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Writer: Mubasher Ahmed (Writer's signature)
Faculty supervisor: Prof. Roald Kommedal External supervisor(s):	
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Declaration

I hereby declare that the work presented in this thesis has been carried out independently and according to the rules and regulations for getting Master's degree in Environmental Technology at the University of Stavanger, Norway.

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Abstract

Freshwater, being vital for mankind survival, has become a very serious concern for the public especially living in countries with limited water, energy and economic resources. Freshwater generation is an energy-intensive task particularly when fossil based fuels are required as energy source. However, environmental concerns and high energy costs have called for the alternative and renewable sources of energy like wind, hydro, geothermal and solar etc. Since solar is the most sustainable, readily available, abundant, low-cost and maintenance free energy source, it can be the best solution to the water scarcity especially the regions of plentiful sunshine. However, the dominant use of solar energy in passive systems for water treatment requires more research and development. In this work, a literature review is conducted on the application of low cost, passive, solar driven water treatment systems for freshwater production from different contaminated water resources. The review includes water quality parameters for intended reuse, traditional water sources, description and application of alternative water sources, existing water recycling technologies, illustrative account and critical analysis of the passive solar driven water treatment systems. In last section, the three passive solar technologies; solar pasteurization, solar water disinfection and solar water distillation are compared and the best out of three is sorted out based on cost, capacity, production and quality.

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1 Introduction

Water is Life. It is the key resource for humanity to generate and sustain economic and social prosperity. Also, water has the main role in natural ecosystems and climate regulations. But, in global perspective, the availability and distribution of fresh water resources is already limited and increasing population, industrialization, un-sustainable use and other such factors has led to the current water stress and shortage scenario. Also, at the same time, global warming, uneven rural and urban distributions of population and economics are adding to and making the issue more complex. Overall, the demand of freshwater is rising, putting a stress on the available resources and water quality. Experts warn of, by 2050, the world population is expected to increase by 33 percent and half of the world's population will be suffering from water scarcity by 2025 (WHO 2015). According to WHO / UNICEF, almost 663 million people do not have access to freshwater and more than 1.8 billion people live over water that is un-drinkable. Also, the water in developed and rich countries such as Europe is also under pressure (EU 2000). However, to cope with this challenge and to make the access to freshwater a reality for everyone, there is strong need for understanding the significance of water conservation-reclamation and reuse of wastewater is the central approach.

1.1 Water availability worldwide

Besides the achievements towards the United Nations Millennium Development Goals, 783 million people still remain without access to safe drinking water in 2015 (McGuigan, Conroy et al. 2012). According to WHO, people living in the low income countries, relatively more suffer from water stress due to the geographic, economic, social and cultural differences- the millennium development target was not met in the 48 under developed countries. Moreover, around 1.8 billion people are using drinking water that is polluted with fecal material. Even the areas where water source is better, a large percentage of water is contaminated during storage and supply because of the poor sanitation conditions (WHO 2015).



Figure 1-1 A child getting water to drink from a municipal drain line in Nakuru, Kenya (McGuigan, Conroy et al. 2012)

An increasing consumption in domestic, irrigation and industrial sectors and reliance on the limited available water sources is leading to the continuous depletion of the fresh water resources. Management of available water resources and use of alternative water sources including wastewater is crucial to ensure the freshwater provision (WHO / UN 2015).

1.2 Millennium goals

The Millennium Development Goals- United Nations' worldwide target to guarantee the access to safe water by improving the water resources efficiency was started in 2002. Under its seventh goal of ensuring environmental sustainability to the world, the part of population that have no access to safe drinking water would be turned down into half by 2015 (UN MDGs 2015). According to the recent facts and figures published by the UN; around 2.6 billion people have got access to improved drinking water sources- more than the MDG's target (United Nations 2015). This achievement has led to the start of Sustainable Development Goals (SDG's)- a new era of sustainable growth for all.

This program comprises of seventeen sustainable goals of which sixth goal ensures the provision and sustainability of water management. Under this action plan, by 2030, the provision of low cost and safe drinking water to all will be made possible. To overcome water scarcity, water quality will be improved by minimizing release of hazardous chemicals, the proportion of untreated wastewater will be turned down to half by the use of wastewater treatment, desalination, recycling and reuse technologies (UN-DESA 2016).

1.3 Water resources

From a global perspective, 97 % is sea water and not readily available for human use. The total volume of fresh water on earth is only 3%; of which 2.15 % is permanently frozen in snow covers and glaciers. So the global fresh water resources available for human use exist in the form of underground aquifers, rainfall, lakes, manmade storage facilities, rivers and constitute only < 1 % of all the fresh water resources and around 0.01 % of the total water on our planet earth. Moreover, much of this available fresh water locates far from human access and the planet’s fresh water ecosystems (UNEP 2002) (WBCSD 2009) (Seneviratne 2007).

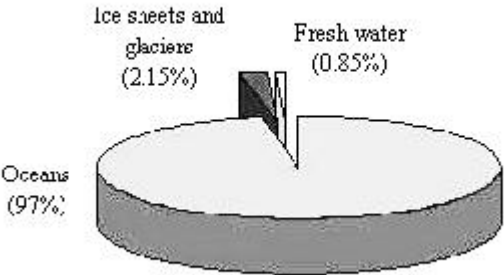


Figure 1-2 Fresh water resources

The distribution and availability of fresh water resources varies over time and space referred to as the natural water cycle. And in addition, unsustainable use and the governance generates large pressures on the availability and quality of resources leading to water scarcity and / or water stress. An area is considered under water stress when renewable water supply drops below 1700 m3 per capita per year; the water stress is higher as the ratio of water use to its availability goes up (UN 2016).

Water stress levels vary country to country because fresh water resources are not evenly distributed over the globe as only nine countries possess sixty percent of the world’s available freshwater resources- among continents; America has 45 percent, Asia 28 percent, Europe 15.5 percent and Africa 9 percent of the earth’s all freshwater resources (FAO 2003) (UNEP 2002).

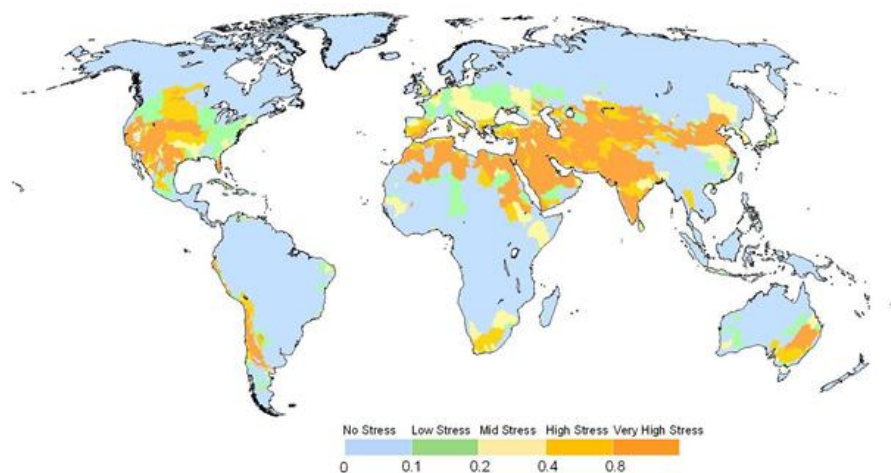


Figure 1-3 Water stress: withdrawals to availability ratio (UNESCO 2013)

Water scarcity is the three dimensional phenomena as: physical- mainly driven by the climatic changes, economical- due to the lack of financial or technical resources and institutional water scarcity- because of the governance failure in provision of safe and equitable fresh water supply (FAO 2012).

Considering the availability of limited global fresh water resources and the increase in world population by 33% - grown into 9.3 billion by 2050 will generate higher water stress and ever increasing demands for freshwater supply. Furthermore, most of this increase will occur in developing countries, which already are water stressed and insecure areas having limited capacity to cope with (UN 2011).

1.4 Global water use

Worldwide, agricultural sector is the biggest user of fresh water and constitutes around seventy percent of the total withdrawal. Where irrigation is the key use along with other minor consumptions. After agriculture, industry comes as the second largest user of water and accounts for about twenty percent of the global freshwater withdrawals. Various industrial activities such as production processes, cooling, energy generation etc. make up the twice as much water required for households. Moreover, cooling is the single largest use of water by industry. The amounts of water used for domestic purposes such as for drinking, cooking, bathing and washing are relatively small compared with the total global water withdrawal and use (WWC 2000).

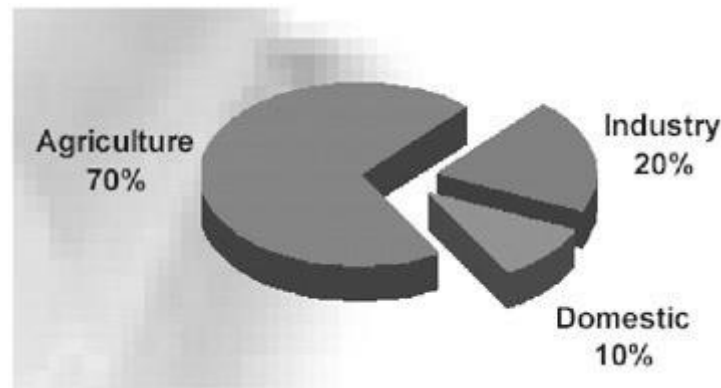


Figure 1-4 Global water use by sector (UN-Water 2016)

However, fresh water withdrawal and use turning into water scarcity is different geographically and between the different sectors. 90 percent of the agriculture exists in the under developed countries whereas the developed countries generally withdraw less water for agriculture. Industrial use of water differs with the country's income as; low in middle income countries and high in rich countries. While in case of domestic water use, people living in developed countries consume about 10 times more water than those residing in developing countries (UNESCO 2000). Moreover, as by 2050, the world population is expected to increase by 33 percent. It can therefore be deduced that; the water demand in agriculture sector will increase by 1.3 times, in industry 1.5 times and domestic consumption by 1.8 times (WWC 2000). It can therefore be concluded that the current increase in water use and water stress is occurring mainly in developing countries (UNEP 2000s).

1.5 Water Management

Water is the basic resource for all type of life on planet. As the time advances, access to fresh water is becoming more difficult and limited. To cope with this challenge, it is crucial to overcome water scarcity. Water scarcity can be controlled by the supply enhancement and / or demand management. Supply enhancement contains increased access to conventional water reserves, re-use of wastewater and drainage water, desalination, and pollution control. While the demand management can be achieved by raising the economic efficiency of fresh water use as a natural resource. The practices like recycling and reuse of drainage and waste water, development of new dams, water conservation particularly by water harvesting, reducing runoff, increasing the infiltration and storage of water are very crucial in terms of supply enhancement in water scarce regions (FAO 2012).

Over recent decades, primarily the water exploitation by mankind has resulted in water pollution, aquifer depletion and salinity intrusion into the coastal aquifers. For example, the withdrawals ratio of freshwater resources in Israel and Palestine is quite close to 100 percent. To cope with the management of fresh water reserves and quality, there is strong need to

abandon the ways contributing water scarcity: limit the excessive withdrawal of water from underground aquifers, stop exploiting the withdrawal and use of surface waters, avoid polluting the freshwater resources and reducing the inefficient use of freshwater (FAO 2003) (WBCSD 2009).

1.6 Study Objective:

Worldwide, almost 1 out of 5 deaths under the age of 5 is due to the diseases associated with water. Nearly half of the world's hospital beds remain filled with the people suffering from water-borne diseases. In developing countries, 80 percent of the illnesses are the result of contaminated water and poor sanitation conditions. And around 443 million school days are lost every year due to the water related illnesses. Moreover, 783 million people are living without access to clean and safe water. Around 84 percent people living in rural areas do not have access to the improved water (WaterAid) (WHO/UNICEF 2015), (UNDP) (UNEP) (UN FAO) (CDC USA) (UN WATER).

The already limited availability and uneven distribution of freshwater resources, massive population growth, industrialization, unsustainable use, contamination of ground and surface water sources and other such factors has led to the current scenario of freshwater scarcity particularly in the developing and under-developed countries. Water conservation, treatment, reclamation and reuse is the only approach to overcome this challenge and make the everyone's access to freshwater a reality. As the water reclamation carried out through the existing advanced water treatment technologies involves relatively more expense and complex infrastructure, hence the implementation of solar driven passive water treatment techniques is comparatively a more feasible option especially for the regions having energy crisis, low income and resources, and arid climate.

The main objective of this project is to conduct a literature review on the application of low cost, passive, solar driven water treatment systems for freshwater production from different contaminated water resources. Following topics are covered in the development of current study:

- An introduction to the required water quality parameters i.e. sensory, physical, chemical and biological for intended use
- A brief description of the traditional water sources such as ground water, surface water, rivers, lakes, streams, rain water etc.
- A detailed description of the alternative water sources such as seawater, rainwater, runoff, municipal wastewater, greywater, industrial wastewater and groundwater of non-potable quality.
- An illustrative account of the reuse applications of alternative sources in industries, irrigation, natural water systems recharge, ecological restoration and potable.

- A general description of the existing water recycling technologies includes; conventional wastewater treatment, membranes, various filtration techniques, nanotechnology, wetlands, lagoons and solar water purification.
- A full description with critical analysis of the passive solar driven water treatment systems for freshwater production
- Discussion, conclusion, proposed solutions and future perspectives are included in the last part of the manuscript.

