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Low-Cost Sustainable Technologies for the Production of Clean Drinking Water—A Review[*]

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ABSTRACT

Water has always been an important and life-sustaining drink to humans and is essential to the survival of all known organisms. Over large parts of the world, humans have inadequate access to drinking water and use water contaminated with disease vectors, pathogens or unacceptable levels of toxins or suspended solids. Drinking such water or using it in food preparation leads to widespread, acute and chronic illnesses and is a major cause of death and misery in many countries. The UN estimates that over 2.0 billion people have limited access to safe water and nearly 800 million people lack even the most basic supply of clean water. The main issue is the affordability of water purifying systems. Many people rely on boiling water or bottled water, which can be expensive. Therefore, technologies that are cost effective, sustainable, ease of operation/maintenance and the treatment processes with locally available materials are required. In this article, some unique low-cost sustainable technologies available/or in-use, *i.e*. natural filtration, riverbank filtration, biosand filtration, membrane filtration, solar water disinfection technique, biologically degradable materials such as moringa powder, scallop powder treatment, and biosand pitcher treatments have been discussed.

KEYWORDS

Sustainable Technology; Clean Drinking Water; Low Cost; Bio-Sand Filtration; Natural Filtration; Solar Disinfection

1. Introduction

Water has always been an important and life-sustaining drink to humans and is essential to the survival of all known organisms. Over large parts of the world, humans have inadequate access to drinking water and use sources contaminated with disease vectors, pathogens or unacceptable levels of toxins or suspended solids. Drinking such water or using it in food preparation leads to widespread, acute and chronic illnesses and is a major cause of death and misery in many countries. The UN estimates that over 2 billion people have limited access to safe water. Of these, nearly 800 million people lack even the most basic supply of clean water. There are few methods commonly advocated for the disinfection of drinking water at the household level. These include boiling of water for about 10 minutes, or the use of certain chlorine compounds available in the form of tablets (Halazone tablets, or calcium hypochlorite tablets) or solutions (sodium hypochlorite solutions). These tablets have an expiration date, and the instructions call for the addition of 1 to 2 tablets per liter of water and waiting for 25 minutes before use.

As each of these procedures has its own drawbacks,

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their application is extremely limited in the developing regions of the world where water-borne diseases are prevalent, and the safety of drinking water supplies cannot always be assured. Availability and costs are the only part of the problem. In the case of boiling, for instance, the need for about one kilogram of wood to boil one liter of water is totally unjustifiable in fuel-short regions already suffering from aridity and desertification. Besides, the disagreeable taste of boiled water often discourages consumers. The addition of 1 to 2 drops of 5% sodium hypochlorite solution per liter of water requires the use of a dropper and liter measure, both being uncommon devices in most homes. In view of these difficulties and constraints, technologies that are cost effective and sustainable must be developed. Sustainable operation of these treatment processes with locally available materials and ease of maintenance is required. In this review article, we focused on the low-cost sustainable technologies available or in-use for the production of clean drinking water.

2. Available Sources of Water

Water although covering 70% of the Earth's surface, most water is saline. Freshwater comprises only three percent of the total water available to humans. Of that, only 0.06 percent is easily accessible—mostly in rivers, lakes, wells, and natural springs. Even then, accessible water is not necessarily safe drinking water. The freshwater sources from which most of our drinking water is derived are exposed to a variety of contaminants, many arising from the unsafe production, utilization, and disposal of inorganic and organic compounds.

Freshwater is available in almost all populated areas of the earth, although it may be expensive and the supply may not always be sustainable. Sources where water may be obtained include:

1) Groundwater: The water emerging from some deep ground water may have fallen as rain many thousands of years ago. Soil and rock layers naturally filter the ground water to a high degree of clarity and often it does not require additional treatment other than adding secondary disinfectants.

2) Upland lakes and reservoirs: Typically located in the headwaters of river systems, upland reservoirs are usually sited above any human habitation and may be surrounded by a protective zone to restrict the opportunities for contamination. Bacteria and pathogen levels are usually low, but some bacteria, protozoa or algae will be present. Where uplands are forested or peaty, humic acids can color the water. Many upland sources have low pH, which require adjustment.

3) Rivers, canals and low land reservoirs: Low land surface waters will have a significant bacterial load and may also contain algae, suspended solids and a variety of dissolved constituents.

4) Atmospheric water generation is a new technology that can provide high quality drinking water by extracting water from the air by cooling the air and thus condensing water vapor.

5) Rainwater harvesting or fog collection which collects water from the atmosphere can be used especially in areas with significant dry seasons and in areas which experience fog even when there is little rain.

6) Desalination of seawater by distillation or reverse osmosis.

7) Water supply network: Tap water, delivered by domestic water systems in different countries nations, refers to water supply network.

