. Every year, 5 million people die of waterborne diseases (Lenntech, 1998-2009). According to an assessment commissioned by the United Nations, 4,000 children die each day as a result of diseases caused by ingestion of filthy water.

The report says four out of every 10 people in the world, particularly those in Africa and Asia, do not have clean water to drink. Villagers collect water from boreholes and consume without any treatment mostly which are highly contaminated by more than one pollutant (Okoye and Okpara, 2010). Most waterborne diseases occur worldwide. In developed (Western) countries, contagion is prevented by drinking water purification and by hygienic measurements. But even in developed countries, people can fall ill from waterborne diseases. This is caused by using insufficiently disinfected water, by implementing non-hygienic food preparation and by insufficient personal hygiene. Water disinfection is necessary to eliminate pathogens, as many horticultural products are to be consumed raw and in regions with high values of solar radiation it can be used for this purpose (Tripanagnostopoulos and Rocamora, 2007).

In developing countries, waterborne diseases are a major problem which contributes to the vicious circle that people are in. In many developing countries, there is a lack of medicine to treat ill people. Vaccination is usually very scarce as well. Many people weaken because of waterborne disease and, as a result, are more susceptive to other infections. Their physical capacity decreases and they cannot work and provide their families with money and food. A lack of sufficient nutritional food weakens people, especially children, even further. They become even more susceptible to diseases. Children run behind at school, because they cannot be educated when they are ill. Waterborne diseases frustrate the economic development of many people. During wars and natural disasters (floods) many people are infected with waterborne diseases. Diseases are easily spread because water treatment and sewage no longer function or are lacking completely (Lenntech, 1998-2009).

To improve the economical progress of developing countries, water contamination and spread of infectious diseases must be handled. This is achieved through (drinking) water treatment, sewage, waste and sewage water treatment and education on personal and food hygiene. Analysts say eliminating disease and death due to unclean water and poor sanitation would reap billions of dollars in health and productivity gains. They estimate that for every dollar spent, there would be an economic return of between $3 and 34, depending upon the country.

ROLE OF RENEWABLE ENERGY

- Minimise long term environmental consequences (global warming of CO_2 emissions)
- Minimise near-time health impact of fossil fuel emissions
- Create new economic opportunities for companies and workers
- Job creation in the industrial world
- Potential for growth in the developing countries
- Spend less on energy, more on community

DISINFECTION METHODS

Water can be disinfected with heat, chemicals, or light. For chemical disinfection of water the following disinfectants can be used: chlorine (Cl_2); chlorine dioxide (ClO_2); hypo chlorite (OCl^-); ozone (O_3); halogens: bromine (Br_2), iodine (I), bromine chloride (BrCl); metals: copper (Cu^{2+}), silver (Ag^+); kaliumpermanganate ($KMnO_4$); phenols; alcohols; kwartair ammonium salts; hydrogen peroxide; several acids and bases. Chlorine also oxidizes iron and manganese so they can be filtered out. Ozone may be used to disinfect public water supplies, but is rarely used for private supplies (Liukkonen, 2006).

The factors that determine the selection of disinfectants are mainly availability, cost factors, logistics, cost of equipment and safety factor.

UV DISINFECTION OF WATER

Solar radiation is a form of renewable energy that is abundant and accessible in most Southern countries. Sunlight with wavelengths of 315-400 nm on the ultraviolet (UV) range of the electromagnetic spectrum is most effective at destroying bacteria. Since colourless glass or plastic can transmit light in this near ultraviolet range, they are the best materials for disinfection. Visible light (400-750 nm) next in terms of efficiency, with the visible band of violet and blue light (400-490 nm) is the most useful within this range. As a result, violet, blue and very light green-tinted glass follow colourless glass or plastic in order of suitability (Lawand *et al.*, 1997).

As noted by Wolfe (1990), the disinfection of drinking water with ultraviolet light first took place in the early 1900s. However, the systems were not highly successful for a number of reasons, including high operating costs, poor equipment reliability, maintenance problems and the advent of chlorination, which was found to be more efficient and reliable. The UV technology has improved and become less expensive since the turn of the century. In Europe, UV has been used for the bacteriological disinfection of water for a number of years (Taylor, 2003). Currently, approximately 2000 water treatment plants in Europe use UV disinfection systems (Wolfe, 1990).