2 Background / Literature Review:

2.1 Water Quality

The quality requirements depend primarily on the use of the water. In case of wastewater reuse; each reuse option requires different water quality and levels of treatment. The quality aspects and requirements for the use of reclaimed water in industrial sector will be different than that of domestic or irrigation use. In addition, again the quality requirements will vary with the purpose; for instance, at domestic level, the quality required for the reuse in toilet-flushing, clothes or car washing and bathing will be different than that of required for drinking purpose. However, the quality of reclaimed water ought to be as close to the freshwater quality as possible (de Koning, Bixio et al. 2008). According to American Public Health Association, water quality must be expressed in terms of use as well with the sensory, physical, biological and chemical parameters (APHA 1998) (FAO 2003)

Presence of any physical, chemical and / or biological substance in water, other than water molecules lowers the water quality and is termed as contaminant. Even small amounts of some contaminants present in drinking water might be harmful if consumed at certain levels. The presence of some contaminants does not necessarily mean that the water cannot be used for drinking purpose and will pose a potential health risk and / or any other human use for example bathing, washing or irrigation. However, a complete laboratory analysis is required to detect and find the levels at which they are found in freshwater (EPA USA).

In general, physical contaminants such as sediments or organic material present in water mainly impact the physical appearance or its physical properties. Chemical contaminants might be naturally occurring or manmade; include the presence of salts, pesticides, metals, bacteria, nitrogen, surfactants, human or animal waste in water. While the Biological contaminants are referred to as the presence of microbes in water like viruses, bacteria, parasites or protozoans. Moreover, some radiological substances can also be present in some drinking water supplies (EPA 2016)

Methods and quality of treatment depends principally on the degree and type of contaminants present in water, and the reuse purposes. For example, on IVAR water treatment facility the water is treated to produce drinkable water by following the steps of decoloring the water, pH adjustment by the use of marble filters, UV disinfection, chlorination and if required small amounts of minerals like iron is added. However, its sensory, microbiological, chemical and physical parameters must be within the NEQs to cope with the drinkable water quality standards as below: (IVAR 2016).

The guidelines are used to develop and promote potable water standards appropriate for the public health and national situations. The drinking water standards may differ among countries (WHO 2011). For example, In Scotland, the ten out of fifty-one different drinking water parameters are considered more significant. They are: pH, Turbidity, color, coliforms, E-coli, Iron, Manganese, Lead, Aluminum and Trihalomethanes (THMs) (DWQR 2016).

- It is necessary to discuss here that the consumption of safe drinking water does not pose any health risk. But, around 80 percent of all the diseases in developing countries are waterborne. That is, almost 1 billion people suffer from waterborne diseases such as diarrhea, cholera, organ damage, mal-nutrition, at any given time in under-developed countries (Burch & Karen 1998). Water-borne illnesses are caused by the microbes or pathogens present in polluted water. Additionally, around 88 percent cases of diarrhea are because of the contaminated water and poor sanitation resulting in 1.5 million deaths every year in poor countries. Water, contaminated from human or animal feces, municipal sewage are the main causes of diarrhea (WHO 2000) (CDC 2012).

- Prevention from these diseases lies in the provision of improved and safe water sources such as America got a return rate of 23 to 1 by the use of clean water technologies in the first half of 20th century. Though the United Nations' Millennium Development Goals regarding access to freshwater and good sanitation are achieved by 2015, it still has left around 790 million and 1.8 billion people without access to freshwater supply and adequate sanitation (CDC 2015)

2.2 Traditional water sources

Water access have been a primary challenge since the existence of homo sapiens. Human civilizations started to develop around the areas where water sources such as ponds, springs, lakes, stream or rivers were available. Moreover, evidences of different water / wastewater collection and treatment methods can be traced back through the ancient civilizations.

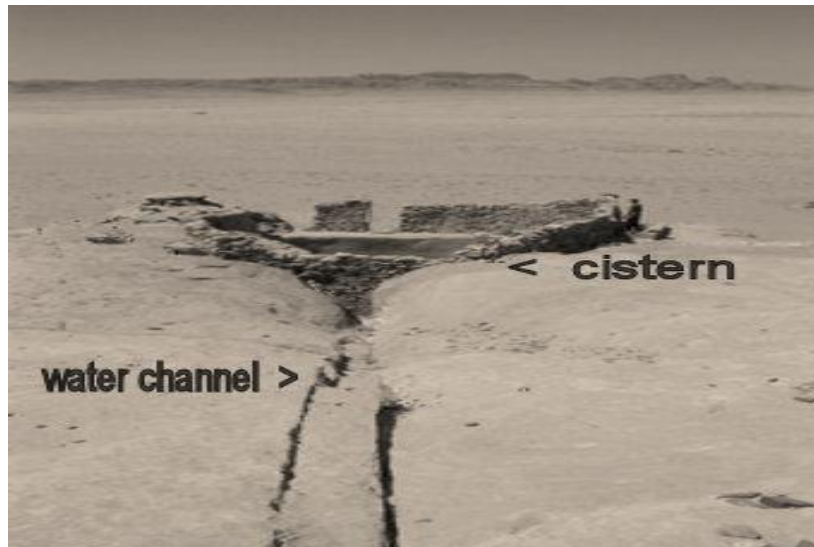


Figure 2-1 A traditional water source

2.2.1 Ground water

Ground water have been the major source of water throughout the history. Groundwater bodies (aquifers) having almost negligible rate of recharge are considered non-renewable water resources. Around 30 percent of the world's freshwater reserves are underground; providing almost two billion people with the drinking water supply and irrigating 40 percent of the land for food production (FAO 2003).

Most of the groundwater systems act as natural filters and remove microbial contaminants. Though some contaminants might penetrate depending on the location; groundwater systems are more protected from pollutants than surface water bodies. Moreover, it takes years for a contaminant to pollute a groundwater system as a result of the slow movement of contaminants and the underground water. However, very high cost is required for the monitoring and analysis of groundwater quality (UNEP 2010).

In coastal areas around the world, unsustainable extractions have led to the groundwater salinity due to seawater intrusion. Rising sea level because of the climate change and certain unsustainable irrigation practices can also lead to the salinity and higher concentrations of nitrate and pesticide in groundwater systems. For example, in Bangladesh, public health is at risk due to the presence of high levels of arsenic in groundwater (UNEP 2010).

2.2.2 Surface water

Surface water is a generic on-ground water body such as river, lake, stream, pond, spring etc. and ever have been the main source of accessible water on earth. Though it is hard to define

and differentiate between the ground and surface water, but the water that didn't intrude the ground is termed as surface water. Lakes and ponds form, where surface run off accumulates in low land areas or dugs and with appropriate management, are the good sources of freshwater than ground water. However, as the lakes and ponds are continuously fed by the surface run off, particularly the small systems, adequate treatment is necessary prior to the use as freshwater. Rivers and streams, generally, occur and fed by the surface run off in case of rainfall or ice melting. These systems are also unprotected and thus treatment is required before the water can be used. However, in less populated hilly areas, the stream water quality might be good- requiring no or little treatment.

Surface water bodies are renewable water systems- continuously recharged by the earth's water cycle (FAO 2003). Both, the surface and ground waters interact and effect each other. For example, rivers and lakes are fed by groundwater given the groundwater levels are high enough. While dams always cause the surface water levels to drop. This exchange between the surface and ground water bodies is termed as overlap and thus surface water systems consist of a significant part of the ground water systems (UWEC 2004) (FAO 2003).

2.2.3 Rain water

Traditionally, rain water has been one of the main water sources, for thousands of years, to fulfil human needs. It has been the primary source for drinking and irrigation purposes around the globe. Different rain water harvesting and filtration techniques like passing it through a series of gravels and sand have been adopted throughout the human history (FAO 1991).

Currently, domestic units for rain water harvesting are installed by small companies especially in the Pacific Northwest. The rainwater is collected in a storage tank at home. Water from the tank is initially passed through a screen to remove larger objects, then micron filters to eliminate tiny contaminants. Finally, intense ultraviolet light is passed for disinfection (UWEC 2004).



Figure 2-2 An example of domestic rain water harvesting system (UWEC 2004)

A domestic rain water harvesting system installed at a home in the Portland; state of Oregon USA is shown above in the figure. Reclaimed water fulfils all the domestic needs except drinking such as bathing, laundry, kitchen and watering the plants.

2.3 Alternative water sources

Alternative water sources are the sustainable sources of water used to meet the fresh water demand. In the regions of extreme water scarcity, increasing pressure on naturally occurring freshwater sources has led economies towards the non-conventional water sources such as: the reclamation of industrial and municipal wastewaters for different industrial, agricultural and domestic uses- that the domestic use of freshwater produced from brackish or saline water by desalination. Around 3.93 km³ of desalinated water per year is produced in the east region. And the countries like Saudi Arabia, Kuwait and the United Arab Emirates use around 77 percent of the total desalinated water accounted for that region. The quality of reclaimed water can be different in terms of physical, biological and chemical parameters – as the quality standards depend on its intended use such as drinking, washing or irrigation (FAO 2003).

2.3.1 Municipal wastewater

Since 1980, the reclamation and reuse of municipal wastewater has become one of major alternative water sources as a result of the strict effluent discharge limits and the present severe shortage of natural water resources. Recently, the municipal wastewater reuse has become an attractive alternative and is widely used for agricultural irrigation, ground water recharge, different industrial and urban recreational purposes (EPA 1981) (Metcalf & Eddy 1999).

As the raw municipal wastewater stream contains potential contaminants such as pathogens, heavy metals, organics and other bio-degradable compounds, so an adequate and effective treatment is necessarily required before reuse. Depending on the required quality and purpose of reuse, a wide range of treatment technologies are adopted to treat the municipal wastewater ranging from secondary to advance levels (Chen & Chu 2009).

According to Anderson and Meng; primary human health risks associated with the reuse of treated municipal wastewater, due to residual organic matter left behind after treatment and the pathogens, mainly depend on the reuse purposes. For example, less risks are associated with the use in industrial processes, ground-water recharge and irrigation (Anderson & Meng 2011). Moreover, Bixio and Thoeye et al. assert the reuse of reclaimed municipal wastewater in urban, industrial, environmental and recreational sectors, aquifer recharge and / or as a mixed use of any or above all (Bixio, Thoeye et al. 2006)

2.3.2 Sea water

Seawater, the earth's major water reservoir is not suitable for human use unless the salts are removed through desalination. The desalinated water has always been of good quality and a sustainable source for the production of fresh water without remineralization (Van der Bruggen and Vandecasteele 2002). Use of sea water as an alternative water source has been practiced since decades. It is estimated that; worldwide more than 75 million people get their fresh water from desalinated sea water. Nowadays, some countries, the middle east countries in particular, depend on the desalinated water to meet their fresh water demands. Moreover, it is expected that the use of desalination technique for freshwater generation will continue to grow in future (Khawaji, Kutubkhanah et al. 2008). However, high energy is required for the production of desalinated fresh water than any other recycling or reclamation technique. The high economic costs make desalination an expensive water supply option (Cooley et al. 2006).

2.3.3 Industrial wastewater

The major part of the water use in any industry is associated with the cooling purposes. Around seventy to eighty percent of industrial wastewater is the cooling water, wasted daily from cooling towers that can be recovered, treated and effectively reused (Wang, Fan et al. 2006). Statistics depict that the primary source of water used as make-up water for cooling purposes in refineries, food industry, electronics, textile, chemical, steel and power stations is the portable and groundwater. Though the cooling wastewater has large volume and slightly contaminated, generally, industries are reluctant to reclaim this water because of the higher costs required for the treatment (You, Tseng et al. 1999).

However, the waste water from cooling towers contains pollutants such as micro-organisms, colloids and ions like Ca^{+2} , Mg^{+2} , HCO_3^- and CO_3^{-2} thus cannot be reused directly prior treatment. Impurities like colloidal particles, suspended solids and micro-organisms can be removed by traditional methods of treatment such as coagulation, sedimentation and filtration. Further desalination is required to remove high salt contents (Wang, Fan et al. 2006).

2.3.4 Run off

The part of the precipitation or snow melt appearing in drains, surface streams or rivers is referred to as runoff (USGS 2016). This runoff water is collected and made available for irrigation or domestic use in the periods of water shortage. The method includes: a catchment area for the collection of runoff water, a conveyance system like channels to direct the runoff and finally a storage system to accumulate the water for treatment and use.

In semi-arid areas of seasonal droughts and where rainfall is not sufficient, runoff water harvesting helps to cope with the water shortage. It is used for the ground water (aquifer) recharge, to minimize erosion, growing crops and reduce flooding (FAO 2011).

However, rainfall water is slightly acidic because of the dissolution of carbon dioxide from atmosphere and considerable amounts of soil particles, minerals, some organics and microorganisms are mixed with the rain water as surface runoff (FAO 2002). Improved runoff water management provides the access to sufficient and safe water for domestic use (FAO 2011).

2.3.5 Grey water

Graywater is the wastewater generated from laundry, showers or bathroom sinks. It does not include the waste water from kitchen sinks, toilet flush or urine. It can be reused directly for irrigation purposes, in cooling towers as make up water or to flush toilets. Watering the plants and gardens is the best direct reuse of greywater as the detergents (only environment friendly) and pathogens are immediately neutralized as applied to soil. Otherwise, for more improved water services and reuse; simple water purification system is required to clean the water as it contains little amounts of contaminants (AWWA 2010). A well designed greywater reclamation system can significantly save the water and energy consumptions to achieve sustainable water-management (Wiley 2014).

Moreover, Etchepare and van der Hoek conducted the risk assessment of grey water reuse to human health. They applied the three tiered approach to examine the possible health hazards due to the presence of micro-pollutants in greywater and concluded that the most of the compounds present, do not pose any potential risk to human health even if the reclaimed

greywater is being used the whole life for drinking purposes (Etchepare and van der Hoek 2015).