The most efficient way to transport and deliver potable water is through pipes. Plumbing can require significant capital investment. Some systems suffer high operating and maintenance costs. Because of these high initial investments, many developing nations cannot afford to develop or sustain appropriate infrastructure, and as a consequence people in these areas may spend hardship for water. Over 40 countries in the world suffer from a safe drinking water deficit, with an estimated 1.2 billion people drinking unclean water on a daily basis and five million people, mostly children, dying every year from water-related diseases. The United Nations estimates that, by 2025, 2.7 billion people will not have access to safe drinking water. However, three major factors including 1) untreated municipal and domestic sewage; 2) untreated industrial effluents; and 3) agricultural run-off are attributed to the freshwater crisis in developing countries.

3. The Challenge of Monitoring Water Quality

Sustainable water quality management requires rigorous and regular monitoring of water resources for all potential contaminants so that appropriate actions can be taken to prevent or remediate water pollution. But rigorous and regular water quality monitoring is not a simple task. The CWA (Clean Water Act, 1972) triggered engineering changes in manufacturing processes and wastewater treatment which led to significant progress toward cleaner water in rivers and lakes of US. Today, hundreds of new synthetic organic compounds, like pesticides and volatile organics in solvents and gasoline, have been introduced into the environment over the last four decades. Moreover, improved laboratory techniques have led to the discovery of a large number of microbial and viral contaminants, pharmaceuticals, and endocrine disruptors not detected or measured in the past. There is a growing demand for monitoring pollutants at ultra-trace levels (*i.e.*, below parts per million [ppm]) but requires adequate financial and human resources.

4. Technology Development Challenges

A great challenge involving technological development is the need to develop technology that is appropriate, relevant, economic and sustainable to the stakeholders. On the other hand, effective removal of emerging contaminants, synthetic chemicals, and pesticides, as well as spills of chemicals into rivers is some of the challenges. Technology implementation that provides safe and affordable drinking water can markedly improve the human condition for billions across the globe.

Drinking water treatment technologies have been used and continuously developed over the ages. The earliest known treatment method was the application of chemical alum to contaminated water to remove suspended solids by the Egyptians around 1500 BC (Lenntech 2009). Heating, sand and gravel filtration was among the oldest technology used as long ago as 2000 BC. Chemical applications of water treatment (like chlorine filtration) were discovered in nineteenth century, and membrane distillation was discovered in the twentieth century.

In this review paper, natural filtration, riverbank filtration, sand filtration, membrane filtration, bio-sand filtrations, combined physical and chemical treatments were discussed. In addition, membrane filtration systems, solar distillation and pasteurization system and other purification systems in the developing regions were also discussed.

4.1. Natural Filtration

Natural filtration has been employed since the beginning of the written history. Quite simply, natural filtration takes advantage of the soils that act as filters as the water passes through them. In order to understand how water is purified naturally, one must know the hydrological cycle which is the cycling process of water molecules from the ocean to the atmosphere, to the land and back to the ocean, and the storage in various reservoirs. Simply, water evaporated from the ocean eventually condenses as water droplets in clouds. If the cloud grows large enough, the droplets coalesce and fall as precipitation, mostly as rain, sometimes as snow or ice. About 74% of all water evaporated into the atmosphere falls as precipitation on the ocean, mostly in the tropics, and about 26% falls on the land. But the distribution of rainfall is very uneven. Some of the water runs into streams, lakes, and rivers (as shown in **Figure 1**), which return the water to the ocean while some soaks into the ground (infiltrates) and becomes groundwater. The water then can percolate deeper into the ground supplying water to subsurface reservoirs. The rate of infiltration depends on: many factors such as the type of soil. Sandy soils absorb water faster than clay soils. Vegetation also can tend to delay runoff. While the water content of the soil also plays an important role. Soils saturated with water absorb little more. The rainfall rate, whether a tremendous amount is a short period or a prolonged period, have different absorption rate. Some rainfall evaporates back into the air, or it is absorbed by plants, which transpire the water into the air. This is called evapotranspiration. Evapotranspiration describes the transport of water into the atmosphere from surfaces including soil, and from vegetation (transpiration).

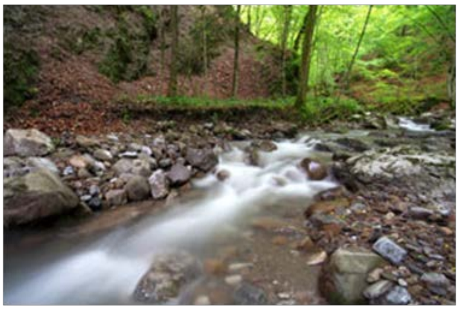

Figure 1. **Natural water sources.**

Purification of water in liquid form ultimately depends on natural filtration, chemical absorption and adsorption by soil particles and organic matter, living organism uptake of nutrients, and living organism decomposition processes in soil and water environments. Human activities that compact soil, degrade soil structure in other ways, contaminate storm water with pollutants, or alter the composition of soil and water-based organisms, eventually reduce or retard the natural water purification process and cause accelerated movement of unfiltered water through the system and into our water supplies. Soils, especially in wetland and riparian areas, along with vegetation and microorganisms play very important roles in natural water purification. Microorganisms in soils, wetlands and riparian areas either utilize or breakdown numerous chemical and biological contaminants in water.