Ultraviolet disinfection of water consists of a purely physical, chemical-free process. The UVC radiation in particular, with a wavelength in the 240 to 280 nanometers range, attacks the vital DNA of the bacteria directly. The radiation initiates a photochemical reaction that destroys the genetic information contained in the DNA. The bacteria lose their reproductive capability and are destroyed. Even parasites such as Cryptosporidia or Giardia, which are extremely resistant to chemical disinfectants, are efficiently reduced. The sterilized microorganisms are not removed from the water. UV disinfection does not remove dissolved organics, inorganic compounds or particles in the water (Harm, 1980). However, UV-oxidation processes can be used to simultaneously destroy trace chemical contaminants and provide high-level disinfection, such as the world's largest Indirect Potable Reuse plant in Orange County, California (Wikipedia, 2009a). To assure thorough treatment, the water must be free of turbidity and color. Otherwise some bacteria will be protected from the germ-killing ultraviolet rays. Since ultraviolet light adds nothing to the water, there is little possibility of its creating taste or odor problems.

Common UV applications: One of the most common uses of ultraviolet sterilization is the disinfection of domestic water supplies due to contaminated wells. Coupled with appropriate pre-treatment equipment, UV provides an economical, efficient and user-friendly means of producing potable water. The following list shows a few more areas where ultraviolet technology is currently in use: surface water, groundwater, cisterns, breweries, hospitals, restaurants, vending, cosmetics, bakeries, schools, boiler feed water, laboratories, wineries, dairies, farms, hydroponics, spas, canneries, food products, distilleries, fish hatcheries, water softeners, bottled water plants, pharmaceuticals, mortgage approvals, electronics, aquaria, boats and RV's, printing, buffer processing, petro-chemical, photography and pre- and post-reverse osmosis.

Factors affecting the effectiveness of UV disinfection:

- Because UV does not leave any measurable residual in the water, it is recommended that the UV sterilizer be installed as the final step of treatment and located as close as possible to the final distribution system. Once the quality of your water source has been determined, you will need to look at things that will inhibit the UV from functioning properly (e.g., iron manganese, TDS, turbidity and suspended solids)
- Iron and manganese will cause staining on the quartz sleeve and prevent the UV energy from transmitting into the water at levels as low as 0.03 ppm of iron and 0.05 ppm of manganese. Proper pre-treatment with a sediment filter and Triangular Wave Deposit Control System is required to eliminate this staining problem
- Total Dissolved Solids (TDS) should not exceed approximately 500 ppm (about 8 grains of hardness). There are many factors that make up this equation such as the particular make-up of the dissolved solids and how fast they absorb the available UV energy. Calcium and magnesium, in high amounts, have a tendency to build up on the quartz sleeve, again impeding the UV energy from penetrating the water. A triangular wave deposit control system will handle TDS before it becomes a problem for the UV system
- Turbidity is the inability of light to travel through water. Turbidity makes water cloudy and aesthetically unpleasant. In the case of UV, levels over 1 NTU can shield microorganisms from the UV energy, making the process ineffective. Suspended Solids need to be reduced to a maximum of 5 μ in size. Larger solids have the potential of harboring or encompassing the microorganisms and preventing the necessary UV exposure. Pre-filtration is a must on all UV applications to effectively destroy microorganisms to a 99.9% kill rate
- An additional factor affecting UV is temperature. The optimal operating temperature of a UV lamp must be near 40°C (104°F). The UV levels fluctuate with temperature levels. Typically a quartz sleeve is installed to buffer direct lamp-water contact thereby reducing any temperature fluctuations

Advantages of ultraviolet light: Automatic, no taste or odor and low contact time. A major advantage of UV treatment is that it is capable of disinfecting water faster than chlorine without cumbersome retention tanks and harmful chemicals. UV treatment systems are also extremely cost efficient.