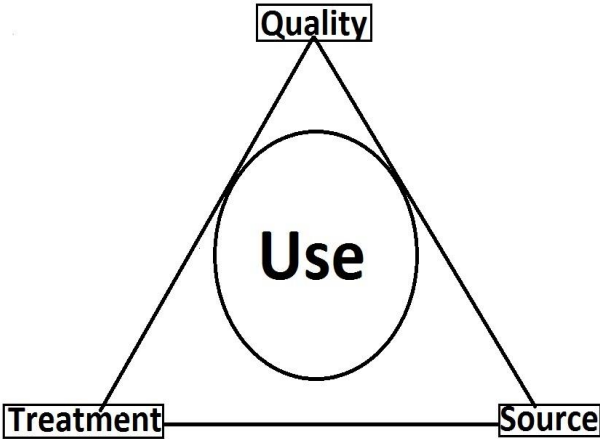
2.3.6 Ground water of non-potable quality

The water found under the earth’s surface in soil and rocks is termed as ground water. As the earth’s hydrologic cycle, precipitation and surface geology and water sources have a direct impact on the ground’s water table and quality. That is, surface water streams can be a major source of the underground aquifer contamination and vice versa. And due to this interaction of ground water and surface water, it is normally considered a single water resource (USGS 2013).

Generally, the ground water is considered safe and does not require any treatment before consumption, given that, in some settings of shallow aquifers, the ground water can be contaminated by the nearby any polluted surface waterbody (USGS 2013).

2.4 The reuse of alternative water sources

Water treatment is the restoration process of water to a required quality, that has been used or contaminated by mankind or nature. Water might be treated to any required level of quality for intended use, for instance, ecological, irrigation, industrial or drinking water with the relative increase in cost. This section describes the wastewater treatment technologies that are predominantly in use these days. However, the technology selected as suitable for one application cannot be the ideal for another and the selection will depend upon the factors, such as economics, climatic conditions, availability of resources etc. of that specific area (Englande Jr, Krenkel et al. 2015).



The available resources (cost, labor, raw material to be used), geography (place where the technology or product is going to be used) and the purpose (required quality and expected use of the reclaimed water) are the key parameters that set up the basis for technology selection (Burch & Karen 1998) (Chittaranjan & Ravi 2011). However, the crucial indicators such as sustainability, efficiency and simplicity of the mechanism can never be declared insignificant (Wade Miller 2006) (J. Martinez & W. Clark, 2015) (Okun 2000)

The use of alternative water sources arises as a necessity in order to cope with the challenges like dramatic increase in water demand due to urbanization and population growth, declining of available fresh water resources leading to water scarcity and the environmental pollution. Worldwide, the water / wastewater from such sources is used in direct and indirect way: the direct reuse, without any treatment has traditionally been implemented in agriculture and recreational sectors, while the indirect use includes aquifer or surface water bodies recharge (Karabelas J. Anastasios et al. 2002). Moreover, the reuse of alternative water sources such as domestic and industrial wastewater is developing in municipal and industrial sectors around the globe like USA, Japan, Australia and Mediterranean countries (Kellis, Kalavrouziotis et al. 2013).

Additionally, the use of alternative water sources such as municipal wastewater (raw or treated), Sea water, industrial cooling wastewater, run-off, grey water, ground water of non-potable quality etc. has the great potential for; not only helping in the conservation of freshwater resources but also the reduction of nutrient rich wastewater's release into the surface water bodies resulting in environmental stress. As according to John Sheaffer, wastewater should be considered a resource- freshwater having nutrients for plants and vegetation (McKenzie 2005).

The application of reclaimed water depends upon the degree of treatment. Also, with respect to use, the water from these sources is refined and made useable i.e. the reuse purpose and influent water quality set the treatment level and quality requirement of the treated effluent (Kellis, Kalavrouziotis et al. 2013) (Vigneswaran 2009).

2.4.1 Industrial applications

The major use of water in industrial sector includes water for make-up purposes in cooling towers, boiler-feed water and process water. As, in general, many industrial applications do not require the water of high enough quality, so depending on the industrial category and activities the reuse of reclaimed water can always be the ideal option (Vigneswaran 2009).

The largest use of water in any industrial operation is the cooling water for makeup purposes. The requirements concerning water quality for industrial cooling purposes are usually lower in

comparison to other processes such as for boilers and process- water. The cooling is carried out in two ways; closed and open circuit. In closed-circuit cooling process, there are no associated environmental or human-health hazards, while in the open-circuit cooling aerosols generating legionella can pose risks (Huertas, Salgot et al. 2008). Likewise, complications such as clogging, corrosion, scaling, fouling and bio-film growth may occur in the cooling recirculation water-towers due to the existence of micro-organisms and nutrients in reclaimed wastewater (Vigneswaran 2009).

Many cases of such reuse of reclaimed wastewater in different industrial applications can be seen across the globe. For instance, Israel recycles around 2.5 MCM wastewater per year from its petro-chemical industries situated at Haifa and reuses for industrial cooling purposes (Kellis, Kalavrouziotis et al. 2013). Also, in Kerman city of Iran, a research and analysis of treated municipal wastewater resulted in recommendation of the reclaimed-water reuse in industrial cooling tower applications (Hajian, Niknam et al. 2014).

Another successful example demonstrating the reclamation and reuse of wastewater in industrial facilities can be seen at a power-station situated in New South Wales- Australia. This power plant called Eraring power-station was situated quite near large urban area. As, generally, the power stations have large cooling water requirements- though the huge amounts of domestic waste water were generated by the nearby municipalities but around 4 million liters of water per day from a local potable-water supply was being consumed by the power plant. As a result of the conducted feasibility study, a full scale municipal wastewater treatment plant comprising of the membrane filtration was installed to replace the requirement and consumption of potable water with the reclaimed municipal effluent to reuse as cooling water in power generation (Vigneswaran 2009).

2.4.2 Reuse for irrigation

Wastewater from alternative sources such as runoff, greywater, seawater, municipal and industrial can be used directly i.e. without any treatment to irrigate parks, public lawns, commercial nurseries, gardens and non-food crops. And the treated or partially treated wastewater can be used to grow crops and vegetables that are usually cooked before consumption, given that the controlled irrigation patterns are adopted and the feed water quality is sufficiently good to avoid the environmental and human health hazards. However, for such crops' growth and vegetation, measures like regular soil testing and prevention of animal's entrance into the fields irrigated with such wastewater must be implemented (Hajian, Niknam et al. 2014). Furthermore, salinity can be an issue need to be monitored and controlled appropriately. For instance, in Dan region of Mediterranean, highly saline reclaimed water recovered from the aquifer has been successfully used for almost 15 years to grow a variety of crops. According to Salgot et al. techniques like sprinkling and drip irrigation help to avoid the contamination of crops and vegetation grown-up by the use of raw or insufficient treated water

of low quality, still the measures such as the use of water having adequate quality and self-protection are recommended to avoid any possible human health hazards (Salgot, Huertas et al. 2006, Huertas, Salgot et al. 2008, Kruzic and Liehr 2008).

In general, the reuses for agricultural irrigation purposes do not require higher quality levels of treatment. However, the quantity and geographical location of wastewater generally define the choice for reuse of available reclaimed-water in different irrigation applications. For instance, in Riyadh city of Saudi Arabia, the recycled effluent from the six large waste water treatment plants was considered suitable for restricted irrigation. And, the previous standards were declared more stringent in comparison with the WHO's guiding principles and was recommended to adjust the standards according to the local conditions (Vigneswaran 2009) (Al-Jasser 2011).

In context of wastewater reuse for agricultural irrigation; globally, it has been the prime way of disposing wastewater in most of the under-developed and developing countries. Also, this practice is very common in other parts of the world such as California uses 60 percent, Japan 41 percent and Tunisia 15 percent of its recycled water in agricultural irrigation applications respectively. Moreover, China irrigates around 1.33 MH (Million Hectares) of its agriculture land with the raw or partly-treated municipal wastewater, and in Mexico more than 70000 H (Hectares) of land growing crops is irrigated by the recycled wastewater. A little more detail over it; In Israel, the proportion of reused wastewater in irrigation is around 36 percent. Tunisia is growing its almost all kind of crops except vegetables by irrigating with the wastewater treated up to secondary level. Australia is using its reclaimed water in irrigating a variety of crops such as sugarcane crop, growing tea plants and watering timber-forests. Furthermore, numerous large scale waste water irrigation schemes are already in practice in countries like Spain, Morocco, Egypt, Cyprus and Malta etc. (Vigneswaran 2009) (Kellis, Kalavrouziotis et al. 2013) (Bouwer 2000) (Kruzic and Liehr 2008) (Salgot, Huertas et al. 2006).

The reuse of wastewater for recreational and landscape irrigations is one of the largest applications practiced for many years. Examples of such cases can be seen in many countries around the globe such as in USA, Japan, Australia, Saudi Arabia, Mexico etc. and no associated adverse effects are reported. However, the water reused for such purposes must be sufficiently treated before use to avoid the possible environmental and human-health risks. An excellent example of such reclamation and reuse can be quoted from South-well Park, Canberra-Australia, where the sewage wastewater is treated and reused for landscape irrigation (Vigneswaran 2009) (Kruzic and Liehr 2008) (Salgot, Huertas et al. 2006)

No doubt, the reuse of wastewater in agricultural irrigation applications is very beneficial in context of low cost and providing necessary fertilizers for plant-growth, but it can create problems such as the contamination of surface or ground-water, degrade the quality of grown crops and adverse health concerns in settings of inappropriate planning, management and use.

However, the research conducted over the use of reclaimed municipal wastewater in agricultural irrigation has proven that there are no any harmful environmental and human-health effects associated with the consumption of even un-cooked food crops irrigated with such recycled water. In addition, the study recommended the tertiary level treatment plus appropriate disinfection of the waste water to be reused for such purposes (Vigneswaran 2009) (Bouwer 2000) (Kellis, Kalavrouziotis et al. 2013) (Salgot, Huertas et al. 2006) (Kruzic and Liehr 2008).

2.4.3 Potable reuse

Water from various alternative water sources can be treated up to the high quality and turned into the potable water. As stated by Vigneswaran; potable reuse is categorized into direct and indirect reuse. The direct reuse as drinking water includes the addition of reclaimed wastewater straight into the regular potable-water supply systems, whereas the indirect reuse comprises of the procedures such as the reclaimed water or wastewater is mixed and diluted with the other potable water sources or supplies (Vigneswaran 2009).

Another way of in-direct potable reuse can be the recovered treated water from recharged aquifers. For instance, reclaimed water having high TDS from a sewage treatment plant is mixed with the standard drinking water and reused for potable purposes in the Mexico City. Also in Arizona- USA, many municipalities get their potable water supplies from the recovered ground-water recharged with the treated domestic wastewater up to the tertiary level along with the downstream disinfection. Likewise, Israel uses its lake water for aquifer recharge and then recovers and reuses for drinking purposes (Vigneswaran 2009).

The direct-potable reuse, though seems un-aesthetical and unacceptable but the reuse of recycled waste water as potable water has been practiced since ages. An excellent example of such direct reuse arose in emergency situations in Chanute town of Kansas- USA in 1950: where in the periods of constant droughts, the sewage wastewater was treated, recirculated and being used as potable water. However, as a result, few cases of abdominal and stomach infections were reported (Vigneswaran 2009).

The reclamation of wastewater and direct reuse as potable water in Windhoek city- the Namibian capital, is a successful example for all arid and semi-arid areas on the globe facing severe water scarcity. The scheme was started in 1968, initially the domestic wastewater was treated up to the secondary treatment level, mixed with the dam water and added straight to the freshwater supply. But since 2002, as a result of extension and upgradation in the previous plant, the Goreangab water reclamation facility started producing around 5.5 million gallons of high quality potable water per day from domestic and industrial wastewater- fulfilling the freshwater demand of approximately 350,000 inhabitants of the Windhoek city (Pisani, Lahnsteiner et al. 2006) (du Pisani 2006).

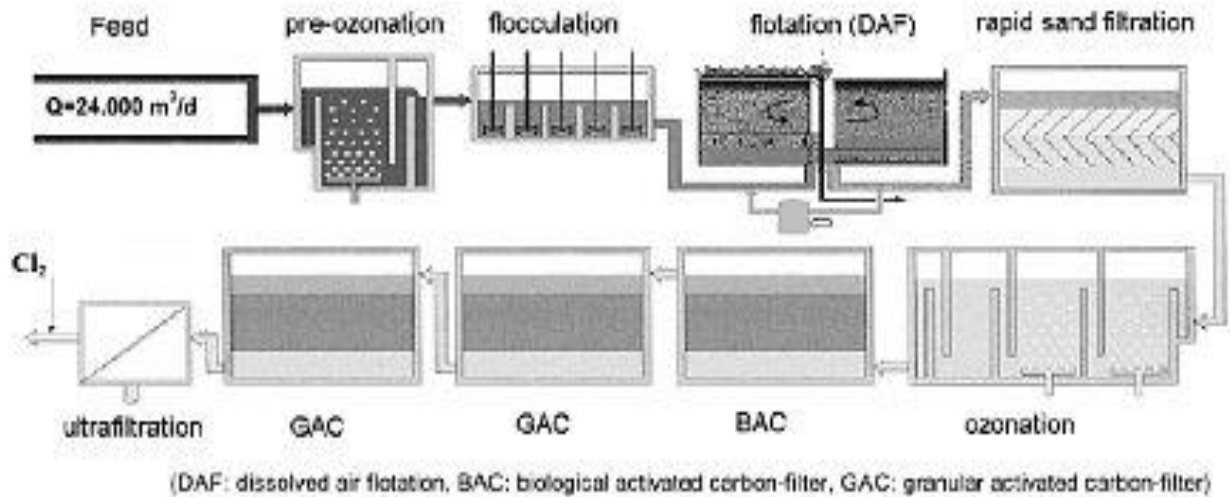


Figure 2-3 Process flow schematic of the Goreangab water reclamation plant, Windhoek- Namibia (du Pisani 2006)

The treatment process at Windhoek comprises of two consecutive but separate plants. The wastewater treatment plant situated at Gammams treats the raw wastewater in a conventional biological way (activated sludge process), and the effluent produced is then discharged into the ponds (in series) for some natural treatment. While the water reclamation facility existing at Goreangab consisting of units like ozonation, coagulation / flocculation, dissolved air floatation, sand filtration, activated carbon filtration, and chlorination treats the effluent coming from ponds and produces the drinking water of high quality, that meets all potable water standards and fully accepted by the consumers (Vigneswaran 2009) (Pisani, Lahnsteiner et al. 2006) (du Pisani 2006) (Angelakis, Asano et al. 1996, Angelakis, Asano et al. 1996) (Okun 2000).

