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RAINWATER HARVESTING FOR DRINKING WATER WITH SOLAR DISINFECTION SYSTEM

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Improved Food and Livelihood Security in Bagerhat District, Bangladesh in the Context of Increased Disaster Risk and Climate Change Project

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EXECUTIVE SUMMARY

Safe drinking water is a pre-requisite for development of any society. All the known civilizations have flourished with water source as the base and it is true in the present context too. Availability of safe drinking water is one of the basic minimum requirements for healthy living. Despite the advancements of technology in recent pasts, the global scenario still remains grim, as all the inhabitants of the world do not have access to safe water.

Towards sustainable management of freshwater with respect to the physical alternatives, the possible solutions could be finding alternate or additional water resources using conventional centralized approaches; or utilizing the limited amount of water resources available in a more efficient way. Among the various technologies to augment freshwater resources in order to reduce the scarcity of safe water, rainwater harvesting and its utilization could be an environmentally sound solution, which can avoid many environmental problems often caused by conventional large-scale projects using centralized approaches.

Rainwater is an important water source in many areas with significant rainfall like Bangladesh, but lacking proper maintenance and technique. It is also a good option in areas where good quality fresh surface water or ground water is lacking, such as coastal areas of Bangladesh. The problem is that the technique of rainwater harvesting in practice lacks hygiene and the type of maintenance it requires to keep it safe for long term use is not familiar to all. Thus the lack of maintenance and reluctance in preserving rainwater through proper way by rainwater harvesters restricts them to store it for only a few days. In this research, the important parameters to keep the stored rainwater safe, from catchment to user's collection point, were taken into consideration.

In order to cope with these issues, ITN-BUET carried out a research under EC-CAFOD funded *Improved Food and Livelihood Security in Bagerhat District, Bangladesh in the Context of Increased Disaster Risk and Climate Change Project.* Mongla, a thana of Bagerhat district, is one of those areas in coastal zone where safe drinking water source is scarce which has made rainwater harvesting a largely practiced option for safe water. But this water is often contaminated for poor maintenance and is also little harvested for lack of ability and adequate knowledge, not only in Mongla, but in other places also. In this project, ITN-BUET emphasized on proper maintenance of the system to store rainwater for a longer period without any contamination in stored water. In addition, a solar water heater was installed with the system to reduce the risk of any microbial contamination that may occur at any point of the system. The results show that microbial contamination can be reduced by implementing proper maintenance and can be brought down below the health limit by using solar water heater as the temperature found was high enough to destroy harmful microorganisms that are often found in stored rainwater.

Chapter 1

Introduction

1.1 Crisis of Safe Drinking Water

Water crisis is a general term used to describe a situation where the available water within a region is less than the region's demand. The water security is a shared threat to human and nature and it is pandemic. Earth has a limited supply of fresh water; stored in aquifers, surface waters and the atmosphere. The amount of fresh water supply provided by the hydrological cycle does not increase and water everywhere on the planet is an integral part of that global hydrologic cycle. Sometimes oceans are mistaken for available water, but the amount of energy needed to convert saline water to potable water is very expensive, explaining why only a very small fraction of the world's water supply derives from desalination. Therefore, it is of major concern to find and implement suitable technology for different geographic parts which will be feasible for the local community both in terms of available resources and adaptive capability.

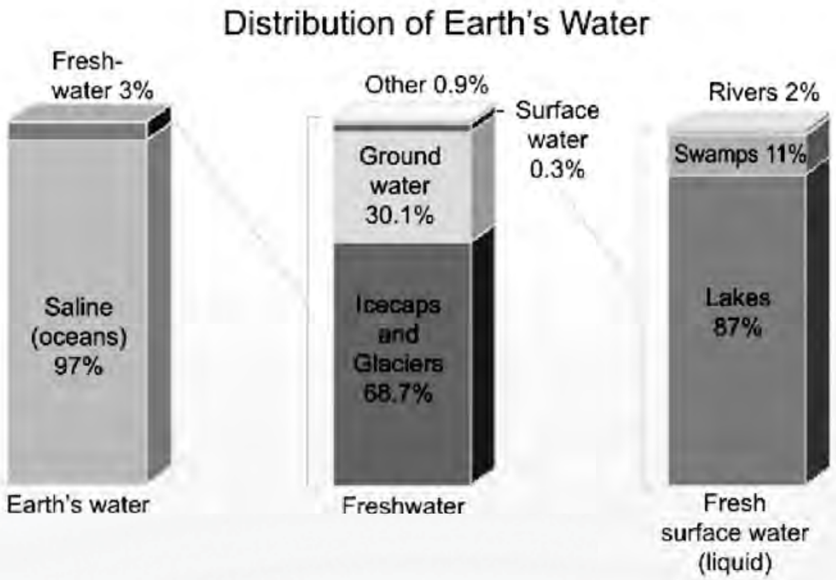

Figure 1.1: Distribution of Earth's water.

Source: (http://ga.water.usgs.gov/edu/waterdistribution.html)

Water is essential to sustain life and a satisfactory supply must be available to all. Improving access to safe drinking water results in tangible benefits to health. The nature and form of drinking water standards vary among countries and regions. There is no single approach that is universally feasible. Approaches that may work in one country or region will not necessarily transfer to other countries or regions. Therefore, the extent of sufferings regarding access to safe drinking water that are not up to the standard varies in different parts of the world. Apart from the limited supply of safe drinking water, quality of available water is of great concern also. The great majority of evident water-related health problems are the result of microbial (bacteriological, viral, protozoan or other biological) contamination (WHO, 2004). To ensure adequate supply of safe water and thereby protect public health, particular attention should be directed to implementation of comprehensive water safety plans and techniques.