The most common form of natural filtration used currently is sand filtration in a natural setting. Also, simple wells can be classified as using natural filtration, assuming the soil isn't contaminated and most of the water drawn from the well is a result of rainfall infiltration. The best materials to be used for natural filtration are unconsolidated alluvial deposits due to high hydraulic conductivity. The greatest disadvantage of using unconsolidated soil is that there is the possibility of the introduction of anthropogenic contaminants from the land surface to groundwater (typically alluvial aquifers are unconfined aquifers). However, there are clear advantages: natural filtration of appropriate travel time can induce a 3 - 5 log reduction in microbes and protozoa [1]. A 1 log reduction represents a 90% removal of the bacteria or protozoa. Therefore, a 3 - 5 log reduction removes all unwanted biological and viral components from water to an undetectable—or at the very least, an acceptable—level.

However, due to the changing redox conditions, there are often increased amounts of manganese and iron in naturally filtered water, as well as the formation of some sulfurous compounds that are malodorous. These negative effects are eliminated when using rapid sand filtration, but the advantages are also subdued, as will be seen in the section below on sand filtration [2].

4.2. Riverbank Filtration

Riverbank filtration (RBF) is a water treatment technology that consists of extracting water from rivers by pumping wells located in the adjacent alluvial aquiferas shown in **Figure 2**. During the underground passage, a series of physical, chemical, and biological processes take place between the surface water and groundwater, and with subsurface, improving the quality of the surface water, substituting or reducing conventional drinking water treatment. In addition to the removal of pollutants (particles, microorganisms, organic, and inorganic compounds, etc.) there are two additional advantages of RBF. The first is relative to the fact that the flow through the aquifer acts as a barrier against concentration peaks that may result from accidental spills of pollutants. The second is the regulation on the temperature variations in the river water: during winter, when air temperatures are low, the filtered water is usually warmer than surface water, and in summer it is cooler. The lowest variation in temperature improves the quality and further processing of the bank filtrate [2].

Riverbank Filtration: An Efficient and Economical Drinking-Water Treatment Technology

Riverbank filtration technology has been a common practice in Europe for over 100 years, particularly in countries such as Switzerland where 80% of drinking water comes from RBF wells, 50% in France, 48% in Finland, 40% in Hungary, 16% in Germany, and 7% in the Netherlands [3]. In Germany, for example, 75% of the city of Berlin depends on RBF, whereas in Düsseldorf RBF has been used since 1870 as the main drinking water supply [4]. In the United States, on the other hand, this technique has been used for nearly half a century, especially in the states of Ohio, Kentucky, Indiana, Illinois, among others [5]. Other countries that have recently started implementing RBF for drinking water supply are India [6], China, and South Korea [7].

Riverbank filtration wells can be designed either vertically (as the most common practice especially for the extraction of low water quantities) or horizontally (for higher extraction rates). Horizontal wells (sometimes with a radial pattern), also known as *collector* wells, are usually directed toward the river and extract water from beneath the riverbed, whereas vertical wells extract water along the riverbed [5]. Also, RBF wells can be distributed parallel to the riverbank in galleries or groups [8].

Organic pollutants such as pesticides, herbicides, odorous compounds, oil sub-products, and pharmaceuticals are of great concern for water quality. Riverbank filtration has been extensively used for drinking water pretreatment in places with such pollution problems [9, 10]. The removal and the behavior of organic compounds during RBF depends on factors specific to pollutants such as the hydrophobicity of the compound, the potential for biochemical degradation, the amount of organic matter in the aquifer, microbial activity, infiltration rate, biodegradability, etc. [3]. Another aspect that apparently influences the removal of certain organic contaminants such as antimicrobial residues is the redox condition of the aquifer together with the travel time [11].

Although the RBF has proven to be efficient in removing organic matter (total and dissolved organic car-

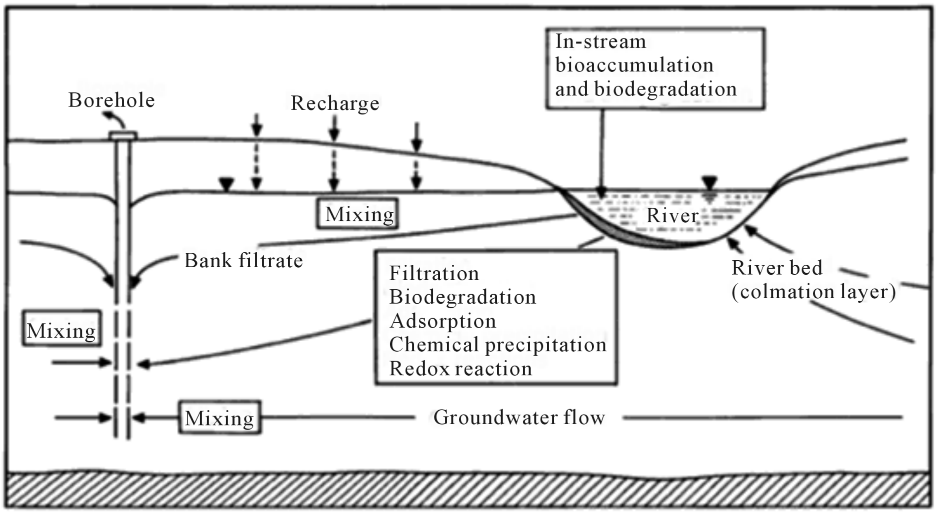

Figure 2. Basic scheme of riverbank filtration and main attenuation processes (Adapted from Hiscock *et al*. [2]).