2.5 Case studies:

The factors such as climate change, population growth, depletion of traditional water sources and saltwater intrusion has led many communities to find alternative water solutions like water conservation, reclamation, reuse and even desalination to meet their freshwater needs. A few case studies of the communities that have been through such circumstances are represented below:

2.5.1 Water reclamation and reuse in Florida:

Despite the abundant rainfall, Florida faces drought conditions due to the uneven distribution and seasonal variations in the precipitation patterns. To conserve its freshwater resources, Florida treats its domestic wastewater and reclaims around 727 million gallons of water per

day. In Florida, the principal reuse of reclaimed water is irrigation of public areas such as parks, playing fields, residential lawns, etc. The second largest uses include industrial cooling water and groundwater recharge. The use of reclaimed water in agriculture sector consists of growing crops and feedstuffs that can't be consumed directly. However, crops can be grown up by the use of reclaimed water in Florida, but the higher treatment and disinfection is required to meet the stringent water quality standards prior to use for such purpose (J. Martinez & W. Clark, 2015).

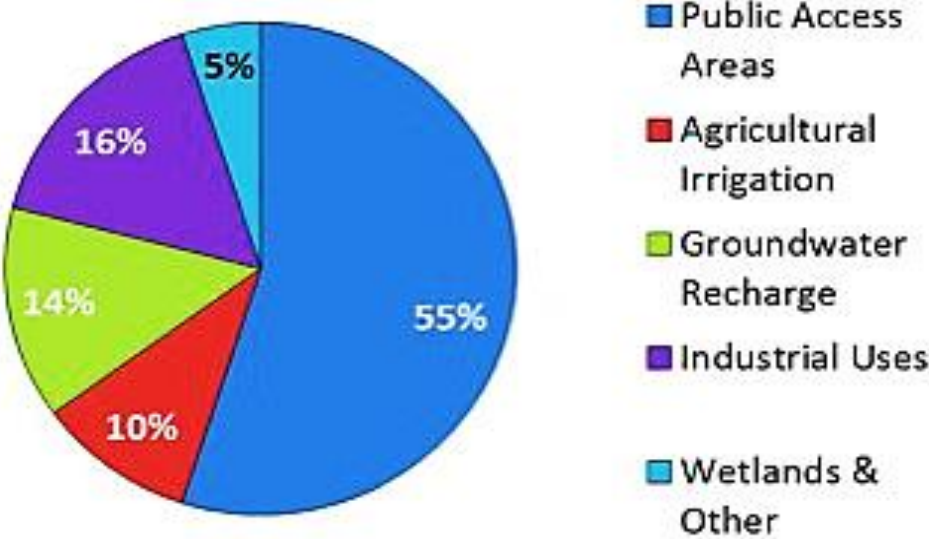


Figure 2-4 Representation of reclaimed water utilization in Florida (FDEP, 2015)

Florida's wastewater treatment and reclamation scheme is one of the world's largest dual municipal-water distribution systems and oldest in the United States. St. Petersburg was the first city of Florida who constructed such a large-scale wastewater treatment and reclamation structure in the 1970s (Wade Miller 2006). It consists of four water reclamation plants and supplies the potable-water through one distribution system and non-potable water by the other (McKenzie 2005). At facility, the wastewater is treated, at minimum, up to a secondary level and basic disinfection. The water is either directly reused or discharged, or if necessary, subjected to an advanced level of treatment (also termed as tertiary treatment).

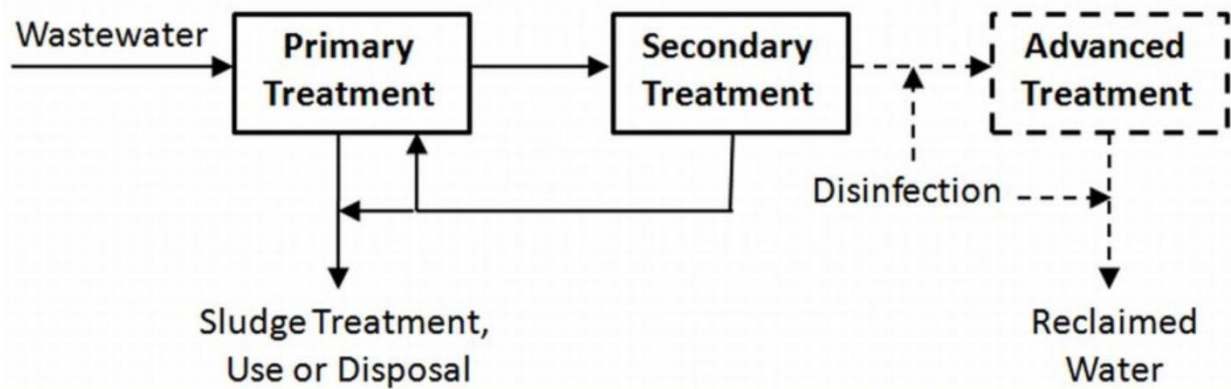


Figure 2-5 Schematic of wastewater reclamation process employed in Florida (FDEP, 2015)

As, conventionally, the three stages of wastewater treatment process include; primary, secondary and tertiary (advanced). During the primary treatment; wastewater is subjected to bar-screen structures to remove suspended solids or large fragments and grit chambers for settling. The water enters the secondary treatment plant, where biological treatment decomposes and further reduces the organic matter present in wastewater. The water is then clarified to filter any residual organic material, disinfected with chlorine and used or discharged. To further purify, the water is additionally subjected to a tertiary level of treatment where physical, chemical and / or biological processes remove the remaining nutrients, solids, chemicals or organic material. After tertiary treatment, the water is disinfected with chlorine for the complete removal of contaminants and enhance the water quality. However, the pollutant contents in reclaimed water depend on the employed wastewater treatment process and the advanced level treatment is an optional step (McKenzie 2005) (Wade Miller 2006).

By the fit-for-purpose rule, Florida follows the Environmental Protection Agency- United States' guidelines regarding the treatment and quality standards requirements for the reuse of reclaimed water (EPA, 2012). For instance, Secondary degree treatment and basic disinfection is carried out for the reuse in industrial applications such as cooling or process water. And, for different land applications, such as irrigation of residential or publicly accessible areas and watering the edible crops, secondary degree treatment with filtration and a high level of disinfection is required. However, additional treatment might be required to meet any specific application needs (FAC, 2012) (FDEP, 2015). Currently, the conventional wastewater treatment process practiced in Florida consists of deep bed and multimedia filtration, and high degree disinfection with chlorine (Wade Miller 2006).

Up till now, the Florida community favors and loves the service; the prices of reclaimed water are considerably low as compared to the potable water rates. The reclaimed water prices fluctuate from around \$0.39 to \$0.50 per 1000 gallons (Wade Miller 2006), potable water costs around 5 to 10 times more than the reclaimed water (McKenzie 2005). Besides, membranes are

not used in water treatment and reclamation due to the cost considerations, even though the Florida has more desalination units than any other state of America (Wade Miller 2006).

2.5.2 El Paso, Texas wastewater reclamation

El Paso Water Utilities (EPWU) situated in the water scarce desert of Texas has a philosophy that always consider the water as a valuable and don't use it only once. Since 1963, EPWU is, as a recognized leader in the application of water conservation and reclamation, operating the utilities of water from diverse sources such as storm water, brackish water, waste water and reclaimed water in El Paso county, Texas. The sources of water are: ground water from the Hueco Bolson and the Mesilla Bolson aquifers, surface water from the Rio Grande river and the reclaimed water (WRA, 2007) (EPWU 2014)



Figure 2-6 Representation of the water sources' locations for EPWU (EPWU 2014)

Since 1963, the EPWU is delivering reclaimed water for different non-potable reuse applications. Since that time, around 5 Million gallons of water per day (Mgal/d) from its four treatment facilities is being used for non-potable reuses like industrial, landscape irrigation, public parks and lawns, school grounds and such other purposes. And, around 2.5 million gallons of water per day is being used for in-plant and potable services as a reuse through ground water recharge and recovery. So, the nearly 7.5 Mgal/d of reclaimed water is being used in industrial, groundwater recharge, irrigation, construction and other such applications.

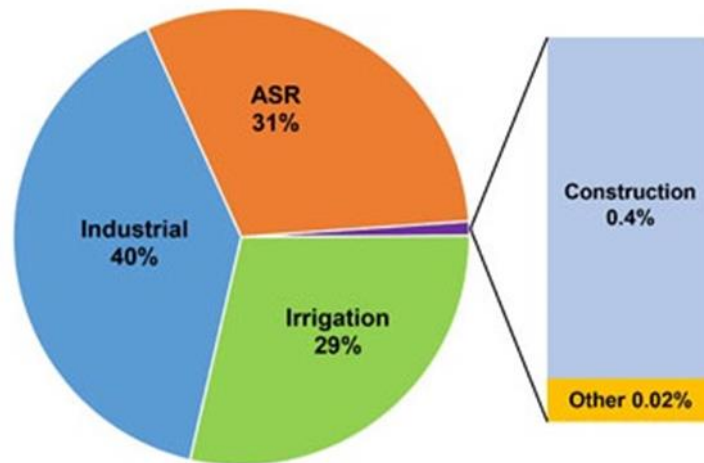


Figure 2-7 Distribution of reclaimed water use in El Paso county, Texas (EPWU 2015)

Primarily, the gradual depletion of the Hueco Bolson aquifer and the need for upgradation and expansion of water treatment facility serving the northeast area led to the water reclamation and reuse concept in El Paso. So, the use of reclaimed municipal wastewater for the Hueco Bolson recharge was considered the most economical alternative by the United States' Geological Survey department.

EPWU runs four ground-water (arsenic), two surface water, a brackish water desalination and four wastewater treatment and reclamation units (WRA, 2007). In the four reclamation plants, water is collected from surrounding areas and treated. At one of the four units, the water from sources such as under-ground aquifers and Rio Grande river is treated up to the advanced tertiary level generating the high quality freshwater that exceeds the EPA's drinking water quality standards. The other three units produce reclaimed water of Type 1 quality, in accordance with the water reuse quality standards and guidelines regulated by the Texas Commission on Environmental Quality (TCEQ). Type I reclaimed water is defined as the water that poses no human health risks upon contact and use (US EPA). According to Texas Commission on Environmental Quality, the approved and declared safe applications of Type 1 reclaimed water include; landscape irrigation, industrial, aquifer recharge, construction and others such as fire protection (Huertas, Salgot et al. 2008) (Salgot, Huertas et al. 2006, Kruzic and Liehr 2008) (Al-Jasser 2011).

Water reclaimed from the El Paso facility, injected into an aquifer supplies around 65 percent of the county's water demand. According to Okun, coagulation, carbonation, sand and granular-activated-carbon filtration and disinfection is required subsequently the secondary degree water treatment, and studies regarding the aquifers show that the residence time i.e. the time between injection and recovery of water should be five to fifteen years (Okun 2000)

As a result of several new schemes named; Central Reclaimed Water Project, Northeast Reclaimed Water Project, Northwest Reclaimed Water Project and Mission Valley Reclaimed Water Project, launched for upgradation and extension of the facility (EPWU 2015)- Currently, EPWU processes about 20 billion gallons of surface-water per year. It has the capacity of around 220 Million gallons of potable water per day (Mgal/d), and 100 Mgal/d of groundwater, surface water and desalinated brackish water treatment. In addition, the desalination plant built in east El Paso produces almost 27.5 Million gallons of potable water per day (Mgal/d) from the Hueco Bolson's brackish water sources (EPWU 2014)

2.5.3 Case study Orange County- California

The Orange County, California is one of the instances in the world where potable reuse mightn't be avoided. The Orange County Water District (OCWD) is the district of Orange County in US California and called a land of severe droughts. It was formed in 1933 to protect the county's rights to Santa Ana river water and manage the county's groundwater basin. The OCWD, a leader in water reuse, started turning the wastewater into usable water in 1976, to overcome the challenge of diminishing freshwater sources and providing water for different applications such as industrial, irrigation and potable (Geselbracht and Evans-Walker 2005) (McKenzie 2005) (Smith 1995, Okun 2000).

The OCWD provides 2.4 million residents of Orange County with high-quality water at the lowest cost in a sustainable way from the Santa Ana river, county's groundwater basin and the Groundwater Replenishment System (GWRS). The GWRS is the world's largest and most advanced system for indirect potable reuse. It takes the already treated wastewater and further purifies it through micro-filtration, reverse osmosis and ultraviolet light with hydrogen peroxide and generates the water that is injected into the Orange County's groundwater basin (US OCWD) (Geselbracht and Evans-Walker 2005). Moreover, in the mid-90s, under GWRS, OCWD built the Water Factory 21 to treat municipal wastewater for injection into the ground as a barrier against the seawater intrusion into freshwater aquifers (Smith 1995) (WRA, 2004) (Geselbracht and Evans-Walker 2005).