In recent times, the problem of acute water crisis, compounded by pollution, is causing indisputable harm in most of the poor countries of Asia and Africa. The population in poor countries like Bangladesh is growing so fast that improvements on water supply have failed to keep pace with it. Bangladesh's water crisis affects both rural and urban areas, and is a matter of both water quantity and quality. Although Bangladesh has made commendable progress in supplying safe water to its people, gross disparity in coverage still exists across the country. Though the ground water table has risen in some of the areas, the water is not suitable for drinking in many of those areas. Some areas suffer Arsenic (As), Iron (Fe) contamination and a large portion of coastal belt is suffering salt water intrusion. As the type of technology suitable for a particular area depends on the groundwater level, water quality and hydro geological conditions, these adversities in ground water characteristics is hampering the supply of safe water in Bangladesh. The important and mostly used water supply technologies used in the rural and semi-urban areas of Bangladesh include:

- Shallow shrouded tube well (SST) and Very shallow shrouded tube well (VSST)
- Deep Tube well;
- Dug Well;
- Pond Sand Filter (PSF);
- Protected Ponds;
- Household Filters; and
- Rainwater Harvesting

The size of the urban population is increasing at alarming rates. The poor from the rural areas are continuing to migrate to the urban areas with the hope of being able to earn larger wages to support their families. To supplement these migrants along with the current residents with safe water in urban areas, the water supply system is facing a lot of difficulties with its limited resources. Therefore, it is high time to look for the alternatives to reduce the burden on current system in urban areas also.

1.2 Rainwater as an Alternate Source of Water

It is said that nature's renewable sources will probably never end. But these resources are not usually explored enough to mitigate the crisis. Rainwater is one of those resources available from nature which is abundant in almost all parts of Bangladesh. Rainwater harvesting, in its broadest sense, is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments using simple techniques such as jars and pots as well as engineered techniques. Rainwater harvesting has been practiced for more than 4,000 years, owing to the temporal and spatial variability of rainfall (UN-HABITAT). It is an important water source in many areas with significant rainfall but lacking any kind of conventional, centralized supply system in most of those areas. It is also a good option in areas where good quality fresh surface water or ground water is scarce. The application of appropriate rainwater harvesting technology is important for the utilization of rainwater as an alternative of current paradigm in water supply sector.

Rainwater collected from rooftops is generally free of mineral pollutants like fluoride and calcium salts which are generally found in ground water. But it is likely to be contaminated with other types of pollutants: air pollutants and surface contamination (e.g., silt, dust). The cleanliness of the roof in a rainwater harvesting system most directly affects the quality of the captured water. The cleaner the roof, the less strain is placed on the treatment equipment. To improve water quality, several treatment methods are available. It is the responsibility of the individual installer or homeowner to weigh the advantages and disadvantages of each method for appropriateness to the individual situation. Maintaining the quality of water is very important for long time storage, especially in areas where people's perception of safe water is not based on scientific assumptions.

Well designed rainwater harvesting systems with clean catchments and storage tanks supported by good hygiene at the point of use can offer drinking-water with very low health risk, whereas a poorly designed and managed system can pose high health risks. The quality of rainwater may deteriorate during harvesting, storage and household use. Poor hygiene during storing and collecting water from tanks or at the point of use can also cause health concerns. However, risks from these hazards can be minimized by good design and maintenance using technologies.

1.3 Solar Energy with Rainwater Harvesting to Avoid Microbial Contamination

In order to prevent microbial contamination in stored rainwater, ITN-BUET constructed two rainwater harvesting systems with solar water heater in the coastal areas of Mongla, Bagerhat to provide access to safe drinking water to the beneficiaries of EC-CAFOD funded IFLS project. The system was designed to store drinking water for the scarcity period (4 months) to supplement 10 families during that period. As the reservoir tanks are supposed to store water for whole year, the quality of the stored water throughout the year is a major concern. Due to the common perception of local people in those areas that rain water is always safe, people are reluctant to maintenance of catchment roof, interconnection pipes etc which are very important to keep the water free from contamination. Therefore, microbial contamination is often found in stored rainwater and the quality deteriorates with time due to the lack of maintenance. Considering these issues, a solar water heater was attached with the system to heat water before collection in high temperature that was found satisfactory to kill harmful microorganisms in water. Although the temperature does not rise up to boiling point, the maximum temperature was found as 80° C. If water is allowed to stay in that temperature for at least 30 minutes, it will destroy the pathogens that are normally found in rainwater. Easy operation and maintenance of the system also makes it conducive for users. This Combination of rainwater harvesting system with solar water heater requires very low maintenance cost and can solve the problem of rainwater contamination for long term storage to encourage use of rainwater as an alternative source of water in order to reduce the pressure on current water supply system and thus mitigate water crisis in many areas.

Chapter 2

Concept and Challenges of Rainwater Harvesting

Rainwater harvesting is a good alternative in areas where there is sufficient rain but the ground water supply and surface water resources are either lacking or insufficient. It could also be thought as a long term answer to the problem of water scarcity. Rainwater harvesting system has been particularly practiced in remote and hard-to-reach areas as it can be maintained independently. There are a number of ways in which rainwater harvesting can benefit a community– rainwater harvesting enables efficient collection and storage of rainwater, makes it accessible and substitutes for poor quality water. A rainwater harvesting system collects and stores water within accessible distance of its place of use. While traditional sources are located away from the community particularly in peri-urban areas, collecting and storing water close to households, villages or pastures greatly enhances the accessibility and convenience of water supplies. The rainwater collected can be stored for direct use or can be recharged into the ground water to improve the quality of ground water. Rainwater harvesting is an ideal solution to water problems in areas having inadequate water resources and helpful in mitigation of the effects of drought.

Rainwater harvesting can provide an alternative source for good quality water seasonally or even the year round. Rainwater is also the cheapest form of raw water. This is relevant for areas where ground water or surface water is contaminated by harmful chemicals or pathogenic bacteria or pesticides and/or in areas with saline surface water. The rainwater harvesting systems can be both individual and community/utility operated and managed. Rainwater collected using various methods has less negative environmental impacts compared to other technologies for water resources development. The physical and chemical properties of rainwater are usually superior to sources of ground water that may have been subjected to contamination. Rainwater is relatively clean and the quality is usually acceptable for many purposes with little or even no treatment. Rainwater harvesting technologies are flexible and can be built to meet almost any requirements. Construction, operation, and maintenance are not labor intensive. The role of rainwater harvesting systems as sources of supplementary, back-up or emergency water supply will become more important, especially in view of increased climate variability and the possibility of greater frequencies of droughts and floods in many areas. This will particularly be the case in areas where increasing pressure is put on existing water resources. In this research study, the objective was set to explore the viability both in terms of economical and regional scenarios, of the rainwater harvesting system in coastal areas that has been suffering acute water scarcity for years. Ensuring quality of stored rainwater was also a challenge in this study. Many people in Bangladesh do not accept stored rainwater for drinking purposes due to contamination which is caused due to lack of maintenance. Also people do not want to drink stored rainwater for a long time for aesthetic reasons.