bon, TOC and DOC) as well as certain disinfection byproducts (DBPs) [5,12,13], if chlorination is used as the disinfection method, there might be an increase in trihalomethane concentration. It could then be recommended to use ACF before disinfection to reduce the amount of TOC and thus the formation of trihalomethanes (THMs). River bank-filtrate water usually requires additional treatment before disinfection, such as activated carbon filtration (ACF), ozonation→filtration→ACF, or aeration→ filtration. This is especially common in rivers with high concentration of ammonia, organic compounds, and micro-contaminants.

The main limitation on the efficiency of RBF is the clogging of the bed and the banks of the river, which decreases the hydraulic conductivity in the hyporheic zone. This clogging can be caused by the infiltration of fine sediments, gas entrapment, biofilm formation related to microbiological activity, or the precipitation and co-precipitation of inorganic compounds, being the first of this most influential factor in clogging formation. The current understanding of the processes and mechanisms behind this technique are still very empirical. The use of this technology in tropical countries is almost nonexistent even though there is a great potential for exploring this RBF in developing countries.

4.3. Slow Sand Filtration

4.3.1. Slow Sand Filters

Slow sand filters are used in water purification for treating raw water to produce a potable product. They are typically 1 to 2 meters deep, can be rectangular or cylindrical in cross section and are used primarily to treat surface water. The length and breadth of the tanks are determined by the flow rate desired by the filters, which typically have a loading rate of 0.1 to 0.2 meters per hour (or cubic meters per square meter per hour). Slow sand filters differs from all other filters used to treat drinking water in that they use complex biological film on the surface of the sand. The sand itself does not perform any filtration function but simply acts as a substrate. They are often the preferred technology in many developing/developed countries because of their low energy requirements and robust performance [14]. Typical configuration of a housed slow sand filter system has been presented in **Figure 3**.

Slow sand filters work through the formation of a gelatinous layer (or biofilm) called the hypogeal layer or Schmutzdecke in the top few millimetres of the fine sand layer. The Schmutzdecke is formed in the first 10 - 20 days of operation [15] and consists of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae. The Schmutzdecke is the layer that provides the effective purification in potable water treatment, the underlying sand providing the support medium for this biological treatment layer. The water produced from a well-managed slow sand filter can be of exceptionally good quality with 90% - 99% bacterial reduction [15]. Unlike other filtration methods, slow sand filters use biological processes to clean the water, and are non-pressurized systems. Slow sand filters do not require chemicals or electricity to operate. Slow sand filters require relatively low turbidity levels to operate efficiently. In summer conditions and in conditions when the raw water is turbid, blinding of the filters occurs more quickly and pretreatment is recommended. Unlike other water filtration technologies that produce water on demand, slow sand filters produce water at a slow, constant flow rate and are usually used in conjunction with a storage tank for peak usage. This slow rate is necessary for healthy development of the biological processes in the filter [16,17].

As they require little or no mechanical power, chemicals or replaceable parts, and they require minimal oper-

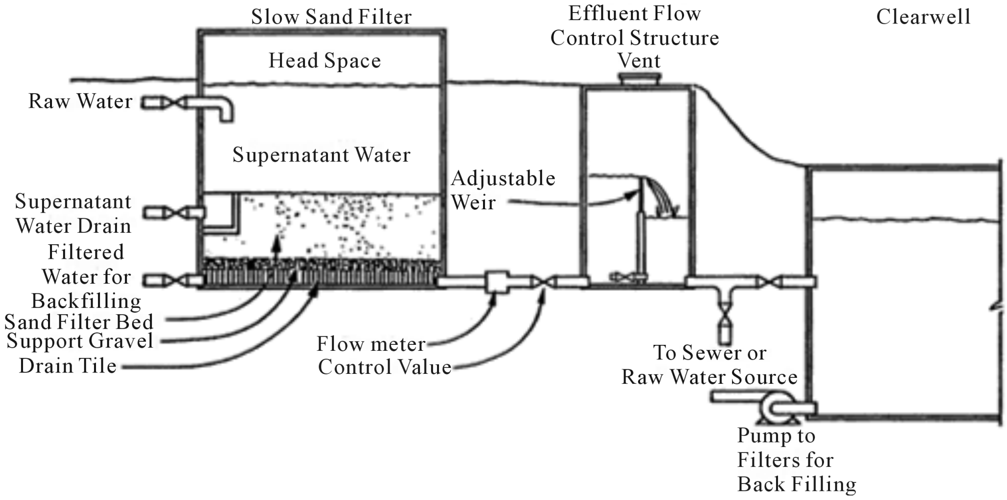

Figure 3. **Typical configuration of a housed slow sand filter system.**

ator training and only periodic maintenance, they are often an appropriate technology for poor and isolated areas. Slow sand filters, due to their simple design, slow sand filters have been used in Afghanistan and other countries to aid the poor. Slow sand filters are recognized by the international Organizations and the United States Environmental Protection Agency as being superior technology for the treatment of surface water sources. Due to the low filtration rate, slow sand filters require extensive land area for a large municipal system [16]. Many municipal systems in the U. S. initially used slow sand filters, but as cities have grown, they subsequently installed rapid sand filters, due to increased demand for drinking water.