The advanced wastewater treatment process employed by the Water Factory 21 in Orange County includes; chemical coagulation, re-carbonation and pH neutralization, media filtration, granular activated carbon filters and reverse osmosis so that the treated water would meet the total dissolved solids (TDS) requirements for the blended and injected water. The source of water for the Water Factory 21 is the secondary effluent from an adjacent sanitation district's wastewater treatment plant treated through the processes of lime clarification, re-carbonation and pH control, media filtration, activated carbon filtration, reverse osmosis and chlorination. Before injection, this water is further blended (2:1) with the uncontaminated deep aquifer water. The blended water is also chlorinated before injection. Such extensive treatment and high quality water also prevents from the clogging of deep well injections (Geselbracht and Evans-Walker 2005) (WRA, 2004) (US OCWD) (Smith 1995).

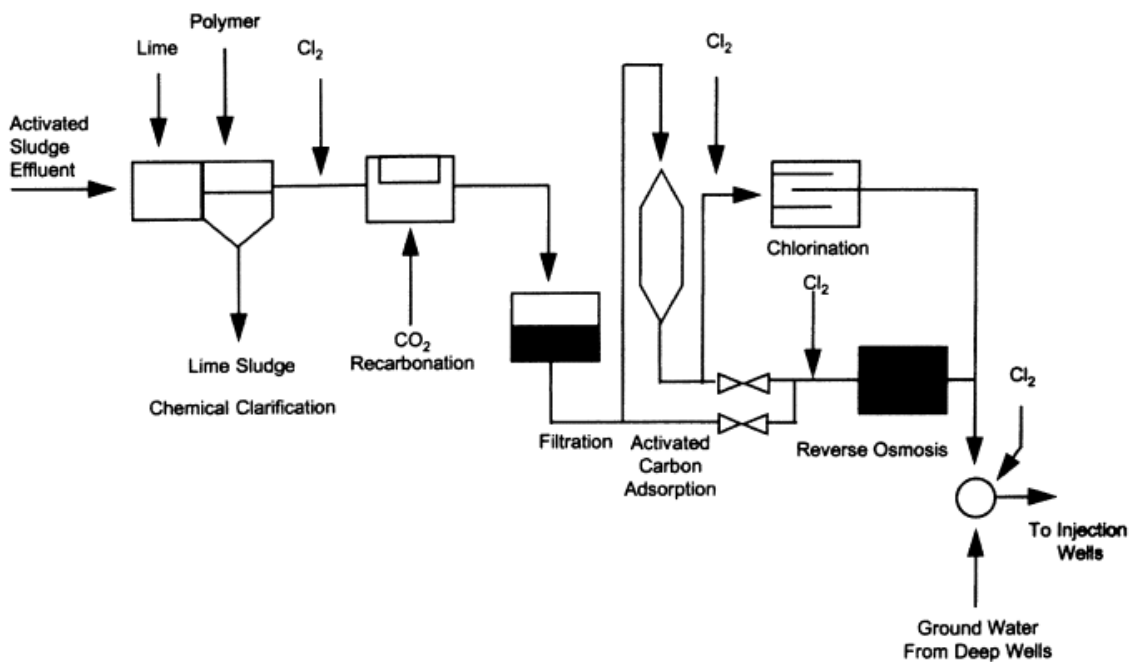


Figure 2-8 Schematic of flow for Water Factory 21, OCWD (US OCWD)

Through comprehensive monitoring, it has been verified that the product water from Water Factory 21 is absolutely pathogen free and meets all potable water standards. In the past, two human carcinogens (N-nitrosodimethylamine and 1,4-dioxane) were found in reclaimed water exceeding the water quality standards. However, an immediate action was taken to bring the level within the compliance (WRA, 2004).

The GWRS produces around 70 million gallons of water per day that exceeds the high quality freshwater standards. Since May 2015, this production is increased to 100 Mgal/d. Around 35 Mgal/d of this reclaimed water is pumped into the injection wells as a barrier to seawater intrusion and the remaining two-thirds for the recharge of basins in Anaheim-California where the water is naturally filtered by sand and gravels towards the deep aquifers resulting in drinking water (US OCWD) (Karabelas J. Anastasios et al. 2002) (Kellis, Kalavrouziotis et al. 2013) (Vigneswaran 2009) (EU 2014) (Smith 1995).

Worldwide, the artificial recharging of natural water systems from different alternative water sources has been adopted for centuries. This method, no doubt, provides the additional treatment and improves the water quality. Also it acts as; storage in periods of low water demand and readily available source in times of water shortage. Such recharge systems can be in-channel such as small dams or levees across or in the stream-bed respectively, or off-channel like ponds and basins. In cases of unfavorable soil conditions and composition such as absence

of sand and gravel or less permeable and / or contaminated soil, artificial recharge and infiltration is achieved by the use of trenches or pits. Also, in case of confined aquifers, the recharge is obtained by the use of injection wells- that is of course an expensive option because it requires an adequate pre-treatment before recharge to avoid clogging problems (Bouwer 2000), (Bouwer 1996).

The ground water (aquifer) recharge with the wastewater is most widely used technique for water reclamation and reuse. The water penetrates through the available soil, sand or gravels of the ground and starts moving downward with speed, almost in the range of 100 to 400 meters per year. According to a report published in USA by the National Academy of Science; the reuse of water recovered from such aquifers has no any harmful effects, given that the water used for recharge purposes must be sufficiently treated prior to recharge to avoid the deterioration of ground water quality and to lessen the treatment before use. Moreover, this method significantly reduces the pre- treatment requirements and the contamination present in the wastewater (Vigneswaran 2009).

Ground-water recharge techniques are comparatively more sustainable, eco-friendly and economical than surface waterbodies recharge as no problems of evaporation losses and algal bloom in ground water recharge. Moreover, the groundwater recharge systems are more effective in cleansing the wastewater due to the natural filtration ways of the under-ground soil formations (Bouwer 2000), (Bouwer 1996). The soil and the other aquifer's geological material adsorb and thus remove the contaminants from water. According to Chittaranjan and Ravi; except disinfection, there is no need of any additional treatment if such natural groundwater filtration systems are adequately designed and maintained (Chittaranjan & Ravi 2011).

In most areas of the world, this natural water filtration technique has been adopted and increasing with the passage of time. For instance, in Europe, most of the contaminants from water are removed by the movement of water through the soil or aquifer, when the wells installed at appropriate distances from the river stream pump out water on continuous basis (Chittaranjan & Ravi 2011). Also, in arid / semi-arid areas of the world like the Morocco and Israel use ground-water (aquifer) recharge technique to treat the water and remove contaminants from alternative water sources- Israel uses lake water for recharge purposes (Vigneswaran 2009). According to Bouwer, this artificial recharge technique provides the secondary and tertiary level treatment because the underlying soil formations act as natural filters and produce pure and odorless water (Bouwer 1996, Bouwer 2000) (Laura & Bernd 2014).

3 Technologies for water recycling

Water treatment is the restoration process of water to a required quality, that has been used or contaminated by mankind or nature. Water might be treated to any required level of quality for intended use, for instance, ecological, irrigation, industrial or drinking water with the relative increase in cost. This section describes the wastewater treatment technologies that are predominantly in use these days. However, the technology selected as suitable for one application cannot be the ideal for another and the selection will depend upon the factors, such as economics, climatic conditions, availability of resources etc. of that particular area (Englande Jr, Krenkel et al. 2015).

The availability of resources include cost, labor, raw material to be used, geography (place where the technology or product is going to be used) and the purpose (required quality and expected use of the reclaimed water) are the key parameters that set up the basis for technology selection (Burch & Karen 1998) (Chittaranjan & Ravi 2011). However, the crucial indicators such as sustainability, efficiency and simplicity of the mechanism can never be declared insignificant.

In technology selection for wastewater treatment and reclamation, primarily, the three parameters set the basis: the water production capability, possibly cost effective and as possible less maintenance required (Burch & Karen 1998). Also, the geography, availability of resources and most important the desired quality and purpose of water reuse plays a key role in technology selection. For instance, membrane filtration technology has the ability to feed water ranging from small to large communities, while, on the other hand, solar distillation; a fairly low cost technology, can supply water to a family unit or small neighborhood in tropical and desert regions of the world (Chittaranjan & Ravi 2011).

The water recycling technologies are considered sustainable and efficient if the treatment methods use less energy, low consumption of chemicals and man-power, relatively cheap and have simple process mechanism. Moreover, the efficiency of reclamation system is based on the production of high quality freshwater that does not require any additional treatment. In general, water reclamation techniques include; coagulation, flocculation and disinfection, membranes, different filtration techniques such as activated Carbon filters, Granular Activated Carbon (GAC) filtering, Nano filtration materials, natural aquifer filtration, wetlands as natural water treatment bodies, solar pasteurization and distillation (Chittaranjan & Ravi 2011).

3.1 Conventional wastewater treatment

Conventional treatment of wastewater consists of coagulation, flocculation, clarification and disinfection unit. In coagulation and flocculation, small particles of turbidity, color and bacteria

are converted into large particles (flocs) and are removed in the next step of sedimentation / clarification (EPA 2016) (WHO 1996) (WHO 2007).

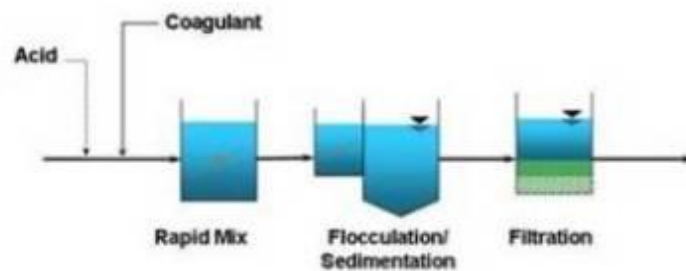


Figure 3-1 Representation of conventional wastewater treatment

In coagulation, a coagulant (positively charged) is mixed with the wastewater that destabilizes contaminants (negatively charged). Addition of some polymer and acid is also required to enhance the coagulation process depending on the load and nature of influent water. In general, particulate matter and the organics present in wastewater impact coagulation. Flocculation process involves the agglomeration of destabilized particles into precipitates called flocs. The process is mainly dependent on the mixing regime occurring inside the tank. From flocculation unit, water enters the clarifier where these flocs (contaminants) are removed by gravity settling or skimmed off the surface of clarification tank (EPA 2016) (WHO 1996) (WHO 2007).

According to Burch and Karen, in developing countries, coagulation and flocculation is carried out in both natural and industrial way, while for filtration, the techniques such as slow-sand, rapid-sand, cartridge, local-media made from local available materials such as rice-hulls or coconut-shells are used (Burch & Karen 1998). Disinfection is almost considered the final step in conventional wastewater treatment process to kill the micro-organisms. Chlorination, ozonation and / or use of ultraviolet light are the common methods of disinfection. Chlorination is considered the best among these three most common techniques used for disinfection because of its low cost and long lasting effects (WHO 1996) (EPA 2016) (WHO 2007).

3.2 Membranes

Membranes have an important role in the wastewater treatment and reuse such as generation of drinking water from the brackish and / or sea water by desalination and wastewater treatment in a sustainable way because of the small process foot-prints and high separation efficiency. Depending on the pore sizes; membranes are classified as microfiltration, ultrafiltration, Nano-filtration and reverse osmosis (Chittaranjan & Ravi 2011). Broadly, the membranes are characterized into two categories; porous and non-porous. In porous membranes, contaminants

are removed through size exclusion while in nonporous, differential pressure known as trans-membrane pressure is the driving force behind separation mechanism.

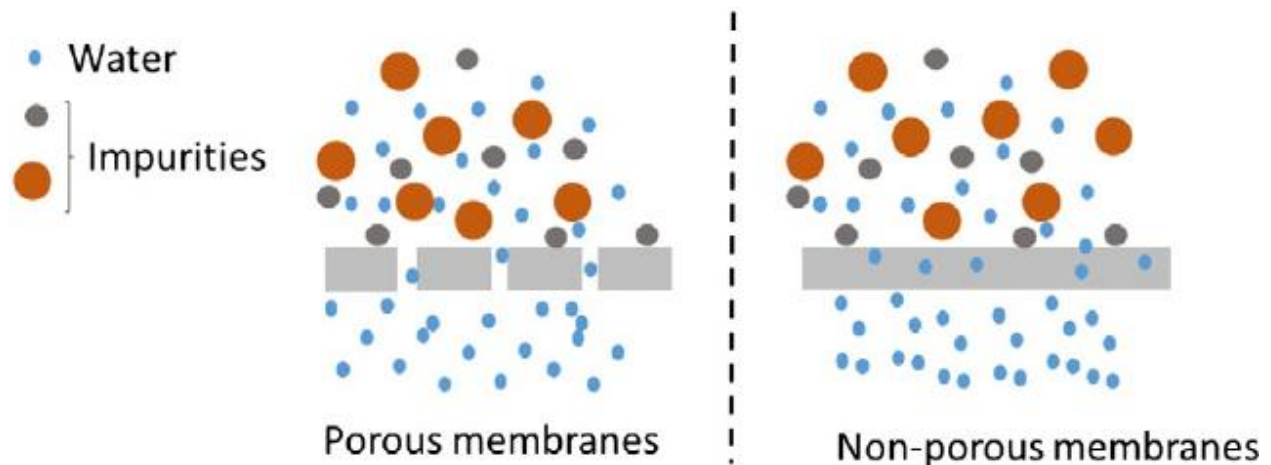


Figure 3-2 Transportation mechanism in porous and non-porous membrane

However, Reverse Osmosis (RO) has emerged as leader in the future sea water desalination membrane filtration technology (Uribe, Mosquera-Corral et al. 2015). But, due to the high costs and energy required, membrane filtration technique is an expensive option for the wastewater treatment.

3.3 Activated Carbon filters

Activated carbon filtering technique has wide range of applications in removing diverse nature of contaminants from municipal, industrial wastewaters and contaminated ground waters of non-potable quality. Activated carbon filters can reduce lead, chlorine, organic chemicals and other taste and odor producing contaminants present in the wastewater (EPA 2016). However, not all activated carbon units have the ability to reduce lead (Lemley, Wagenet et al. 1995).