2.1 Water Crisis in Coastal Areas of Bangladesh

The coastal area of Bangladesh represents an area of 47,211 km^2, which is 32% of the country's geographical area, wherein 35 million people i.e. 28 percent of the country's total population live at 6.85 million households (Population census in 2001). In terms of administrative consideration, 19 districts out of 64 are considered as coastal district. A study of IPPC (Inter Governmental Panel of Climate Change) in 2001 reveals that 20 percent and 40 percent of the world population live within 30 kilometers and 100 kilometers of the coast respectively, which is very true in regards to Bangladesh's perspective. Increasing rates of sea level rise caused by global warming are expected to lead to permanent inundation, drainage congestion, salinity intrusion and frequent storm surge inundation in these areas. All these hazards are making the scenario worse for safe drinking water sources.

Therefore, people in this part of Bangladesh are suffering inadequacy of safe water both in terms of quality and quantity.

The low-cost hand pump tube well technologies have been designed and installed in the coastal areas to collect water from very shallow aquifers and are serving the purpose in many coastal districts. But the shallow aquifers formed by displacement of saline water by fresh water have become a rarity in many part of the coast in recent past. People have started to abandon many of these shallow tube wells along with the deep tube wells and dug wells in areas of many coastal districts like Satkhira, Khulna and Bagerhat. The arsenic contamination is also a concern in some part of coastal regions where people are dependent on groundwater. The use of Pond Sand Filter (PSF) technology has been a popular one in many areas, but the salinity of water is not remediable by such type of technology. The people along the coastal areas were used to fetch water from protected ponds in past. But the frequent surges of saline water in those areas and seepage of saltwater due to the sea level rise have left most of the ponds' water not potable. The invasion of sea water towards the inland is denying the coastal people to use these natural sources of water for drinking, agriculture and other household purposes and thereby, people there are forced to pay more to collect water to run their daily livelihoods.

2.2 Potential of Rainwater Harvesting

Bangladesh is a tropical country and receives heavy rainfall during the rainy season. The average annual rainfall in the coastal and hilly regions is more than 3000 mm, against an average rainfall of about 2400 mm in Bangladesh (Ahmed and Rahman, 2010). The collection and storage of rainwater is an alternate option of water supply in these areas. Rainwater harvesting is a potential water supply option in the acute arsenic and iron affected areas of Bangladesh, as well as the areas affected by salinity. This technology has been practiced for a long time on a limited scale in Bangladesh.

In the coastal districts, particularly in the offshore islands of Bangladesh, rainwater harvesting for drinking purposes is a common practice in a limited scale for long time (Chowdhury et al., 1987). In some areas of the coastal region with high salinity problem, about 36 percent households have been found to practice rainwater harvesting in the rainy season for drinking purpose (Hussain and Ziauddin, 1989). In the present context, rainwater harvesting is being seriously considered as an alternative option for water supply in Bangladesh in the areas where ground or surface water are lacking quality or quantity to satisfy the demand and areas like Mongla should be considered under the rainwater harvesting scheme in order to mitigate the ongoing crisis of safe drinking water.

The major constraints in developing a rainwater harvesting system are:

- Suitable catchment area
- Storage of rainwater for using it yearlong i.e. keeping the quality.

There are few other factors such as the initial cost may prevent a family from installing a rainwater harvesting system. The water availability is limited by the rainfall intensity and available roof area. Sometimes the flat taste of mineral-free rainwater is not liked by many and also may cause nutrition deficiencies in people who are on mineral deficient diets.

Despite of these limitations, rainwater harvesting is an ancient technique enjoying a revival in popularity due to the inherent quality of rainwater and interest in reducing consumption of treated water. Rainwater is valued for its purity and softness. It has a nearly neutral pH and is free from disinfection by-products, salts, minerals and other natural and man-made contaminants. The quality of rainwater is comparatively good. The system is independent and therefore suitable for scattered settlements, which is a common sight in rural areas of Bangladesh. Local materials and craftsmanship can be used in construction of rainwater harvesting system. Energy costs can be avoided in the system, a very important feature as substantial part of Bangladesh are in running deprived of power.

From a financial perspective, the installation and maintenance costs of a rainwater harvesting system for potable water may not compete with water supplied by a central utility, but is often cost-competitive with installation of a well in rural settings. Considering these merits of rainwater harvesting system along with the current status of safe water in the coastal areas near the shore, this system could be worth of reducing the vulnerability of the people by storing water for the scarcity period, at least. The scope of this research is to serve as a primer in the step of incorporating rainwater harvesting with suitable technology for small and large scale use for a long period.

2.3 Rainwater Quality

Rainwater is relatively free from impurities except those picked up by rain from the atmosphere, but the quality of rainwater may deteriorate during harvesting, storage and household use. Wind-blown dirt, leaves, faecal droppings from birds and animals, insects and contaminated litter on the catchment areas can be sources of contamination of rainwater, leading to health risks from the consumption of contaminated water from storage tanks. Poor hygiene in storing water in and abstracting water from tanks or at the point of use can also represent a health concern. However, risks from these hazards can be minimized by good design and practice. Well designed rainwater harvesting systems with clean catchments and storage tanks supported by good hygiene at point of use can offer drinking-water with very low health risk, whereas a poorly designed and managed system can pose high health risks.

Microbial contamination of collected rainwater indicated by *E. coli* (or, alternatively, thermotolerant coliforms) is quite common, particularly in samples collected shortly after rainfall. Pathogens such as *Cryptosporidium, Giardia, Campylobacter, Vibrio, Salmonella, Shigella* and *Pseudomonas* have also been detected in rainwater. However, the occurrence of pathogens is generally lower in rainwater than in unprotected surface waters, and the presence of non-bacterial pathogens, in particular, can be minimized *(Source: http:// www.who.int/water_sanitation_health/gdwqrevision/rainwater.pdf).* Higher microbial concentrations are generally found in the first flush of rainwater, and the level of contamination reduces as the rain continues. A significant reduction of microbial contamination can be found in rainy seasons when catchments are frequently washed with fresh rainwater. Therefore, Microbial quality of rainwater needs to be monitored as part of verification. Rainwater, like all water supplies, should be tested for E. coli or thermotolerant coliforms. The levels of lead, zinc or other heavy metals in rainwater should also be measured occasionally when it is in contact with metallic surfaces during collection or storage.