4.3.2. Rapid and Slow Sand Filtration

Rapid sand filtration is mainly used in combination with other water purification methods. The main distinction from slow sand filtration is the fact that biological filtration is not part of the purification process in rapid filtration. Rapid filtration is used widely to remove impurities and remnants of flocculants in most municipal water treatment plants. As a single process, it is not as effective as slow sand filtration in production of drinking water. In general, slow sand filters have filtration rates of up to 0.4 m/hour, as opposed to rapid sand filters which can see filtration rates of up to 21 m/hour.

A rapid filter passes quickly through the filter beds. Often, it has been chemically pre-treated, (such as chlorination or flocculation) so that little biological activity is present. Physical straining is the most important mechanism present in rapid filters. Particles that are larger than the pore size between the sand grains are trapped—smaller solids however can pass through the filter. Rapid sand filtration removes particles over a substantial depth within the sand bed. Rapid sand filters are usually cleaned on a daily basis using backwashing, whenever terminal head loss is reached. To clean the filter, the flow of water is reversed through the filter bed at a high rate so that all materials trapped between the sand will be flushed-out. Rapid sand filters are suitable for large urban centers where land scarcity is an issue, whereas slow sand filters tend to be more suitable for areas where land is more available, since they need a much larger surface area to treat the same amount of water. Slow sand filtration is simpler to operate than rapid filtration, as frequent backwashing is not required and pumps are not always necessary.

4.4. Membrane Filtration

Membrane filtration technology (as shown in Figure 4) is simply the filtering of water through a sieve or semi-permeable layer such that water molecules are allowed to pass through, but bacteria, chemicals, and viruses are prevented from passing. The most effective membrane technology often require significantly more energy than other membrane systems due to electrical or mechanical systems required to maintain the pressure. The pore size in the membrane can be significantly smaller, allowing higher removal rates of contaminants. The most common application of membrane technology is RO desalination although the application of membrane technology has been used for bacterial and protozoan removal as well. Other membrane filtration including nano-filtration [NF], ultra-filtration [UF], micro-filtration [MF]) and electro-dialysis (ED) has also been used. All these membrane filtration systems are primarily used to purify seawater or brackish water (water containing less salt that seawater, but still more salty than WHO regulations). Reverse osmosis is used to take saline water and convert it into pure water. The technical measure of fresh water is to contain less than 1000 mg/l of salts or total dissolved solids (TDS) and the World Health Organization has established a baseline of 250 mg/l, which is also supported by the US EPA [18]. Therefore, any water containing higher levels of salts or TDS must undergo some sort of removal process.

Figure 4. Membrane systems remove 0.05-micron particles from water.

The type of membrane media determines how much pressure is needed to drive the water through and what sizes of micro-organisms can be filtered out. For drinking water, membrane filters can remove virtually all particles larger than 0.2 um—including *giardia* and *cryptosporidium*. Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water). However no filtration can remove substances that are actually dissolved in the water such as phosphorus, nitrates and heavy metal ions. The overwhelming majority of technical papers and research articles produced on membrane filtration focus solely on desalination. However, the use of membrane filtration for pretreatment of RO plants is becoming more common. The differentiation between each is the pore size of the membranes (as they are considered porous, unlike RO membranes), with MF being the largest pore-size and NF being the smallest. The ability of each filter to filter out contaminant is beneficial in various environments, and the correct application of membrane pore-size is largely dependent on the most common contaminants in the feed water.

4.5. Solar Distillation

The basic concept of using solar energy to obtain drinkable fresh water from salty, brackish or contaminated water. Solar distillation is the use of solar energy to evaporate water and collect its condensate within the same closed system. Unlike other forms of water purification it can turn salt or brackish water into fresh drinking water (*i.e*. desalination). The structure that houses the process is known as a solar still and although the size, dimensions, materials, and configuration are varied, all rely on the simple procedure wherein an influent solution enters the system and the more volatile solvents leave in the effluent leaving behind the salty solute [19]. The structure of double pane solar still has been shown in **Figure 5**.

Solar distillation of potable water from saline (salty) water has been practiced for many years in tropical and sub-tropical regions where fresh water is scarce. The rate of evaporation can be accelerated by increasing the water temperature and the area of water in contact with the air. The pan is painted black or some other dark color to maximize the amount of solar energy absorbed. It should also be wide and shallow to increase the water area exposed to air. The solar distilled water costs much less than bottled water, therefore, this technology could be useful in household application in many developing countries.