Activated carbon filters are mainly divided into Granular Activated Carbon (GAC) and Powdered Activated Carbon (PAC) filters in wastewater treatment. Difference in particle size is the primary parameter in this categorization (EPA 2016).

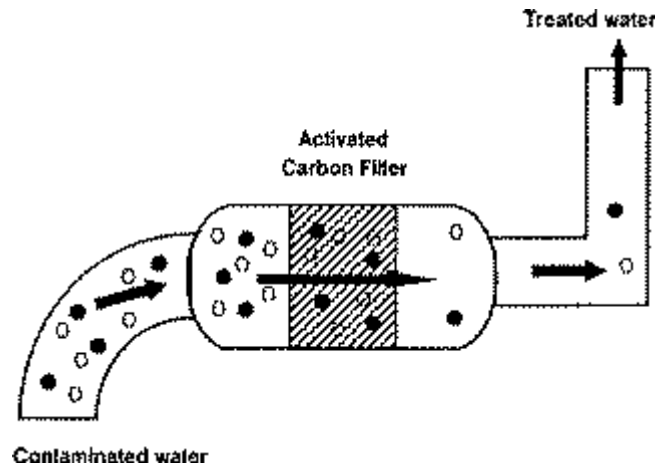


Figure 3-3 Representation simple sketch of Activated Carbon filter

Physical adsorption is the main functioning principle by which the removal of organic contaminants takes place in activated carbon filters. The contaminants are adsorbed on the surface of the carbon surface. Contaminants of hydrophobic nature are more likely to adsorb. The characteristics of the carbon material and the nature of contaminants are the main driving forces behind the effectiveness of the process (Lemley, Wagenet et al. 1995).

3.4 Nanotechnology

Materials of size less than 100 nm in one dimension (at least) are termed as nano-materials and have diverse applications in waste water treatment. Mainly, nano-materials are used for the disinfection and microbe's removal from water. Nano-materials such as nano-TiO₂ and nano-Ag have the strong microbe removal tendency. Also, these are added into membranes to reduce fouling and enhance membrane's stability (Qu, Alvarez et al. 2013) (Brame, Li et al. 2011) (Westerhoff, Song et al. 2011).(Wiesner, Li et al. 2013).

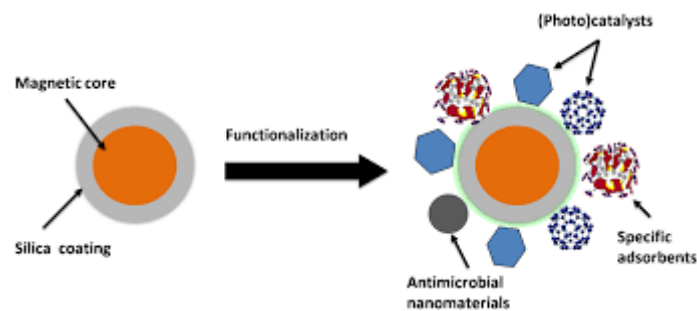


Figure 3-4 Representation of multi-functional nanoparticles (Qu, Alvarez et al. 2013)

TiO₂ is cheap, low toxic, chemically stable photo-catalyst used widely in water treatment. Nano-TiO₂ is tested and proved to be the more suitable option for potable water production. Nano-Ag, being powerful anti-microbial nano- material and having low toxic effects to human

health; is widely used as disinfectant in wastewater treatment (Li, Mahendra et al. 2008) (Brame, Li et al. 2011).

Current developments of nanotechnologies in water treatment have changed the concept of reliance on large infrastructures required for wastewater treatment. It has not only made possible the wastewater industry to overcome the recent mega challenges but also have provided with the sustainable, smart and efficient solutions (Wiesner, Li et al. 2013) (Brame, Li et al. 2011). Though technology is still at the laboratory research stage and not launched at commercial scales yet, it has shown its worth to deal with the water treatment challenges with robust solutions (Wiesner, Li et al. 2013)

3.5 Wetlands and Lagoons

Wetlands are the efficient, low cost, easy to operate and maintain waste water treatment technologies. In general, wetlands are of three types on the dominant plants basis as; swamps, marshes and bogs. The functional mechanism of these systems involves: plants convert the inorganics present in the wastewater into organic material (basis of food chain in wetlands)-high rates of primary productivity generate high organic matter and an-aerobic conditions in the system resulting in reduced rate of decomposition and providing high levels of waste water treatment. Wetland systems have the ability to reduce the organic matter, inorganic contents and the pathogens from wastewater. Moreover, hydrological cycle is the main factor influencing the functioning, productivity and governing the water quality in wetlands (Kivaisi 2001).

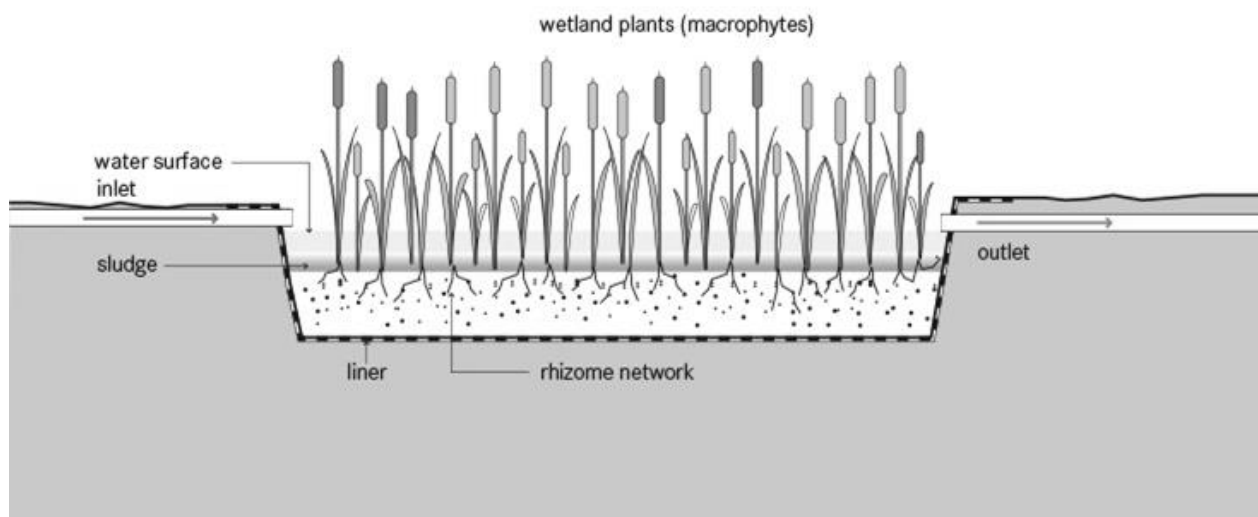


Figure 3-5 Representation of schematic of a constructed wetland

Domestic, industrial and agriculture wastewater have been efficiently treated by constructed wetlands. For instance, UK has recently published database regarding design and performance of around 900 wetlands treating domestic wastewater (Kruzic and Liehr 2008). Netherlands and

Spain reuse wetland's effluent in agricultural and recreational sectors (de Koning, Bixio et al. 2008).

Also, in short, lagoons having anaerobic conditions and being natural wastewater treatment systems can remove organic solids (Kruzic and Liehr 2008). Moreover, the wastewater treated by lagoons in series plus downstream chlorination have the ability to produce water of moderate quality that can be used for limited irrigation purposes. Examples of such treatment facilities can be seen in Mediterranean countries (de Koning, Bixio et al. 2008).

3.6 Solar pasteurization

Pasteurization is the sustainable way to remove microbes or pathogens from contaminated water. This process requires to keep the non-potable water at a specific temperature for a given time period. However, pasteurization can take place at relatively low temperature if the given time for boiling is increased and vice versa. A rule of thumb regarding the time-temperature for pasteurization process is to keep boiling the contaminated water at 75°C for 10 minutes to kill almost all the major microorganisms (Burch and Thomas 1998).

In remote areas, having shortage of electricity and freshwater but a great sunshine, pasteurization is the inexpensive and easiest method to produce drinking water. For a certain time period, a simple cylindrical bottle can be exposed to sunlight to pasteurize water (Chittaranjan & Ravi 2011).

3.7 Solar distillation

Solar driven water distillation provides a promising alternative water purification process that can partially support humanity's needs for fresh water with free energy, simple technology and a sustainable environment. However, researchers have tried to investigate several means to improve the productivity of solar still and enhancing the thermal efficiency. Several have tried to condense the water vapors externally such as in additional condensing surfaces and the wasted latent heat of condensation was also recovered (Fath 1998). No doubt, solar water distillation technique is the sole, most effective, low cost and sustainable solution to meet the freshwater needs of the public residing in remote and underdeveloped areas of the world. Moreover, It can use low quality brackish water or groundwater for producing potable water. These systems can solely operate with solar energy. The scale of application is for individual households to very small communities (Chittaranjan & Ravi 2011) (Burch & Karen 1998)

4 Passive solar driven systems for water treatment

Freshwater and energy; both are the fundamental and inseparable necessities of mankind to sustain on earth. During the recent past, rapid increase in population and industrialization, particularly in the under- developed and developing parts of the world, have caused pressing demands for the both resources (Gude, Nirmalakhandan et al. 2010). There is strong need to conserve and preserve, both the resources for sustainable development of our planet. Besides, there is critical deficiency of both the energy and water, particularly in the developing and under-developed countries (Shankar & Kumar 2012).

Due to rapid growth in the world population and then industrialization, the need for energy has increased tremendously. As a result, the use of fossil fuels as a main source of energy in almost every aspect of human life has led to the deterioration of our globe. Environmental pollution, climate change, ozone depletion, green-house effect and global warming are the results of mankind's exploitation of natural resources. Also, unfortunately, this scenario has caused a scarcity of freshwater due to the contamination of ground and surface water sources. To overcome the challenges, there was strong need to reduce the abundant use of fossil fuels and adopt the renewable and sustainable sources of energy. Various studies and research conducted in this regard, led to focus on the alternative energy sources such as solar, wind, hydro and geothermal energies (Compain 2012) (Kalogirou 2004) (Chaichan and Kazem 2015).

Solar energy comes as the best one of these sources due to its availability in abundance, low cost, maintenance free and most sustainable features. Also, basically, all forms of energy are the solar in origin. For instance, the formation of oil, gas and coal by the photo-synthetic processes and then complex chemical reactions- decaying vegetation subjected to high temperature and pressure for years (Kalogirou 2004) (Şen 2004) (Tiwari 2015). Besides, the solar energy is available only during the day times; the systems functioning over solar energy can operate only during sunshine hours in the summer and more less hours during the winter. Therefore, the intermittent nature of solar energy is considered as the prime problem that hinders the advancement and promotion of this technology (Chaichan and Kazem 2015).

As discussed earlier in the section 3, water treatment and reclamation is carried out through several ways; coagulation, flocculation and disinfection (conventional wastewater treatment), membranes, different filtration techniques, reverse osmosis and nanotechnology etc. In place of most of the existing water treatment technologies using fossil fuel as a direct or indirect source for energy, the use of solar energy has emerged as the most sustainable alternative energy source in many parts of the world particularly the under- developed and developing countries.

Primarily, the solar energy is used in two ways; indirect and direct. The indirect use involves the conversion of solar radiations' energy into thermal energy or electrical power by means of solar collectors and / or solar photo-voltaic (PV) panels (Chaichan and Kazem 2015). Whereas

the direct use mean the absorption of solar radiations as thermal energy or heat straight into a system (Shatat, Worall et al. 2013). Likewise, in water and wastewater treatment context, the major indirect uses of solar energy comprise; the power generation to run membranes, ROs (Reverse Osmosis), various kind of filtering and other conventional wastewater treatment plants (Argaw 2003). While, the direct uses include stabilization of ponds, desalination, decontamination and detoxification of water and wastewater.