For microbial water quality, verification is likely to include microbiological testing. In most cases, it will involve the analysis of faecal indicator coliforms, but in some circumstances it may also include assessment of specific pathogen densities. Verification of the microbial of drinking water may be undertaken by the supplier, surveillance agencies or a combination of the two.

Verification of microbial quality of drinking water includes testing for *Escherichia coli* as an indicator of faecal pollution. Among others, Enteric Viruses and Protozoa are more resistant to disinfection; consequently, the absence of *E. coli* will not necessarily indicate freedom from these organisms (WHO, 2004). Therefore, while *E. coli* is a useful indicator, it has limitations also. Regarding these factors, in practice, testing for thermotolerant coliform bacteria can be an acceptable alternative in many circumstances. Persistence of faecal coliforms is affected by several factors, of which temperature is the most important. The most threatening coliforms in drinking water that causes diseases like cholera, typhoid and diarrhea are *Vibrio cholera, Salmonella typhi and E. coli* respectively. Although these coliforms cannot survive higher temperature, some of the thermotolerant coliforms can withstand temperature up to 45-60° C. But it is assured that boiling water is surest and most effective method of destroying microorganisms including disease causing bacteria, viruses, protozoan's, and parasites (WHO, 2004).

Total coliform bacteria that are able to ferment lactose at 44-45° C are known as thermotolerant coliforms. In most waters, the predominant genus is *Escherichia*, but some types of *Citrobacter, Klebsiella and Enterobacter* are thermo tolerant organisms (WHO, 2004). Among these coliforms, *E. coli* has significant impact on water quality as it causes diarrhea. *Klebsiella* have been identified as colonizing hospital patients, where spread is associated with the frequent handling of patients. Some other pathogens who can withstand higher temperatures are *Legionella* (potentially pathogenic for humans; suitable temperature for growth is 25-50°C), *Acanthamoeba* (causes vision problem; can survive within -20 to 56° C) *and Naegleria fowleri* (causes primary ameobic meningoencephalitis in healthy individuals; can grow up to 45° C) (WHO, 2004).

2.4 Microbial Standards for Rainwater Harvesting:

World Health Organization guidelines (WHO, 2004) state that faecal bacteria should not be detectable per 100 ml of sample stored in rainwater. However, Fujioka (1994) stated that a more realistic standard may be 10 faecal coliforms/100 ml. Total coliform tests are not considered a reliable indicator of risk to human health in the tropics as they are naturally present and can reproduce in the soil and water (Fujioka, 1994; WHO, 1996).

2.5 Appropriate Water Boiling Time and Temperature for Disinfection

The recommended times for boiling water in order to make it safe to drink are all over the place. A number of reputable sources cite that you need to boil water for just 1 minute, and not the 3,5,10, or even 20-minutes that we see elsewhere:

- US Centers for Disease Control and Prevention, Treatment of Water to Make it Safe for Drinking lists 1-minute of boiling or 3-minutes above 2000 meters.
- US Environmental Protection Agency, Emergency Disinfection of Drinking Water lists 1-minute boiling time and 3-minutes when above 2000 meters.

The correct length of time needed to boil water in order to destroy disease causing organisms is actually zero minutes. Once the water has reached the boiling point it has been hot enough to destroy organisms for quite some time. After you remove the water from the heat source it will take another period of time for the water to cool down enough for you to be able to drink it, during which it continues to remain hot enough to eliminate pathogens. Even at very high altitudes the boiling point of water is high enough to have eliminated the threat of disease causing organisms (*Source: http://www.survivaltopics.com/survival/how-long-must-water-be-boiled-revisited).*

The pasteurization of milk is accomplished at a temperature of about 145 to 149 degrees F and in many areas of the world water is pasteurized at a similar temperature in order to destroy disease causing organisms. In fact, pasteurization of water at significantly lower temperatures than boiling is often preferred over boiling due to vast savings in fuel. Solar Cooking.org writes "Heating water to 65º C (149° F) will kill all germs, viruses, and parasites. This process is called pasteurization and its use for milk is well known" *(Source: http:// www.survivaltopics.com/survival/how-long-must-water-be-boiled-revisited).*

According to the Wilderness Medical Society, water temperatures above 160° F (70° C) kill all pathogens within 30 minutes and above 185° F (85° C) within a few minutes (Source: http://www.princeton.edu/~oa/manual/water.shtml).

Therefore, considering the above results, it can be said that reaching the boiling point is enough for killing all pathogens. While that is not possible, water heated up to 70° C and allowed to stay at that temperature for at least 30 minutes will be enough to kill all germs in water. Although the later process will require careful monitoring by thermometer, it will save additional fuel required to heat the water to reach the boiling point.

2.6 Disinfection of Rainwater through Solar Energy

The raindrop as it falls from the cloud is soft and is among the cleanest of water sources. Use of captured rainwater offers several advantages. Rainwater is sodium-free, a benefit for persons on restricted sodium diets. The environment, the catchment surface and the storage tanks affect the quality of harvested rainwater. With minimal treatment and adequate care of the system, however, rainfall can be used as potable water, as well as for irrigation.

The falling raindrop acquires slight acidity as it dissolves carbon dioxide and nitrogen. Contaminants captured by the rain from the catchment surface and storage tanks are of concern for those intending to use rainwater as their potable water source. The catchment area may have dust, dirt, fecal matter from birds and small animals, and plant debris such as leaves and twigs. Rainwater intended for domestic potable use must be treated using appropriate filtration and disinfection equipment.

Total dissolved solids (TDS) in rainwater, originating from particulate matter suspended in the atmosphere, range from 2 milligrams per liter (mg/l or ppm) to 20 mg/l across Texas, compared with municipal water TDS ranges of 100 ppm to more than 800 ppm. The sodium content of some municipal water ranges from 10 parts per million (ppm) to as high as 250 ppm. Rainwater intended solely for outdoor irrigation may need no treatment at all, except for a screen between the catchment surface and downspout to keep debris out of the tank, and, if the tank is to supply a drip irrigation system, a small-pore filter at the tank outlet to keep emitters from clogging.

The cleanliness of the roof in a rainwater harvesting system most directly affects the quality of the captured water. The cleaner the roof, the less strain is placed on the treatment equipment. It is advisable that overhanging branches be cut away both to avoid tree litter and to deny access to the roof by rodents and lizards. To improve water quality, several treatment methods are discussed. It is the responsibility of the individual installer or homeowner to weigh the advantages and disadvantages of each method for appropriateness for the individual situation. A synopsis of treatment techniques is shown in Table 2.1.