Solar Pasteurization

Pasteurization is the process of disinfecting water by heat or radiation without boiling. Typical water p*asteurization* achieves the same effect as boiling, but at a lower *temperature* (usually 65˚C - 75˚C), over a longer period of time. Pasteurization is the use of moderate heat to kill disease microbes. It is different from sterilization, in which all microbes are killed. To pasteurize milk in a continuous flow process, only 15 seconds at 71˚C is required. This modest heat treatment would also pasteurize water. A solar pasteurization device is shown in **Figure 6**, where water container put into the box and heated with solar heat and pasteurizes water

The temperatures which will kill at least 90% of microbes within one minute are: 55˚C for worms, and cysts of the protozoa Giardia, Cryptosporidium, and Entamoeba; 60˚C for the bacteria *Vibrio cholerae, Samonellatyphi*, *Shigella*spp, and Enterotoxigenic *Escherichia coli*, and for rotavirus, a major cause of infant diarrhea; 65˚C for Hepatitis A virus. As the temperature increases above 55˚C for protozoa, or above 60˚C for bacteria and rotavirus, the time required for 90% inactivation decreases significantly. For example, 90%inactivation of these bacteria at 65˚C requires only about 12 seconds, and 99.999% kill would result from one minute at 65˚C.

From published data and our own experiments, we established that heating contaminated water to 65˚C will pasteurize the water and make it safe to drink [20]. As batch heating of water will have the water temperatures from 60˚C - 65˚C for several minutes, the cumulative heat effect will reduce the level of live pathogens to zero; similar to what is accomplished in milk pasteurization.

The water pasteurization indicator (WAPI) is a clear polycarbonate tube, partially filled with a wax, and sealed at both ends. The WAPI wax melts at 65˚C. The WAPI is placed at the bottom of a container, which is heated by sunshine. If the WAPI wax melts and falls to the bottom of the tube, it verifies that pasteurization conditions have been achieved [20].

Figure 5. **Double-pane solar still.**

Figure 6. **A *solar pasteurization* device in the shape of a box with a glass cover and a reflecting interior and folding lid. The water container is put inside the box and heated with solar heat. Source: CAWST [15].**

4.6. Solar Disinfection of Water (SODIS)

SODIS is a simple and low cost technique used to disinfect contaminated drinking water. Transparent bottles (preferably PET) are filled with contaminated water and placed in direct sunlight for a minimum of 6 hours. Following exposure, the water is safe to drink as the viable pathogen load can be significantly decreased. Simple guidance for the use of SODIS is given in Figure 7.

SODIS harnesses light and thermal energy to inactivate pathogens via a synergistic mechanism [22]. Around 4% - 6% of the solar spectrum reaching the surface of the Earth is in the UV domain, with maximum reported value of around50W/m2 [23]. UV radiation (200 - 400 nm) can be classified as UVA (320 - 400 nm), UVB (280 - 320 nm), and UVC (200 – 280 nm). UVC is absorbed by the ozone layer along with a proportion of the UVB; therefore UVA represents the main fragment of solar ultraviolet radiation reaching the earth’s surface.

Disinfection of water using solar energy has been carried out since Egyptian times. The process was first studied and reported in scientific literature by London-based scientists Downes and Blunt in the late 1870s [24] and was effectively rediscovered as a low-cost water disinfection method by Acra *et al*. in the late 1970 [20,25].

Laboratory studies have demonstrated the effects of key operational parameters such as light intensity and wavelength, solar exposure time, availability of oxygen, turbidity, and temperature [26,27]. The SODIS mechanism is understood to involve a number of biocidal pathways based upon the absorption of UVA radiation and thermal inactivation.

Direct UVA exposure can induce cellular membrane damage and delay microbial growth [28]. The biocidal action of UVA has also been attributed to the production of reactive oxygen species (ROS) which are generated from dissolved oxygen in water [29] and the photosensitization of molecules in the cell, and/or any naturally occurring dissolved organic matter that can absorb photons of wavelengths between 320 - 400 nm, to induce photochemical reactions [30]. The thermal effect has been attributed to the high absorption of red and infrared photons by water. At temperatures below 40˚C, the thermal effect is negligible with UVA inactivation mechanisms dominating the inactivation process. Significant bactericidal action is evident at temperatures above 40˚C - 45˚C with a synergistic SODIS process observed at temperatures above 45˚C [22,26,30-32]. Studies to improve the efficiency of the SODIS processes using low-cost, commonly available materials have been conducted [33-36]; however, the simple approach of exposing a 2 L PET bottle to full sun for a minimum of 6 hours is the most commonly promoted and practiced method. A graphical description on the solar disinfection (SODIS) household water treatment technique is given in Figure 8.

Figure 7. SODIS process (adopted from Anthony Byrne *et al.*, [21].

A number of low cost additives are capable of accelerating the SODIS in both sunny and cloudy weather, which is indicated by recent laboratory and field experiment. The additives are 100 to 1000 mM hydrogen peroxide (both of the room and prominent temperature), 0.5% to 1% lemon juice, copper metal or aqueous copper plus ascorbate (with or without hydrogen peroxide) [37].