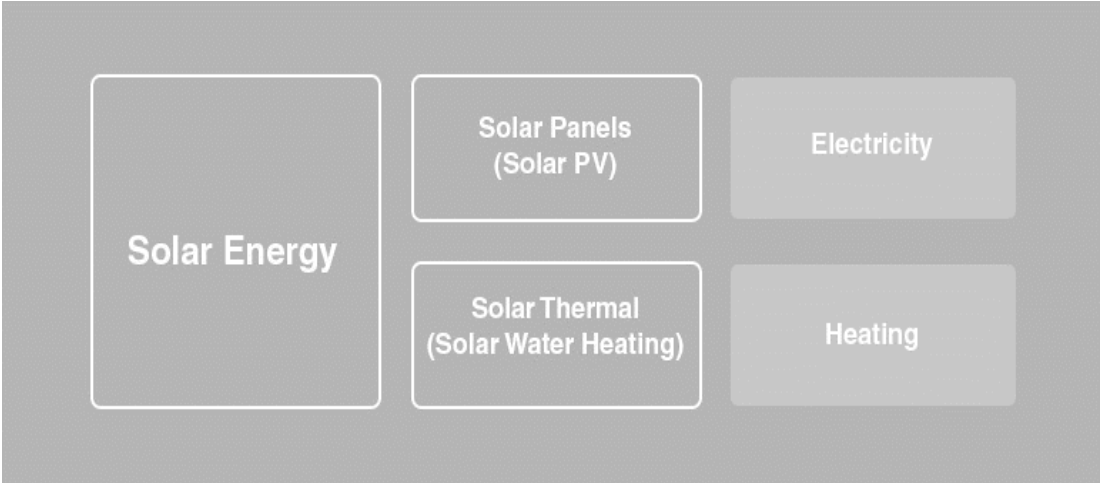


Figure 4-1 Representation of indirect and direct use of solar energy

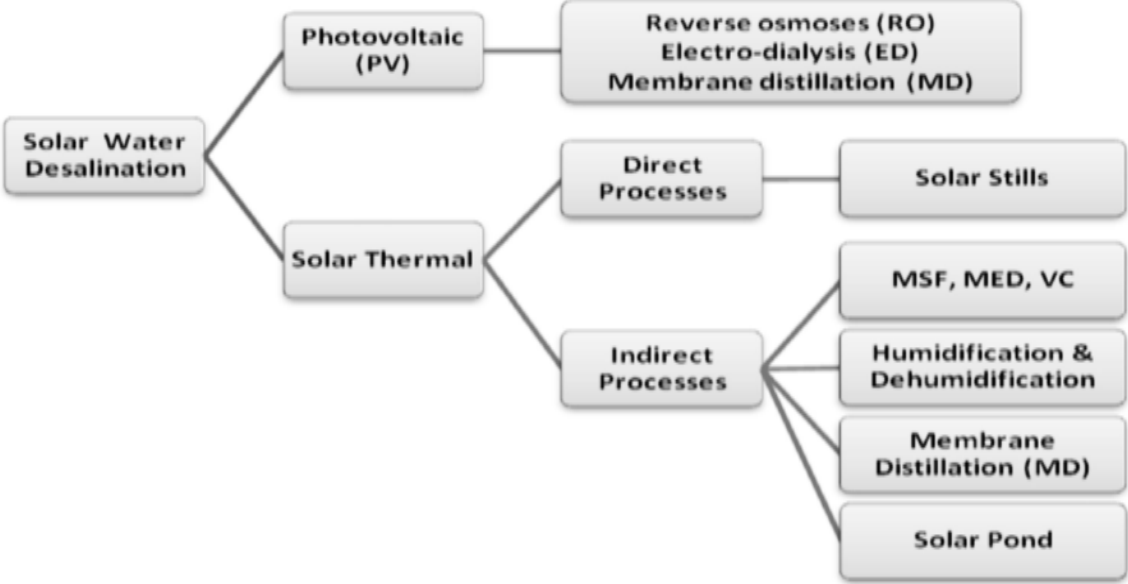


Figure 4-2 Representation of possible solar based water desalination technologies

Indirect use of solar energy always requires a solar collector to attach with any further unit. An instance of such a combination is shown in the figure above (Shatat, Worall et al. 2013). Though the high production is obtained, treating the water with indirect use of solar radiations definitely involves more expense and complex infrastructure. Therefore, the direct use of solar energy leaves a most feasible option especially for the regions having energy crisis, low income, water scarcity and arid climate. In addition, the direct use of solar energy i.e. the passive solar driven water treatment involves almost zero operating cost and thus is comparatively a more admissible option (OECD/IEA, 2006).

The passive solar driven water treatment solutions depict the simplest, cheapest, easily manufactured, high effectiveness and attractive techniques compared to other water decontamination processes. These technologies have the potential for potable water production. They remove the impurities without degrading the environment, in a sustainable way, and thus save huge costs involved in the use of other water purification techniques (Burch & Karen 1998). However, until today, the use of passive solar driven water treatment has been limited to small scale applications due to its low production rate and suited to small household uses residing in the areas of plentiful sunshine only (Chaichan and Kazem 2015) (Tiwari, Singh et al. 2003).

The passive solar driven water treatment of contaminated water, at the very least expense and infrastructure brings up the topic at the three techniques; solar cooking / solar disinfection, solar pasteurization and solar water distillation. The solar disinfection process purifies water by the action of ultraviolet radiations of specific wavelength. While in solar pasteurization, the water is decontaminated by the temperature / heat achieved from solar radiations. Whereas, solar distillation involves the process in which the water is evaporated by solar radiations and condensate is collected within the same enclosed system (Burch & Karen 1998) (Chittaranjan & Ravi 2011) (Meierhoffer & Wegelin 2002) (Caslake et al. 2004). A short introduction of solar pasteurization and solar distillation is already presented in the previous sections 3.6 and 3.7 respectively. However, all the three technologies will be discussed in detail in the further subsections.

Fundamentally, to remove the impurities and to choose an appropriate technique for treatment, it is crucial to get into and understand the characteristics of contaminated water. To decontaminate the water from different sources effectively, a critical analysis of the following characteristics is necessary and presented below: (Burch & Karen 1998)

- Water sources such as ground water, rivers, streams, lakes and springs commonly contain pathogens such as viruses, bacteria, protozoa and worms.
- Surface water sources such as rivers, streams and lakes have more turbidity value than the ground water sources- turbidity is the presence of solid particle in water such as suspended and dissolved materials, however some organic matter might also be present.

- Depending on the geography, both the ground and surface water sources can have hardness- the presence of Calcium and Magnesium ions

4.1 Solar water disinfection and pasteurization

Solar water heating is a simple way of cleansing water by solar radiations. In this method, the dirty water is filled in a transparent plastic or glass bottle and exposed to sun for almost 7 hours to get the pathogens killed by the action of ultra-violet (UV) radiations (Vidan, Shoag et al. 2014). The UV rays of the range 200 to 400 nm are considered more efficient and it is recommended to use transparent bottles or containers having effective transmission in this range (Burch & Karen 1998) (Chittaranjan & Ravi 2011) (Meierhoffer & Wegelin 2002) (Caslake et al. 2004) (Joyce, McGuigan et al. 1996) (Sukkasi and Terdthaichairat 2015).

Ultraviolet radiations coming from the natural sunlight are divided into three bands: UV-A (320 to 400 nm), UV-B (280 to 320 nm) and UV-C (200 to 280 nm). It is well known that UV radiations not only kill the pathogens such as bacteria and viruses but disable the DNAs involved in their reproduction as well. The pathogens such as E. coli and Staphylococcus-aureus are completely killed by UV rays being in the range of 250-300 nm. Also, UV-C radiation is also termed as the germicidal band because of its most effectiveness in killing pathogens (Burch & Karen 1998) (Joyce, McGuigan et al. 1996).

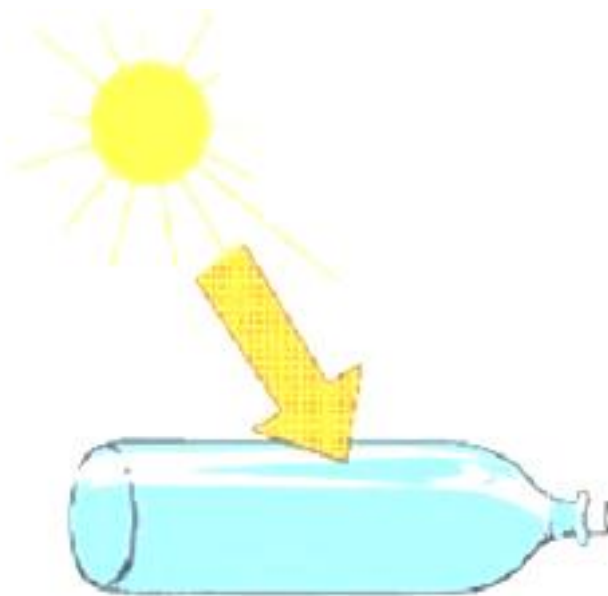


Figure 4-3 Inactivation of pathogens by the use of solar radiations (Burch & Karen 1998)

This method of purifying water has a realistic historical back ground and is widely used in many poor, water scarce areas at domestic level. Simple bottles or other kitchen pots are used to treat water in this way. Even though it is the easiest way to get freshwater, still there is no any

commercial technique, guidance or product available to facilitate the public. That is why, a very narrow fraction of populations in developing world is using this technique. WHO accounts less than 1 percent for such population using solar disinfection (WHO/UNICEF 2011). However, the use of plastic bottles in this manner is not dangerous to human health (Schmid, Kohler et al. 2008).

Though this purifying method does not provide a complete solution to the problem, according to WHO it is the safe and temporary alternative in severe circumstances of emergency and catastrophe so far. Additionally, the cost approximations of 0.63\$ / person / year make it very feasible and reliable source for the communities having very limited incomes or living below the poverty line to get the pathogen free water (McGuigan, Conroy et al. 2012) (Vidan, Shoag et al. 2014). According to McGuigan, solar water disinfection has the capability to kill almost all the germs present in water and does considerably save from waterborne diseases such as diarrhea and dysentery by 45 percent (McGuigan, Conroy et al. 2012) (Vidan, Shoag et al. 2014) (Joyce, McGuigan et al. 1996) (Burch & Karen 1998).

Amongst low cost, passive and sustainable technologies, solar pasteurization, in comparison with solar water disinfection, is relatively more useful alternate that have the capability to treat larger volumes of water. The working mechanism of this method to give the non-potable water a specific temperature for a given time period. Normally, if the water is kept at 65°C for around 6 minutes, almost all the harmful micro-organisms are killed. However, pasteurization can take place at relatively low temperature if the time is increased and vice versa (Chittaranjan & Ravi 2011). In addition, regarding time- temperature, different values with little variations are found in literature such as according to Burch; 75°C is required for 10 minutes to kill almost all the major microorganisms (Burch and Thomas 1998). Nevertheless, it is understood that for shorter times, higher temperatures are required and vice versa to get the maximum pathogens' removal and thus of course improved quality of water (Burch & Karen 1998) (Ray and Jain 2011)

4.1.1 Large scale applications- case studies

Solar Pasteurization—Nyanza Province, Kenya:

According to Metcalf, as the pasteurization technique has been implemented in food productions for decades in an unquestionable manner, it can be established from published facts and experiments that pasteurizing the contaminated water at 65°C will make it safe for drinking purpose and other freshwater usages (Metcalf R, 2009). The alone use of contaminated water's boiling or pasteurization with solar radiations was found two times as effective as the use of chlorine for disinfection and while used together (in combination) it was found four times more effective (SCI 2009)

In Nyakach region of Nyanza Province-Kenya where majority of the public survives on less than one dollar per day, the use of CooKit solar cookers to clean contaminated water under the solar water purification solutions program, was started in 2003. This region of Kenya- Africa, has a history of sufferings from typhoid fever and dysentery due to the high contamination of its water sources i.e. wells and streams with E. coli. However, the usage of the CooKit solar cookers for water decontamination has resulted in a significant decrease in diarrheal diseases, other water-borne illnesses and their need of wood for boiling and cooking purposes as well.



Figure 4-4 Representation of solar water cooking in Nyanza Province-Kenya

Correspondingly, along with the provision of solar cookers, around 3600 inhabitants in 72 districts of Kenya were facilitated with the solar cookers and trainings over the Colilert tubes and Petri-films- the water testing methods. So that they could precisely and inexpensively test their water after pasteurizing with the solar radiations. Results of a survey conducted in the midst of July 2005 showed that the 47 Kenyan households provided with the CooKit solar cookers to clean their water, were pasteurizing around 5–10 liters of water per day. And an

evident reduction in diarrheal spread particularly amongst small children was recorded (Metcalf R, 2009).

The accomplishment of the solar water pasteurization project in Nyanza-Kenya has undeniably validated the potential of this technology for the provision of safe drinking water in remote areas of developing countries particularly where water contamination is not caused by the presence of inorganic chemicals or arsenic (Ray and Jain 2011) (Manchanda and Kumar 2015) (Burch & Karen 1998) (Burch & Karen 1998) (Burch and Thomas 1998).

4.2 Solar distillation

4.2.1 Definitions, concepts

In order to meet the challenges related to drinking water, it is essential to come up with sustainable solutions. This process of producing safe drinking water can be done easily and economically by the application of solar driven water distillation technique (Tiwari, Singh et al. 2003) (Shannon, Bohn et al. 2008).

Solar energy is one of the cheapest and easily available sources for purification of water. The use of solar thermal energy has so far been restricted to small scale seawater desalination applications mainly due to the relatively low productivity rate. However, this problem has triggered scientists to investigate various means of improving solar still productivity and enhancing the thermal efficiency. Several have tried to condense the water vapors externally such as in additional condensing surfaces and the wasted latent heat of condensation was also recovered (Fath 1998).

Solar driven water distillation provides a promising alternative water purification process that can partially support humanity's needs for fresh water with free energy, simple technology and a sustainable environment. However, researchers have tried to investigate several means to improve the productivity of solar still and enhancing the thermal efficiency. Several have tried to condense the water vapors externally such as in additional condensing surfaces and the wasted latent heat of condensation was also recovered (Fath 1998). No doubt, solar water distillation technique is the sole, most effective, low cost and sustainable solution to meet the freshwater needs of the public residing in remote and underdeveloped areas of the world.