Table 2.1: Treatment techniques of water

Treatment Method	Location	Result
Screening Leaf screens & strainers	Gutters and downspouts	Prevent leaves and other debris from entering tank.
Settling Sedimentation Activated Charcoal	Within Tank Before Tap	Settles out particulate matter Remove chlorine*
Filtering Roof washer In-line/multi-cartridge Activated charcoal Slow sand	Before tank After pump After sediment filter Separate tank	Eliminates suspended material Sieves sediment Removes chlorine, improves taste Traps particulate matter
Microbiological treatment/Disinfection Boiling/distilling Chemical treatments (Chlorine or Iodine) Ultraviolet light Ozonation Nanofiltration Reverse osmosis	Before use Within tank or at pump (liquid, tablet or granular) Before activated charcoal filter After activated charcoal filter, before tap After activated charcoal filter, before tap Before use; polymer membrane Pores 10^{-3} to 10^{-6} inch Before use; polymer membrane, (Pores 10^{-9} inch)	Kills microorganisms Kills microorganisms Kills microorganisms Kills microorganisms Removes molecules Removes ions; contaminants and microorganisms

Adapted from *Texas Guide to Rainwater Harvesting, second edition,* Texas Water Development Board, 1997.

2.7 Disinfection of Rainwater through Solar Energy

In this research, the potential of solar energy as means of disinfecting rain water has been explored to some extent. For years, SODIS, a free and effective method for decentralized water treatment, has been applied at the household level and is recommended by the World Health Organization as a viable method for household water treatment and safe storage. It is a method of disinfecting water using only sunlight and plastic PET bottles. But in this research study, an attempt was made where a solar water heater filled with water to its capacity allows the water to get heated through convection heat transfer method. The vacuum tubes of the water heater traps heat and pass it to the stored water in the reservoir of the heater by convection method. The temperature of water inside the heater was measured and found satisfactory to destroy pathogens that are more likely to contaminate stored rainwater.

Chapter 3

Methodologies

Mongla is a thana of Bagerhat district, in the coastal region of Bangladesh. Although there are substantial number of water bodies i.e. canals, ponds and the Pashur river that intercepts Sundarbans on her way to Mongla, there is still huge scarcity of potable drinking water in that area. The quality of groundwater is not satisfactory as the saline water intrusion makes it unusable for drinking or irrigation purposes. Like other places in Bangladesh, Mongla is also blessed with adequate rainfall. Therefore, people of Mongla have been practicing rainwater harvesting technique to store water. But this water is often left waste for poor maintenance and is little harvested, not only in Mongla but in other places also. The technique used for rainwater harvesting in most places lacks hygiene and also the type of maintenance required to keep it safe for long term use is not well known to all. As a result, water gets more contaminated with time and gives rise to the familiar concept of *'rainwater is good enough for anly a few days'*. Thus the lack of maintenance and reluctance in preserving rainwater through proper way by rainwater harvesters restricts them to store it for only a few days. But the case is a bit different in Mongla as rainwater is the only source of safe drinking water to them. Therefore, they use the stored rainwater throughout the year in spite of the deterioration of rainwater quality with time caused by lack of maintenance. To address these issues, in this research, the important parameters to keep the stored rainwater safe, from catchment to user's collection point, were considered. In addition, a solar water heater was installed with the system to reduce the risk of any microbial contamination that may occur at any point of the system and to make water acceptable to the users, considering aesthetic senses. The study area of this research is Mongla, Bagerhat which is one of the most vulnerable areas to climate change. In this chapter, the methodologies that were followed in the research are discussed with brief background.

3.1 Site Selection for Rainwater Harvesting System

In this research, two units of rainwater harvesting system with solar water heater were installed in two different places in South Kainmari village of Mongla thana. Each system was designed for 10 families. To determine the location and size of the system, a questionnaire survey was conducted by ITN-BUET team in that locality. The following were the key findings from the survey that was conducted among the beneficiaries of the project regarding the design and maintenance of the systems.

- The average number of family member in each family was found 3.5 persons /family.
- Daily consumption of drinking water = 10 glasses/day = 2.5 lpcd.
- All the beneficiaries were willing to give space for construction and expressed their willingness to share water with other families who are under agreement of sharing.
- They were willing to remove any obstruction i.e. trees, small structures to facilitate suitable surroundings for the system.
- They will maintain the system as per the instructions and look after the solar water heater collectively.

The selection process of ITN-BUET team considered the technical aspects along with the beneficiaries' perspectives to find and prepare appropriate location for the rainwater harvesting systems. The followings were the issues that were surveyed by the team during their field visit.

(a)

(b)

Figure 3.1: (a) Consultation with beneficiaries about site selection
(b) Beneficiaries cutting trees in order to make space for the system.

Catchment Area Selection: Catchment is a structure, such as a basin or reservoir, used for collecting or draining water. The catchment area of a water harvesting system is the surface, which receives rainfall directly and contributes the water to the system. Rainwater runoff from the following catchments should avoid Tar felted roofs (source of biological and heavy metal contamination), Asbestos sheets (weathered and leached fibers of asbestos – highly toxic) and chemically treated roofs (chemicals used for water proofing, will have high concentration of heavy metals like lead).

In Mongla, most of the houses use corrugated iron sheet as roof. Many of the roofs were found rusty and also some of the roofs did not have enough surface area to be selected. Those rooftop were not selected where there ware chances of leaf falling and rainwater incident is interrupted by trees or any other structure. Regular cleaning of catchment is a prerequisite for clean and good quality stored water. Therefore only those rooftops were initially selected that have easy access to cleaning and maintenance. Sunlight is also important as it kills the harmful elements of atmosphere thus helps the rooftop to stay in better condition from hygienic perspective.

Figure 3.2: Selected catchments for rainwater harvesting system.

Access of Beneficiaries: Each rainwater harvesting system is to serve 10 families and the locations were selected in a way considering the distance the users have to cover for collecting water. The beneficiaries' collect water by pitcher and they don't use any transport for it. So the distance is an important issue as mainly women and children carry water and long distances make it difficult for them.

Adequate Space: Adequate space was a constraint to construct rainwater reservoir as most of houses do not have enough free space. There were a lot of depressions and water bodies and the house pattern was congested so that they had to remove either small structures or give their small yard, cut trees etc for the reservoir.