Improvement of SODIS with Locally Available Materials: (A Study)

Dr. Rabbani and his research group [38] improved SODIS technology with readily available materials like bamboo tray, hay, polythene sheets, etc. as shown in Figure 9, for ultra-poor people in rural or flood affected coastal areas of Bangladesh. The idea is to collect and absorb energy from sunshine and trap it in the device by reducing heat losses as much as possible. In order to make the tool very low cost, a horizontal water bed was considered rather than an angle design. The relatively clear water from river, canals or ponds was filtered through several layers of ordinary clothes to get clean water. Low cost additives (alum, moringa seed powder or

Figure 8. A graphical description on the solar disinfection (SODIS) household water treatment technique.

locally available materials) could be added before clothes filtration to improve the microbiological status of water.

For the solar treatment, bamboo tray (75 cm diameter), a flat rigid surface with raised ends, to hold water, as shown in **Figure 9** was dyed black earlier and dried. A polythene sheet was spread over the black bamboo tray and water was poured to a depth not more than 2 cm [38], which is equivalent to approximately 5.0 liters of water. To stop evaporation another polythene sheet was spread over the water so that it adheres to the water surface in all places (**Figure 9**). Air bubbles (if any), interfere sunlight entering to water should be removed to the ends by finger pressure and movement.

Next, two thin air layers above the water was made by spreading few strands of straw and two transparent polyethylene sheet for heat insulation but allowing sunshine to enter. Finally the polyethylene sheets were stretched out using weights all around as shown in **Figure 9**.

In a clear sunny day, it usually takes 1.5 - 2.0 hours for destroying all diarrheal microorganisms. After the treatment, the top three polythene sheets should be removed and the treated water can be collected in the polythene sheet by holding the ends as shown in **Figure 9**. This is the 'harvest' of safe diarrheal microorganism free drinking water and can be stored in clean containers for further use. One family, may harvests 10 liters in a clear sunny day (9 AM to 3 PM), which is enough for a family [39].

4.7. Combined Method of Disinfection: (A New Study)

Simple technologies such as the application of plant coagulants such as *Moringaoleifera* to treat water have been extensively reported. On the other hand, scallop powder is a new biodegradable sanitizer, and reported to have antibacterial and antifungal action. As this powder is produced from natural sources thus doesn't pose any hazard to the environment, and biodegradable. In addition, FS$^{®}$ and Ultra K1$^{®}$ is also commercial coagulants used for treating turbid or cloudy water by pulling together floating particles—including dirt, other solids, and some pathogens. These compounds are cheap, readily available and naturally biodegradable. [40] reported that *Moringa*seed powder alone has strong coagulant and antimicrobial effect at low doses. On the other hand, 0.01% scallop powder has strong antimicrobial activity under typical environmental conditions. However, combination of these two powders showed effective coagulating and antimicrobial capacity to reduce the turbidity and inactivate the number of inherent microorganisms respectively; including coliform and *E. coli* within 5 min. Similar experimental findings were observed when the mixture of *Moringa*seed powder and sodium hypochlorite was used. On the other hand, both the commercial ultra-K and FS powder showed strong coagulant and antimicrobial effect within 1 minute of application. When this treated water passed through natural bio-sand filtration (charcoal, stone and sand), the resulting water became potable. This small scale work was done in the laboratory and there is a need to scale-up this method to ascertain there reproducibility of the results. The study report suggested that Moringa seed powder and scallop powder are naturally available, cost-effective, and nontoxic antimicrobial agents that have potentials to convert pond water to drinkable water. The treatment process was shown in **Figure 10**.

5. Regulatory Guidelines for Clean Drinking Water (Updated)

Providing sufficient amounts of drinking water of a suit

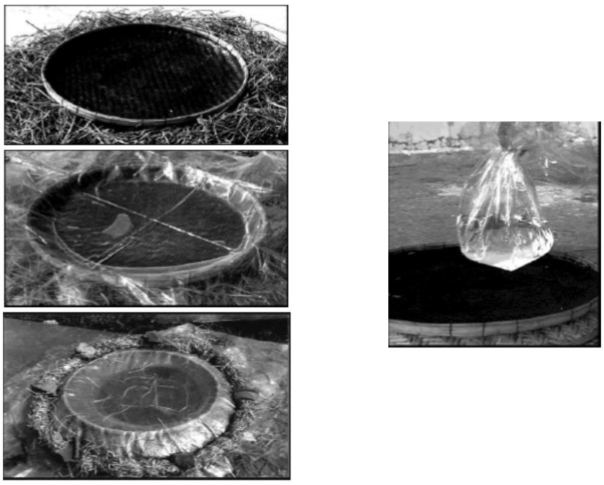

Figure 9. **Sequence of setting up the solar disinfection device and the "harvest" of drinking water (Adapted from Rabbani, [39].**