- Environmentally friendly, no dangerous chemicals to handle or store, no problems of overdosing
- Universally accepted disinfection system for potable and non-potable water systems
- Low initial capital cost as well as reduced operating expenses when compared with similar technologies such as ozone, chlorine, etc.
- Immediate treatment process, no need for holding tanks, long retention times, etc.
- Extremely economical, hundreds of gallons may be treated for each penny of operating cost.
- Low power consumption
- No chemicals added to the water supply-no by-products (i.e., chlorine+organics = trihalomethanes)
- Safe to use
- No removal of beneficial minerals
- No change in taste, odor, pH or conductivity nor the general chemistry of the water
- Automatic operation without special attention or measurement, operator friendly
- Simplicity and ease of maintenance, TWT deposit control system prevents scale formation of quartz sleeve, annual lamp replacement, no moving parts to wear out
- No handling of toxic chemicals, no need for specialized storage requirements, no OHSA requirements
- Easy installation, only two water connections and a power connection
- More effective against viruses than chlorine
- Compatible with all other water processes (i.e., RO, filtration, ion exchange, etc.)

Disadvantages of ultraviolet light: Low penetration power, shielding by turbidity, slime layer develops on tube, no simple test of results, no residual effect and ultraviolet tube gradually loses power.

The cost of ultraviolet disinfection: The estimated one-time capital cost of an ultraviolet system is $500, including valve, fittings and labor. The life of the stainless-steel chamber is expected to be approximately 40 years; the UV lamp requires replacement annually. At 12% discount rate, the annualized capital cost of the UV system is approximately $60 year^{-1}. Assuming that the system is operational for 12 h day^{-1} and that the price of electricity is 8 cents kW h^{-1}, the annual operating cost of a UV system is approximately $44 (including the replacement UV lamp and the cost of electricity). Thus, the total annual cost is approximately $104. It is assumed that the villagers provide their own storage tanks and sand filter; the raw materials for these components are readily available and inexpensive. These are not included in the present cost calculations. Operating for 12 h per day, the system will disinfect 7884 tonnes (7.9 million liters) of water annually. The cost of disinfecting water is thus about I per ton. Based on a per capita drinking water requirement of 10 liters per day, a single system can provide enough water for approximately 2200 villagers. Accordingly, a UV system could ensure potable water year-round for a community of 2200 people at a cost of about 5 cents per villager per year (Gadgil and Shown, 1995).

Guidelines for the application of Solar Disinfection (SODIS) at household level

- Water from contaminated sources are filled into transparent water bottles. For oxygen saturation, bottles can be filled three quarters, then shaken for 20 sec (with the cap on), then filled completely. Highly turbid water (turbidity higher than 30 NTU) must be filtered prior to exposure to the sunlight

Table 2: Suggested treatment schedule

Weather conditions	Minimum treatment duration
Sunny	6 h
50% cloudy	6 h
50-100% cloudy	2 days
Continuous rainfall	Unsatisfactory performance, use rainwater harvesting

- Filled bottles are then exposed to the sun. The effective duration of exposure to the depends on the weather condition as shown in Table 2. Better temperature effects can be achieved if bottles are placed on a corrugated roof as compared to thatched roofs
- The treated water can be consumed. The risk of re-contamination can be minimized if water is stored in the bottles. The water should be consumed directly from the bottle or poured into clean drinking cups. Re-filling and storage in other containers increases the risk of contamination

The following issues should also be considered:

- **Bottle material:** Some glass or PVC materials may prevent ultraviolet light from reaching the water (Wikipedia, 2009b). Commercially available bottles made of PET are recommended. The handling is much more convenient in the case of PET bottles. Polycarbonate blocks all UVA and UVB rays and therefore should not be used
- **Aging of plastic bottles:** The SODIS efficiency depends on the physical condition of the plastic bottles, with scratches and other signs of wear reducing the efficiency of SODIS. Heavily scratched or old, blind bottles should be replaced
- **Shape of containers:** The intensity of the UV radiation decreases rapidly with increasing water depth. At a water depth of 10 cm and moderate turbidity of 26 NTU, UV-A radiation is reduced to 50%. PET soft drink bottles are often easily available and thus most practical for the SODIS application
- **Oxygen:** Sunlight produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) in the water. These reactive molecules contribute in the destruction process of the microorganisms. Under normal conditions (rivers, creeks, wells, ponds, tap) water contains sufficient oxygen (more than 3 mg oxygen per litre) and does not have to be aerated before the application of SODIS
- **Leaching of bottle material:** There has been some concern over the question whether plastic drinking containers can release chemicals or toxic components into water, a process possibly accelerated by heat. The Swiss Federal Laboratories for Materials Testing and Research have examined the diffusion of adipates and phthalates from new and reused PET-bottles in the water during solar exposure. The levels of concentrations found in the water after a solar exposure of 17 h in 60°C water were far below WHO guidelines for drinking water and in the same magnitude as the concentrations of phthalate and adipate generally found in high quality tap water