Sunlight: The solar water heater runs by the sunlight. So the availability of sunlight throughout the photoperiod had to be ensured. The beneficiaries were told to cut trees and remove small structures to make sunlight incident uninterrupted.

Safety of the system: The installed solar water heater is a sensitive device that has 18 vacuum tubes made of aluminum and covered by glass. The beneficiaries were told to look after it to avoid any man made damage. Also the reservoir was not installed along the roadside to protect it from external impacts.

Distance from Nearby Contamination Source: Safety from nearby contamination sources i.e. latrine, bathroom, cattle farm etc were considered so that external contamination do not happen.

Soil condition and water table: To provide stability of the tank, the foundation was below the ground level. The soil texture was more like silty-clay and the water table was very high.

Flood Level & frequency: The beneficiaries were asked about the frequency of flood and the magnitude. They said that flood comes in almost every year but the magnitude varies. The highest level was known close to the road level. The reservoir top was designed well above that height and also the collection point was above the flood level.

3.2 Design of Rainwater Harvesting System:

Typically, a rainwater harvesting system consists of three basic elements: the collection system, the conveyance system, and the storage system. Collection systems can vary from simple types within a household to bigger systems where a large catchment area contributes to an impounding reservoir from which water is either gravitated or pumped to water treatment plants. The categorization of rainwater harvesting systems depends on factors like the size and nature of the catchment areas and whether the systems are in urban or rural settings. The annual average rainfall in Mongla was found as 2116 mm (Source: BMD) for the period 1995 to 2005. The rainfall endowment of Mongla is sufficient to fulfill the requirements of local people. But the water harvesting potential is a concern as many of the houses do not have sufficient, good quality catchment area to harvest rainwater. The availability of catchment area must be taken into consideration during the design of storage tank. The selected sites for rainwater harvesting in this research were verified for availability of sufficient and sound catchment roof to fill the storage tank that was designed for 10 families.

Storage Tank: The objective of this activity to supplement drinking water to 10 families all through the year needed a substantial amount of water to be stored for the scarcity period. The number of annual rainy days also influences the need and design for rainwater harvesting. When the annual rainy days are fewer or the dry period is longer, the need for rainwater storage is more in a region. Therefore, if the dry period was too long, big storage tanks would be needed to store rainwater.

In this case, 4 month was assumed as the period between two substantial rainfall events from which rainwater can be harvested. Therefore the number of days for which water would be stored is 120 days. It was found from the beneficiary survey that the selected 10 families have a total of 35 members who on average drink 2.5 liters of water per day.

Therefore, the volume of the tank (V) = N (No. of people to be served) x q (Per capita consumption per day, Liter) x D (No. of days between two major rainfall events)

$$V = 35 \times 2.5 \times 120$$
$$= 10{,}500 \text{ Liter}$$

This volume of water would serve these 10 families for a maximum of 120 days of no rainfall period.

The reservoirs were made of reinforced cement concrete. The water table in this area is very high and salinity is also a concern for any structure as for a number of times the area gets inundated with salt water in every year.

(a) (b)

Figure 3.3: (a) Reinforcement for base of the storage tank
(b) Storage tank of capacity of 10,500 Liter.

Catchment Area: The characteristics of the catchment area determine the storage conditions. All calculations relating to the performance of rainwater catchment systems involve the use of runoff coefficient to account for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation, which will all, contribute to reduce the amount of runoff. Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface.

Table 3.1: Runoff Coefficient Box

Type of catchment	Coefficient
Roof Catchments	
• Tiles	0.8-0.9
• Corrugated metal sheets	0.7-0.9
Ground Surface Coverings	
• Concrete	0.6-0.8
• Brick pavement	0.5-0.6
Untreated Ground Catchments	
• Soil on slopes less than 10 per cent	0.0-0.3
• Rocky natural catchments	0.2-0.5
• Green area	0.05-0.10

Source: Pacey, Arnold and Cullis, Adrian 1989, Rainwater Harvesting: The collection of rainfall and runoff in rural areas, Intermediate Technology Publications, London.

Water harvesting potential can be measured from the following relations:

Water harvesting potential = Rainfall (I mm) x Area of catchment (A m^2) x Runoff coefficient (C).

For the cases in this study, the potential of the catchment to fulfill the requirements was measured.

From the average rainfall of Mongla, the catchment area required to get 10,500 liter rainwater was calculated as:

Catchment area required, A = Volume required (V m^3) /[Rainfall (I m/year) xRunoff Coefficient (C)]

Runoff coefficient (assumed), C = 0.8 (corrugated metal sheet)
Rainfall, I = 2.116 m/year
Volume required for whole year, V = 2.5 x 35 x 365
= 31,937.5 L
= 32 m^3

So, Catchment area required = 32/ 0.8 x 2.116
= 18.9 m^2
= 204 ft^2
= 15 ft x 15 ft

For both the cases, the catchment area available was more than required.

3.3 Components of Rainwater Harvesting System

All rainwater harvesting systems comprise six basic components, irrespective of the size of the system.

- Catchment area/roof: The surface upon which the rain falls; the roof has to be appropriately sloped preferably towards the direction of storage and recharge.
- Gutters and downspouts: The transport channels from catchment surface to storage; these have to be designed depending on site, rainfall characteristics and roof characteristics.
- First flush diverter and leaf screen: The systems that remove contaminants and debris; a first rain separator has to be put in place to divert and manage the first 2.5 mm of rain.
- Cisterns or storage tanks: Sumps, tanks etc. where collected rain-water is safely stored or recharging the ground water through open wells, bore wells or percolation pits etc.;
- Delivery system: The delivery system for the treated rainwater, either by gravity or pump.
- Water treatment: To ensure sound quality of water at receiver's end.

Apart from these components there are some other issues meed to be considered. The catchment area selection and storage tank design criteria have been discussed above in this chapter. The other components of the system were installed considering the availability of raw materials in the local market and few modifications were made for the environmental issues like salinity. These components are discussed below:

Gutters and Downspouts: Gutter is a narrow trough or duct which collects rainwater from the catchment and diverts it towards the storage tank. The gutter used was made of plain galvanized iron sheet. The size of the gutter should be according to the flow during the highest intensity rain. Gutters were supported so that they do not sag or fall off when loaded with water. The way in which gutters are fixed depends on the construction of the house; it is possible to fix iron or timber brackets into the walls.

Downspouts guide the water after receiving from gutters through funnel towards the storage tank. Gutters and downspouts must be properly sized, sloped, and installed in order to maximize the quantity of harvested rain.