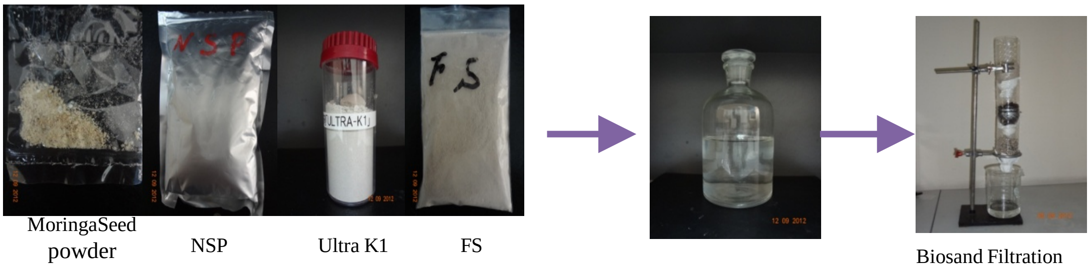

Figure 10. **Treatment process of water by moringa, NSP, Ultra K1, FS and followed by biosand filtration [40].**

able quality is a basic requirement and ensuring the sustainable, long-term supply of such drinking water is a national and international concern. Water testing plays an important part in ensuring the correct process of water supplies, proven the safety of drinking water, exploring disease outbreaks, and validating processes and preventive actions. There are vital challenges in implementing comprehensive and suitable water quality testing, mainly in low-resource settings. As a result, the extent and quality of the information offered by water testing is often insufficient to support effective decision-making.

The following microbial and physico-chemical parameters (**Table 1**) could offer useful information on: 1) the understanding the regulatory requirements; 2) the effects of contamination of drinking water; 3) water quality, and changes in quality; 4) source of contamination, contributions and contact pathways; 5) the efficiency of inspection processes [41].

Table 1. Microbiological and other physical and biochemical parameter of safe drinking water.

Microbiological Parameter	Sanitary survey	Source water characterization	Treatment efficiency	Treated water	Distribution system (re growth)	Outbreak investigation
Total coliform	NR	NR	SA	S	S	S
Thermotolerant coliform	SA	SA	NR	SA	S	S
Escherichia coli	S	S	S	S	N/A	S
Faecal streptococci (enterococci)	SA	SA	N/A	N/A	N/A	S
Total Bacteria (microscopic)	N/A	N/A	SA	SA	S	S
Viable Bacteria(microscopic)	N/A	N/A	SA	SA	S	S
Aerobic spore forming bacteria	N/A	N/A	S	S	N/A	S
Sulphite Reducing Clostridia	NR	NR	N/A	N/A	N/A	S
Clostridium perfringens	SA	SA	SA	N/A	N/A	S
Enteric Virus	S	S	N/A	N/A	N/A	S
Cryptosporidium Oocysts & Giardia cysts	S	S	NR	N/A	N/A	S
Pathogens	S	S	N/A	S	N/A	S
Physico-chemical Parameter						
Colour/Odor	N/A	SA	N/A	S	N/A	S
pH	N/A	N/A	S	N/A	N/A	S
Turbidity	S	S	N/A		N/A	S
Solids (Total/Dissolved)	S	S	N/A	N/A	N/A	S
Conductivity	S	S	N/A	N/A	N/A	S
Particle size analysis	N/A	N/A	N/A	S	N/A	S
Disinfectant residual	N/A	N/A	N/A	S	N/A	S
Organic matter (TOC, BOD, COD)	S	S	N/A	N/A	S	S
Ammonia	S	S	N/A	N/A	N/A	S
Boron, Chloramines compounds	S	S	N/A	S	S	S
Nitrate/Nitrite	S	S	N/A	S	N/A	S
Sulphide as (H_2S)	N/A	S	N/A	S	SA	S
Manganese, copper, zinc, iron	N/A	N/A		S		S
Metal (lead, Arsenic, chromium)	S	S	N/A	S	S	S
Other anions and cations	N/A	N/A	N/A	S	N/A	N/A

Key, S: suitable, SA: suitable alternative, NR: not recommended, N/A: not applicable.

6. Conclusions

Despite the ambition of the Millennium Development Goals (MDGs), water supply and sanitation are still worryingly deficient in many countries of this world. Due to the rapid increase in population, increased urbanization and industrial activities, and absence of a strong regulatory framework, water quality in these countries is impaired due to the high levels of contamination. Because of the challenge of providing safe drinking water from poor quality water sources, development of low-cost technologies should be considered in these countries.

A major problem that people in developing countries are facing is the abundance of organic micro-pollutants in natural water resources. An example of the consequences of this for public health is an increased number of birth defects, spontaneous abortion, cancers, and disturbances of central and peripheral nervous system. Hence, the research on low-cost drinking water treatment technologies should not only focus on removal of contaminants to reduce waterborne diseases, but also on the removal of micro-pollutants to prevent dangerous chronic diseases (including cancer) in large scale drinking water treatment plants.

Concerning the selection of a suitable method for microbial examination, it should be observed that no technique that is 100% sensitive, 100% specific exists. All methods have advantages and disadvantages. Now the challenge is to decide the method that performs the most of the characteristics of the ideal method for the users' practical background. Advantages should be optimally exploited and disadvantages should be recognized. Different users may choose appropriate alternative techniques based on two criteria: 1) corresponding tests to resources and 2) corresponding tests to applications.

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