BOILING

In terms of limiting the need for external inputs, it would be difficult to imagine a technique simpler and more sustainable than boiling water. Water is simply placed in a clean container and brought to a full boil for at least three minutes. This will eliminate all pathogenic activity, including giardia (Extension Bulletin 795, 2003). The best means of water disinfection is boiling (for about 1 h) which destroyed all the coliform in the water (Ibeto *et al*., 2010).

This conventional method can be time-consuming and expensive. In many areas, there is little fuel available for boiling water. Although, very few Indian villagers disinfect their drinking water by boiling it over a cook stove, this is common practice among rural families in some developing countries (e.g., China). The burning of biomass fuels for water disinfection increases the pressure on the forests. In many areas of India as well as other developing countries, deforestation is extensive, wood fuel supplies have dwindled and families are forced to depend on residue fuels such as crop residues, cattle dung and twigs. Collection of fuel wood is an increasingly difficult chore for rural women in India. In addition, there is serious health risks associated with smoke inhalation from biomass-fueled traditional cook stoves (Gadgil and Shown, 1995).

In order to eliminate biological activity, pasteurization temperature (150°F or 65°C) must be achieved. This is difficult to do with plastic bottles alone. The simplest solutions to this problem are the solar box and the solar pond. A solar box consists of an insulated box constructed from wood or cardboard with a glass or plastic lid. The inside surfaces should be painted black. A covered vessel with water (ideally, also black) is placed inside. The pot needs to remain in the box until pasteurization temperature is achieved for a few minutes. On average, a solar box can pasteurize about 1 gallon of water in 3 h on a very sunny day (Rolla, 1998).

Advantages

- Readily available
- Well-suited for emergency and temporary disinfection
- Will drive volatile organic chemicals out of water
- Extremely effective disinfectant that will kill even giardia cysts

Disadvantages

- Requires a great deal of heat
- Time to bring water to boil and cool before use
- Can give water stale taste
- Typically limited capacity
- Not an in-line treatment system
- Requires separate storage of treated water

The cost of boiling water: The estimated cost of wood used to boil water was US$ 0.272 per month for wood collectors and US$ 1.68 per month for wood purchasers, representing approximately 0.48 to 1.04%, respectively, of the average monthly income of participating households (Clasen *et al*., 2008) (Table 3).

Table 3: Costs and capacities of different boiling and solar treatment schemes

System name	Unit cost (US dollar)	Liters of water/dollar
Flame-heated water pot (Heated to boiling with no pasteurization indicator)	Small	50
Flame-heated water pot with pasteurization indicator	3	96
Solar box cooker with pasteurization indicator	23	580
Solar puddle (family size)	6	1800
Solar puddle (community size, 10'×25'')	25	3500

Source: Andreatta *et al*. (1994)

CHLORINE DISINFECTION

Chlorine disinfection kills all pathogens, including giardia. In addition, chlorine has a residual effect; that is, if bacteria are reintroduced into a chlorinated water supply, the new bacteria will die. Although, chlorine disinfection is a well-proven technique, it has a few disadvantages. Often, people dislike the taste and smell of chlorinated water. In some regions, it is difficult to ensure a reliable supply of chlorine. In addition, because it is easy to overdose water with chlorine, it is necessary for a trained person to test chlorine levels before water is consumed. Most importantly, it is necessary to maintain a steady supply of chlorine bleach; the current cholera outbreaks in India are largely attributed to a breakdown in its supply chain (Times of India, 1994).

Advantages

- Provides residual disinfectant
- Residual easy to measure
- Chlorine readily available at reasonable cost
- Low electrical requirement
- Can be used for multiple water problems (bacteria, iron, manganese, hydrogen sulfide)
- Can treat large volumes of water

Disadvantages

- Requires contact time of 30 min for simple chlorination
- Turbidity (cloudy water) can reduce the effectiveness of chlorine
- Gives water a chlorine taste
- May combine with organic contaminants to form cancer-causing compounds
- Does not kill giardia cysts at low levels
- Careful storage and handling of chlorine is required (Curators of the University of Missouri, 1995)

Disadvantages of Chemical method of disinfection: Many disinfection byproducts are bioaccumulative. They are not destroyed by the body and can accumulate in body tissues. Some disinfection byproducts are considered harmful for public health (chloroform, dibromochloromethane and bromoform are probably carcinogenic and dichlorobromomethane, dichloroacetonitrile and chloral hydrates are possibly carcinogenic).