Figure 3.4: Fittings of interconnection pipes and funnels to guide water from gutter into the storage tank.

First Flush Diverter: A first flush (foul flush) device is a valve that ensures that runoff from the first spell of rain is flushed out and does not enter the system. This needs to be done since the first spell of rain carries a relatively larger amount of pollutants from the air and catchment surface. Roof washing, or the collection and disposal of the first flush of water from a roof, is of particular concern if the collected rainwater is to be used for human consumption, since the first flush picks up most of the dirt, debris and contaminants such as bird droppings from the roof and gutters during dry periods. After initial rainfall, someone must close the valve of the device to stop draining out water any more. Thus the water piles up inside the down pipe and finally enters in to the storage tank. After the rainfall, someone must open the valve again so that the first rainfall of next rainfall event does not enter into the reservoir.

(a) (b)

Figure 3.5: (a) First flush diverter to avoid initial rainfall
(b) Funnel to collect rainwater from gutters.

Funnel: Funnel is a pipe with a wide, often conical mouth and a narrow stem. It is used to channel rainwater into pipe network with a small opening. Without a funnel, spillage would occur.

Overflow Pipe: Open pipe protruding above the surface of a liquid in storage tank, to control the height of the liquid. Excess liquid enters the pipe's open end and drains away.

(a) (b)

Figure 3.6: (a) Overflow pipe to drain out excess water
(b) Manhole to facilitate cleaning of the tank.

Delivery System: The delivery system comprises water tap and delivery pipes from the outlet of water heater to the tap. The delivery pipes were made of galvanized iron to withstand the hot water that comes out of heater.

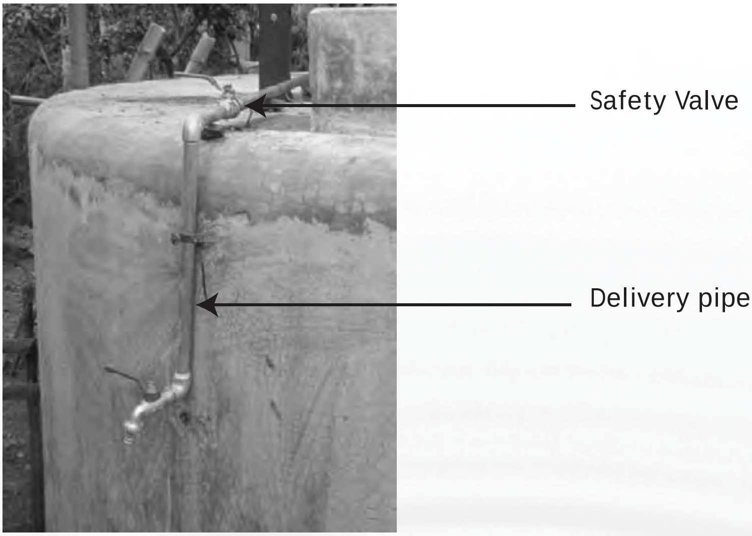

Figure 3.7: Delivery pipe with safety valve.

Manhole: To facilitate the cleaning process, a manhole was provided. The cleaning must be done once in every year before the rainy season.

There were some additional components required to facilitate the solar water heater. A hand pump was installed on the roof of the tank which was connected to the inlet of solar water heater by pipes.

Figure 3.8: Lifting water into solar water heater reservoir from storage tank.

3.4 Solar Water Heater

The solar water heater runs by the principle of convection heat transfer. The vacuum tubes trap heat from sunlight and pass it to the stored water inside the reservoir of the heater. The solar water heater has the following components:

- Vacuum Tube (18 pcs.)
- Reservoir (Capacity 162 liter)
- Steel frame
- Inlet pipe
- Outlet pipe
- Dirt chamber
- Air vent

The reservoir can store 162 liter water and this water gets heated by the heat trapped by vacuum tubes from sunlight. There is a steel frame that holds the reservoir and the tubes together. Water is pumped inside through the inlet pipe by hand pump as there is no electrical pumps are in practice in that area due to no power supply. The outlet pipe allows water to flow towards the collection point. The dirt chamber collects all the solids inside the tank and needs to be cleaned at regular interval. The extra heat goes outside the reservoir through the air vent. A safety valve was attached to avoid any accident to children.

Chapter 4

Performance Analysis

4.1 Temperature Analysis of Solar Water Heater

ITN-BUET constructed two rainwater harvesting systems with solar water heater in the coastal areas of Mongla, Bagerhat to provide safe drinking water to the beneficiaries of EC-CAFOD funded IFLS project. As the beneficiaries are often reluctant to operate the first flush device properly, it causes the deterioration of water quality inside the tank. Due to the perception of local people in Mongla that rainwater is safe; they are reluctant to maintain the catchment roof, interconnection devices etc. As a result, the stored rainwater often gets contaminated and causes water borne diseases. As maintenance is a pre-requisite to keep rainwater safe for long term use, ITN-BUET first trained them how to maintain the system and also discussed the importance of it. As a component of the whole system, a solar water heater was attached to the system to heat the water up to a temperature that is high enough to kill the harmful pathogens prior to the collection of water by beneficiaries. The temperature of water inside the solar heater reservoir was found above 70° C after having 4 hours of uninterrupted sunshine, which according to the guidelines discussed in chapter 2, kills the harmful pathogens, if the water is allowed to keep in that temperature for 30 minutes. During the data collection for temperature trend analysis of the heater, sunshine hour was counted from 9 am to 3 pm and was uninterrupted. The temperature of the water rose up to 78-80° C. Initially, when water was lifted into the water heater reservoir, the temperature was found ambient (29° C). Then within a very short time it rose up to near around 50° C. This sharp rise was due to the heat that was entrapped in the vacuum tubes of the heater because of the sunlight incident on tubes from morning. Then the rise of the temperature was steady and it took four and a half hour to reach 80° C mark. Temperature was found at the same mark after that. The test was performed in September and average of all the days when full sunshine was available was considered to make the graph shown below. The rise of temperature in the heater is shown in the figure:

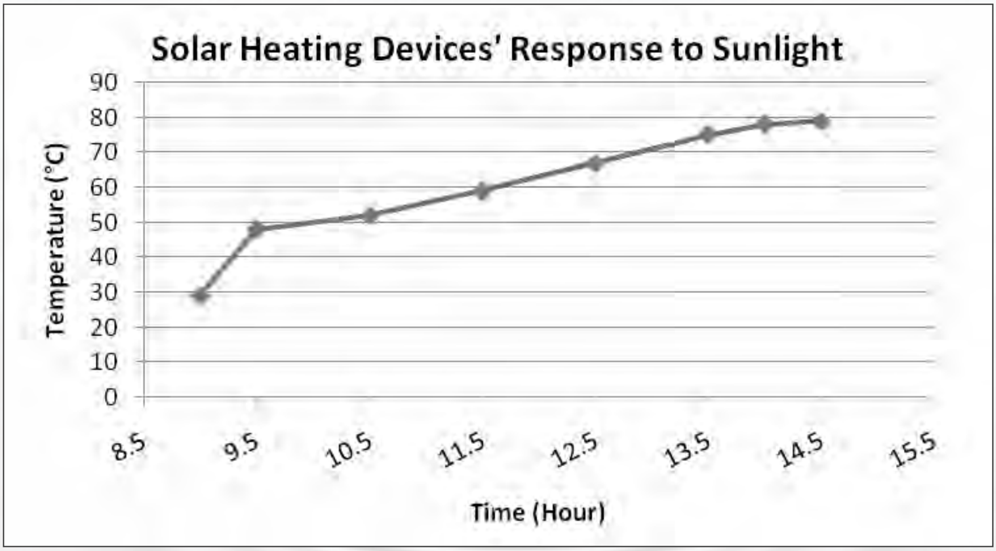

Figure 4.1: Rise of temperature inside solar heater with time in sunny days.

When the temperature of water inside the heater reaches the optimum, the air vent allows the extra heat to pass outside. Once the temperature of water reaches 70° C, it must be allowed to stay at that temperature for a minimum of 30 minutes. After that the beneficiaries could collect the water from the outlet and after the water cools down to ambient temperature, it will be suitable to drink. Analyzing the behavioral pattern of the device and considering the standards for safe drinking water, these instructions should be followed throughout the process:

- Good sunlight from 9 am to 2 pm required to get the desired temperature.
- After reaching 70° C, water must be allowed to stay at that temperature for at least 30 minutes before collection.
- Once the temperature reaches the 70° C mark and then allowed to stay at that temperature for at least 30 minutes, the water inside the tank of the solar heating device is safe although the temperature of water might fall below 70° C in evening. This could happen as the day progresses and the heater loses heat gradually.
- Collection of water from tap must be done carefully as hot water comes out through it. Children should not be allowed to operate the system.
- Safety valve must be opened before collection of water and must be locked after collecting water.
- Avoid collecting hot water during cloudy/rainy days as the temperature of water may not reach the desired level. This is a drawback of the system.
- To get the optimum service, water should be pumped inside the reservoir of the heater in the morning.

Figure 4.2: Measuring temperature of water that comes out of the water heater.

4.2 Microbial Water Quality Testing

To measure the efficiency of solar water heater, samples were measured for total coliform (TC) and fecal coliform (FC). The samples were taken from the reservoirs of stored water, both before and after heating water by solar water heater. These samples were taken in February month that was almost after four months of a rainfall event the beneficiaries last harvested rain from. The results found are shown in the table below:

Table 4.1: Results of microbial water quality tests before heating

Parameters	Unit	Tank #1	Tank #2	WHO standard (2004)
Total Coliform (TC)	CFU/100 ml	8	1	0
Fecal Coliform (FC)	CFU/100 ml	0	0	0

From the above results, it can be said that tank 2 was well maintained as it is less contaminated whereas coliform found in tank 1 sample was higher. The test results of tank 2 suggest that, if the system is maintained properly, contamination can be minimized and even eliminated.

Both the samples collected from two tanks after heating through solar heater up to 70° C and then stored for a minimum of 30 minutes show that there is no trace of coliform bacteria, as expected. The success of this study encourages the use of solar water heater with rainwater harvesting system that could be used for storage purposes in future.

Table 4.2: Results of microbial water quality tests after heating

Parameters	Unit	Tank #1	Tank #2	WHO standard (2004)
Total Coliform (TC)	CFU/100 ml	0	0	0
Fecal Coliform (FC)	CFU/100 ml	0	0	0

Chapter 5

Conclusion

Suitable technology for safe drinking water supply which will be feasible to the local community, both in terms of available resources and adaptive capability in different geographic parts of the world is still an important issue. Apart from the limited supply of safe drinking water, quality of available water is of great concern also. To ensure adequate supply of safe water and thereby, protect public health, particular attention should be directed to implementation of comprehensive water safety plans and techniques. Rainwater harvesting is a good option in areas where good quality fresh surface water or ground water is lacking. It can also be thought as an alternative in areas where centralized water supply system capacity is not able to deal with the whole demand. Therefore, the application of rainwater harvesting technology could be considered as an alternative of current paradigm of water supply sector.

In Bangladesh, acute scarcity of fresh water in rural areas is forcing people to look for other alternatives among which rainwater harvesting is a very familiar one. But lack of maintenance practice and knowledge often turn this water into contaminated water and cause health concerns. Therefore, microbial contamination is often found in stored rainwater and the quality deteriorates with time due to lack of maintenance. So proper maintenance practice is the first priority to maintain the quality of stored water to be used for long period. Apart from that, a solar water heater attached with the system will ensure that the water will be free from pathogens that mainly cause water borne diseases. By heating water before collection in temperature as high as 80°C for at least 30 minutes will be good enough to kill harmful microorganisms in water. In addition, the technology requires very low maintenance cost and can also provide hot water for other purposes also, which is an added value of the system.

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A CASE STUDY ON
RAINWATER HARVESTING FOR DRINKING WATER WITH SOLAR DISINFECTION SYSTEM

by
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Water crisis is a general term used to describe a situation where the available water within a region is less than the region's demand. The water security is a shared threat to human and nature and it is pandemic. Earth has a limited supply of fresh water; stored in aquifers, surface waters and the atmosphere. The amount of fresh water supply provided by the hydrological cycle does not increase and water everywhere on the planet is an integral part of that global hydrologic cycle. Sometimes oceans are mistaken for available water, but the amount of energy needed to convert saline water to potable water is very expensive, explaining why only a very small fraction of the world's water supply derives from desalination. Therefore, it is of major concern to find and implement suitable technology for different geographic parts which will be feasible for the local community both in terms of available resources and adaptive capability.

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