- Scientists fear that 14-16% of all bladder cancer cases can be attributed to exposure to disinfection byproducts (Lenntech, 1998-2009)
- Another study proved that people who were exposed to concentrations of 50 $\mu g\ L^{-1}$ or more had 1.5 times bigger risk developing intestinal cancer (Lenntech, 1998-2009)
- The number of epidemiological studies on exposure to disinfection byproducts and the influence on reproduction and birth defects is small. However, these studies show there is a connection between exposure to trihalomethanes and spontaneous abortion, birth defects and growth delay (Lenntech, 1998-2009)
- The risk on abdominal wall defects increases significantly after higher exposure (Bing-Fang, 2002 in Lenntech, 1998-2009)
- A research in Sweden showed that trihalomethane concentrations lower than the standard levels still have effects on reproduction (Lenntech, 1998-2009)
- Immunity of women exposed to chlorine dioxide is decreased

DEEP TUBEWELLS

In India, many rural families obtain drinking water from deep tubewells. Because the wells are more than 200" deep, the water has been sealed beneath an impermeable layer of earth for a long time and is commonly bacteria-free. One disadvantage of obtaining water from a deep tubewell is that many people dislike the taste. Because the water is old, it has a high dissolved salt content and many people prefer the taste of fresher, surface water. Additionally, deep tubewells can be expensive and time-consuming to construct because of the specialized deep-drilling equipment that is required. Tubewell cannot be easily moved from one place to another as needed (Gadgil and Shown, 1995).

FILTRATION

Filters work by physically removing infectious agents from the water. The organisms vary tremendously in size, from large parasitic cysts (Giardia and Entamoeba histolytica 5-30 µm), to smaller bacteria (*E. coli* 0.5×3 µm, Campylobacter 0.2×2 µm), to the smallest viruses (0.03 µm). Thus, how well filters work depends to a great extent on the physical size of the pores in the filter medium. Hence, Table 4 shows microorganism size and susceptibility to filtration. Reverse osmosis filtration can both remove microbiologic contamination and desalinate water. The high price and slow output of small hand-pump reverse-osmosis units currently prohibit use by rural dwellers; however, they are important survival aids for ocean voyagers.

Filters have the advantage of providing immediate access to drinking water without adding an unpleasant taste. However, they suffer from several disadvantages: micro cracks or eroded channels within the filter may allow passage of unfiltered water, they can become contaminated and no filters sold for field use are fine enough to remove virus particles (Hepatitis A, rotavirus, Norwalk virus, poliovirus and others). In addition, they are expensive and bulky compared to iodine.

Slow Sand Filtration (SSF) is the world's oldest known water treatment system. It emulates nature's purification process when rainwater seeps through the layers of the earth's crust and forms aquifers or underground rivers. Slow filtration is used mainly to eliminate water turbidity, but can be considered a water disinfection system if it is properly designed and operated. Unlike rapid sand filtration, in which the microorganisms are stored in the filter interstices until they are returned to the source water through backwashing, SSF consists of a group of physical and biological processes that destroy waterborne pathogens. It is a clean technology that purifies water without creating any additional source of environmental contamination.

A slow filter is basically a box or tank containing a floating layer of the water to be disinfected, a sand filter bed, drains and a set of regulating and control devices.

Slow f iltration is a simple, clean, yet efficient water treatment system. It needs larger areas than a rapid filtration system to treat the same water flow. Therefore, its initial cost is higher. Its simplicity and low operating and maintenance costs, however, make it an ideal system for rural areas and small communities, considering also that the land in those areas is relatively less expensive.

Table 4: Microorganism size and susceptibility to filtration

Organism	Average size (µm)	Maximum recommended filter rating (µm absolute)
Viruses	0.03	Not specified
Enteric bacteria (*E. coli*)	0.5×3.0–8.0	0.2-0.4
Cryptosporidium oocyst	4-6	1.0
Giardia cyst	6.0-10.0×8.0-15.0	3.0-5.0

Source: Backer (1995)

Factors that influence water disinfection

- **Contact time (CT):** Contact time between disinfectant and microorganism and the concentration of disinfectant, CT is used to calculate how much disinfectant is required to adequately disinfect water. C refers to the final residual concentration of a particular chemical disinfectant in mg L^{-1}. T refers to the minimum contact time (minutes) of material that is disinfected with the disinfectant :

$$CT = \text{disinfectant concentration} \times \text{Contact time} = C\ (\text{mg L}^{-1}) \times T\ (\text{min})$$

  When a particular disinfectant is added to water, it does not only react with pathogenic microorganisms, but also with other impurities, such as soluble metals, particles of organic matter and other microorganisms. The utilization of a disinfectant for reactions with these substances makes up the disinfection demand of the water
- **The type of microorganism:** Disinfectants can effectively kill pathogenic microorganisms (bacteria, viruses and parasites). Some microorganisms can be resistant. *E. coli* bacteria, for example, are more resistant to disinfectants than other bacteria and are therefore used as indicator organisms. Several viruses are even more resistant than *E. coli*. The absence of *E. coli* bacteria does not mean that the water is safe. Protozoan parasites like Cryptosporidium and Giardia are very resistant to chlorine
- **The age of the microorganism:** The affectivity of a particular disinfectant also depends upon the age of the microorganism. Young bacteria are easier to kill than older bacteria. When bacteria grow older, they develop a polysaccharide shell over their cell wall, which makes them more resistant to disinfectants. When 2.0 mg L^{-1} chlorine is used, the required contact time to deactivate bacteria that are 10 days old is 30 min. For bacteria of the same species and of the age of 1 day 1 min, contact time is sufficient. Bacterial spores can be very resistant. Most disinfectants are not effective against bacterial spores
- **Water that requires treatment:** The nature of the water that requires treatment has its influence on the disinfection. Materials in the water, for example iron, manganese, hydrogen sulphide and nitrates often react with disinfectants, which disturb disinfection. Turbidity of the water also reduces the affectivity of disinfection. Microorganisms are protected against disinfection by turbidity
- **Temperature:** The temperature also influences the affectivity of disinfection. Increasing temperatures usually increases the speed of reactions and of disinfection. Increasing temperatures can also decrease disinfection, because the disinfectant falls apart or is volatized

A summary of the degree of cost, required expertise, required external inputs and Adverse health effects of the different disinfection methods is shown in Table 5.

Table 5: Treatment summary

Issues	Boiling	Plastic bottles	Solar box/pond	Iodine	Chlorine	Slow-sand filtration
Cost	Low to high	Low	Low to moderate	Moderate to high	Moderate to high	Low to moderate
Required expertise	Low	Low	Low to moderate	Low to moderate	Low to moderate	Moderate to high
Required external inputs	Low to high	Low	Low to moderate	Moderate to high	Moderate to high	Low to moderate
Adverse health effects	None	None	None	Yes	Yes	None

CONCLUSION

The recent controversy about the safety of chlorine and its by products has renewed interest in other forms of disinfection. From the health point of view, achieving the water and sanitation target by simple technologies would lead to global average reduction of 10% of episodes of diarrhea. The burden of disease associated with lack of assess to safe water supply, adequate sanitation and lack of hygiene is concentrated on children under five in developing countries. Accordingly, emphasis should be placed on interventions likely to yield an accelerated, affordable and sustainable health gains. This review points to household water treatment and safe storage as an option of particular potential with high health improvements and low costs. It is recommended that developing countries inculcate the various outlined disinfection methods adapting it to their local conditions inorder to abate health diseases; thereby ensuring the health safety of the populace.

REFERENCES

Andreatta, D., E. Derek, T. Yegian, L. Connelly and R.H. Metcalf, 1994. Recent advances in devices for the heat pasteurization of drinking water in the developing world. Proceedings of the 29th Intersociety Energy Conversion Engineering Conference, American Institute of Aeronautics and Astronautics, Inc., April 11.

Backer, H.D., 1995. Field Water Disinfection. In: Wilderness Medicine: Management of Wilderness and Environmental Emergencies, Auerbach, P.S. (Eds.). 3rd Edn., St. Louis, Mosby, London, ISBN: 0-8016-7044-6, pp: 1506.

Clasen, T.F., D.H. Thao, S. Boisson and O. Shipin, 2008. Microbiological effectiveness and cost of boiling to disinfect drinking water in rural vietnam. Environ. Sci. Technol., 42: 4255-4260.

Curators of the University of Missouri, 1995. Bacteria in drinking water. http://extension.missouri.edu/publications/DisplayPub.aspx?P=WQ102.

Dale Dorman, M.S., 1998. Water quality problems: Health and household. Environ. Sci. Technol., 42: 4255-4260.

Extension Bulletin 795, 2003. Ultraviolet. The Ohio State University, Michigan Technological University, Master's International Program. http://ohioline.osu.edu/b795/b795_9.html.

Gadgil, A.J. and L.J. Shown, 1995. To drink without risk: The use of ultraviolet light to disinfect drinking water in developing countries. http://solarcooking.org/ultraviolet1.htm.

Harm, W., 1980. Biological Effects of Ultraviolet Radiation. IUPAD Biophysics Series I. Cambridge University Press, Cambridge.

Health Canada, 2008. Water treatment devices for disinfection of drinking water. Environmental and Workplace Health. http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/disinfect-desinfection-eng.php.

Hobbins, M. 2003. The SODIS health impact study. Ph.D. Thesis, Swiss Tropical Institute Basel.

Ibeto, C.N., N.F. Oparaku and C.G. Okpara, 2010. Comparative study of renewable energy based water disinfection methods for developing countries. J. Environ. Sci. Technol., 4: 226-231.

Lawand, T.A., J. Ayoub and H. Gichenje, 1997. Solar disinfection of water using transparent plastic bags. RERIC Int. Energy J., 19: 237-237.

Lenntech, 1998. WHO's drinking water standards 1993. http://www.lenntech.com/feedback2.htm.

Lenntech, 1998-2004. WHO/EU drinking water standards comparative table. http://www.lenntech.com/who-eu-water-standards.htm.

Lenntech, 1998-2009. Waterborne diseases: Contagion by pathogenic microorganisms. http://www.lenntech.com/processes/disinfection/waterborne-disease-contagion.htm.

Liukkonen, B., 2006. Disinfection of well water. University of MN Water Resources Center: Center for Disease Control; MN Dept. Health. No 312.

Okoye, C.O.B. and C.G. Okpara, 2010. Physico-chemical studies and bacteriological assay of groundwater resources in Isuikwuato Local Government Area of Abia State. J. Chem. Soc. Nigeria. Vol. 35(1).

Reiff, F.M., M. Roses, L. Venczel, R. Quick and V.M. Witt, 1996. Low-cost safe water for the world: A practical interim solution. J. Public Health Policy, 17: 389-408.

Rolla, T.C., 1998. Sun and water: An overview of solar water treatment devices. J. Environ. Health, 60: 30-30.

Rose, A., S. Roy, V. Abraham, G. Holmgren and K. George1 *et al.*, 2006. Solar disinfection of water for diarrhoeal prevention in Southern India. Arch. Dis. Childhood, 91: 139-141.

Taylor, M.M., 2003. UV disinfection of drinking-water. UV9 Version 24/03/03 1 MEUT Ministry of Health New Zealand, pp: 1-14.

Times of India, 1994. Government blamed for diarrhea, Cholera deaths in Bihar. August 22, pp: 3.

Tripanagnostopoulos, Y. and M.C. Rocamora, 2007. Use of solar thermal collectors for disinfection of greenhouse hydroponic water. Acta Horticulturae, 801: 749-756.

US Environmental Protection Agency, 2007. Drinking water contaminants. University of Missouri Extension, WQ102.

WHO, 2004. Guidelines for Drinking Water Quality. 3rd Edn., World Health Organization, Geneva.

Wikipedia, 2009a. Solar water disinfection. http://en.wikipedia.org/wiki/Solar_water_disinfection.

Wikipedia, 2009b. UV water disinfection. http://en.wikipedia.org/wiki/uv_water_disinfection.

Wolfe, R.L., 1990. Ultraviolet disinfection of potable water. Environ. Sci. Technol., 24: 768-773.