4.2.2 Historical background

It is found that the solar distillation technique was in use to produce alcohol, perfumes and herbs since the time of middle ages. Delyannis states that in the same era, Arabs were using concave mirrors to converge the sun rays over glass containers to desalinate and purify water (Delyannis, 2003). Aristotle was the first one who introduced a technique to evaporate the impure water and condense it for potable use in the 4th century B.C. However, the first documented and published

work on solar water distillation was presented by the Arab Chemists. In 1589, the Della Porta used wide earthen pots to heat, evaporate and collect the condensate as fresh water by the use of solar radiations. Figure (Tiwari, Singh et al. 2003)

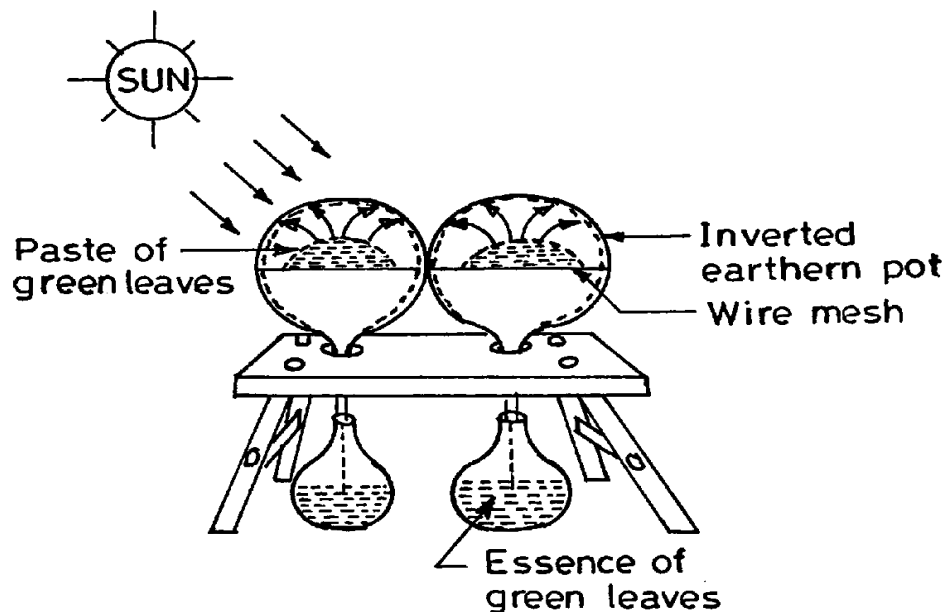


Figure 4-5 Representation of Solar water distillation by Della Porta (1589)

Then until the 19th century, a limited data and few documents over the solar distillation are available. Later on, in 1872, a Swedish engineer Carlos Wilson built the 1st large scale solar water desalination plant having 64 basins, 4459 m² water surface area and 22.7 m³ freshwater production per day, using wood and glass in its construction. His objective was to provide the railways and mines workers with freshwater in Las Salinas-Chile. Moreover, the effluent from that mine was fed to the still and the plant remained in operation for around 40 years (Delyannis 2003) (Talbert et al. 1970)

During the World War II, the necessity of freshwater delivery to the soldiers fighting in remote areas led to the awareness and interest towards the simple distillation systems. As a result of the situations occurred during war and an increasing demand of clean water in the same era, the US Office of Saline Water came into existence in 1953 for the orientation and development of solar stills (Delyannis 2003) (Talbert et al. 1970). Around mid-20s, the rest of the world like Australia, Greece, Portugal, Madeira and India started testing and constructing solar desalination plants. For instance, Australia started producing freshwater in its desert from saline water by the use of solar stills comprising of glass cover and polyethylene coated basin (Delyannis 2003). But in the recent years, small and large scale advanced water purification technologies such as reverse osmosis, a variety of filtration devices, membrane bioreactors etc. have emerged as the optimum solutions rather than the advancement in the large scale solar water distillation units (Delyannis 2003).

Besides, historically, many researchers conducted the review of solar water distillation: In 1970, the Talbert et al. presented a manual on solar distillation, then Delyannis and Delyannis went through and reviewed the major solar water distillation plants round the globe in 1973. The work on passive solar water distillation till 1982 was reviewed by Malik et al. and further updated by Tiwari in 1992, which also encompassed the active solar water distillation. Then Fath reviewed various designs of solar stills right for the potable water production in 1998 (Balan, Chandrasekaran et al. 2011). In recent times, the attention towards small scale and usually compact distillation units has significantly increased. This development has led to the use of smart solar stills by many families, households and small communities around the globe.

4.2.3 Basic principle of solar distillation:

The basic principle of solar distillation depicts the water purification process of our nature- the hydrological cycle. In this method, the contaminated water in a transparent, enclosed and airtight unit is heated by the solar radiations. When the heated water starts evaporating, the water vapors rise to the inclined transparent cover. As the water vapors reach up to the transparent surface, the droplets start sliding along the slope due to condensation. Hence, these droplets of fresh and pure water are collected in a channel at the end of slope (inclined surface) (KALITA, DEWAN et al. 2016).

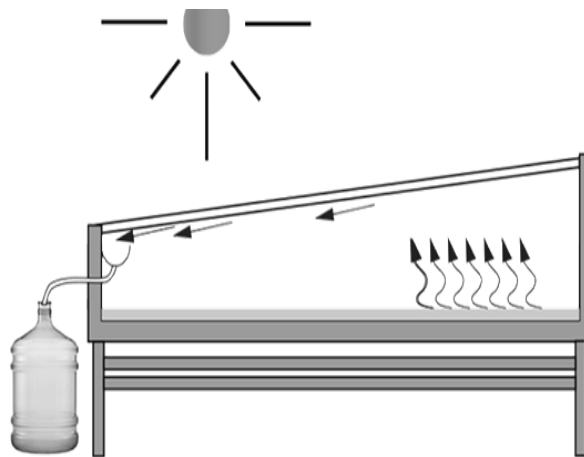


Figure 4-6 Schematic of distillation process in a solar still

The distillation, a fairly slow process, evaporates only water and leaves the impurities behind in the basin. The occurrence of relatively high temperature inside the basin results in microbial death and thus high quality fresh water production. And, regular cleaning is required for the removal of sludge left behind in the still after evaporation of water (Badran and Abu-Khader 2007). The working principle of a solar water distiller is describes below: (Balan, Chandrasekaran et al. 2011)

“Solar radiation is transmitted inside the enclosure of the distiller unit after reflection and absorption by the glass cover. The transmitted radiation is partially absorbed by the water mass and partially reflected by the water mass. The transmitted radiation further reaches the blackened surface where it is mostly absorbed. The thermal energy absorbed by the basin liner (i.e. the blackened surface) is then convected to the water mass in the basin and the rest of the energy is lost in atmosphere by conduction through the insulated bottom and sides of the distiller unit. Due to convection of energy by the basin liner, the water mass in the basin gets heated and the temperature of the water mass is higher than the glass cover temperature, there occurs internal heat transfer from the water surface to the glass cover. The heat is transferred by radiation, convection and evaporation. The evaporated water is condensed on inner surface of glass cover after releasing the latent enthalpy to the condensing surface. Due to cover’s small inclination, condensate flows by gravity into the collection troughs at the lower edge of the glass cover. The cover is at sufficient slope such that surface tension of the condensate water causes to flow only into the collection trough and not to drop back into the basin. Finally, the condensed water is trickled into the container. The collected water is taken out of the system for an appropriate use. Externally the thermal energy received by the glass cover is lost to ambient by convection and radiation.”

Primarily, there are three factors that affect the efficiency of a solar still; the design of still, the amount and intensity of solar radiations and the sunshine duration (Abdallah, Abu-Khader et al. 2009). The design factors include; surface area, the depth of water in basin, material and color of the basin, wind velocity, water temperature, absorbing dish area, inlet-water temperature, air tightness and insulation patterns of the still, inclination angle of the glass, water surface area, depth of water in the still and temperature differences in the water and glass (Velmurugan and Srithar 2011). The intensity of solar rays, wind velocity and ambient temperature are uncontrollable parameters while rest of the parameters can be controlled to improve the performance of solar stills. In case, various designs, operations, modifications and recommendations have been proposed and made available in the literature in regard to the factors affecting the efficiency of a solar still (Sampathkumar, Arjunan et al. 2010) (KALITA, DEWAN et al. 2016). Such as, Murugavel et al. reviewed the developments and improvements in efficacy of the single-basin passive still, while Velmurugan & Srithar reviewed those modifications and improvements in detail (KALITA, DEWAN et al. 2016) (Velmurugan and Srithar 2011) (Prakash and Velmurugan 2015) (Muthu Manokar, Kalidasa Murugavel et al. 2014) (Sampathkumar, Arjunan et al. 2010).

It is evident from the diverse and comprehensive research over the design, operation and geometric parameters influencing the solar stills’ performance, that most of the related work has been endeavored in the Middle East. And on average, the productivity of the still has been recorded in the range of 1.4 to 3.5 liters per square meter in the Middle-East region due to the high influx of solar radiations (more than 800 W/m²) and high values of ambient temperature (more than 40C⁰).

However, the stills installed so far in diverse parts round the globe are reported to be of very low productivity. In this regard, various researchers have tried to improve the still's efficiency by the use of materials such as sponge, stone chips, water ball, jute clothes etc. and also by design modifications such as conical shape and hemispherical shape solar stills etc. In nutshell, a methodical design investigation is essential prior to the manipulation of an improved distillation model. Besides, right to the present time, very limited research and literature has been presented over the application of solar still technology in fluoride removal. In the subsequent part, a detailed overview regarding the various design, operation, geometric and thermodynamic factors is presented.

A basin coated black comparatively absorbs most of the transmitted solar energy and thereby enhances the productivity of solar still. However, the loss of some amount of energy in the basin and inclined glass cover by conduction or convection and radiation might make the still less efficient. Also, the parameters such as inclination angle of the cover, glass thickness, latitude, climatic conditions and radiation diffusion are amongst the key driving forces influencing the still's productivity (Cooper 1969).

The inclination angle of glass and the latitude must be equal to maximize the incoming and received radiation packets for the entire year. And during the summer season, a lower inclination increases the incoming flow of radiation towards the still because the sun's declination angle remains at its highest during summer and a still having 19° inclination maximizes the incoming radiation from during the peak summer days (Muthu Manokar, Kalidasa Murugavel et al. 2014) (Al-Hinai 2003).

Un-saturated air is vital for the occurrence of evaporation in the still because the energy required to transform the water into vapors, the latent heat of vaporization depends on the temperature. And for the condensation process i.e. the transformation of water vapors into liquid (distilled water); a temperature difference between the still's inside and outside air is crucial. Therefore, the still placed in a windy surrounding or providing the outer glass cover with cooling increases the condensation process and thus still's productivity.

The presence of salts in water affects the evaporation rate as well; the evaporation rate decreases with an increase in salinity and vice versa. Arnell states that the salt water has comparatively higher vapor pressure than that of freshwater because of the space occupied by salt molecules / ions in water results in fewer availability of molecules for evaporation. However, according to Ward et al. this effect has a small impact i.e. lowers the 2 to 3 percent evaporation rate in comparison to freshwater (Ward et al. 2000). In addition, Akash et al states that a 10 to 75 percent of increase in salinity results in a still's output decrease of 1.5 liters per day.

Moreover, the productivity of a still depends on weather situations such as the intensity of solar rays, temperature and wind velocity and it is necessary to keep the still air-tight to avoid any

heat losses to the ambient air (Kalidasa Murugavel, Chockalingam et al. 2008) (Kalidasa Murugavel, Sivakumar et al. 2010) (Kalidasa Murugavel, Anburaj et al. 2013) (Kalidasa Murugavel and Srithar 2011). Principally, the intensity and distribution of solar radiations throughout the day-time has the most central role in prediction of a solar still's yield. The average daily production of a still is calculate as:

$$Q = \frac{E * G * A}{L}$$

Where

Q = Daily output of water (l/d)

E = Overall efficiency / effectivity of the still (%)

G= Daily global horizontal solar irradiation (MJ/m²)

A = Aperture area of the solar still (m²)

L = Latent heat of vaporization of the water (J/kg)

The above mentioned equation is used to estimate the productivity of a solar still for both, the prior and post experimental calculations. However, normally, depending the design and material, the efficiency of a still ranges between 30 to 60 percent (Al-Hinai 2003) (Muthu Manokar, Kalidasa Murugavel et al. 2014) (Ray and Jain 2011).

4.2.4 Classification of solar stills:

Fundamentally, the solar water distillation systems are classified into active and passive solar stills. In an active solar still, extra thermal energy is fed into the still system via extra external equipment or devices, while in the case of passive solar still, the sun's radiation is the sole source for heat energy to evaporate the water. Moreover, according to Tiwari and Dimri et al.; active solar stills consist of thermal collectors and / or photovoltaic panels along with the distillation units, whereas the passive solar stills use solar radiations directly for the distillation process (Tiwari, Dimri et al. 2009). Thus the passive solar stills are more safe, clean, eco-friendly, energy and cost saving, small in size, simple in construction and operation and comparatively free of maintenance systems.

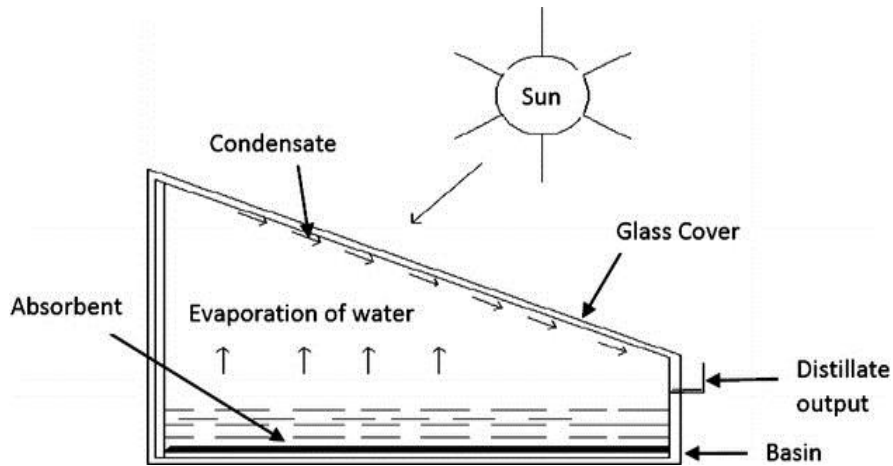


Figure 4-7 Representation of basic structure of a passive solar still

Primarily, different types of existing solar stills include; single basin, multi-effect and hybrid stills. A single basin still comprises of one basin containing water, enclosed in a transparent cover that can have various shapes. The multi effect solar still consists of more than one basin that are established like one on top of the other- utilizes the latent heat of condensation in lower basin and heats up the water in upper basin. While a hybrid solar still uses the external sources such as solar collectors or solar photovoltaic (PV) to run the heat exchanger that enhances the evaporation rate (Müller-Holst, Engelhardt et al. 1999) (Muftah, Alghoul et al. 2014).

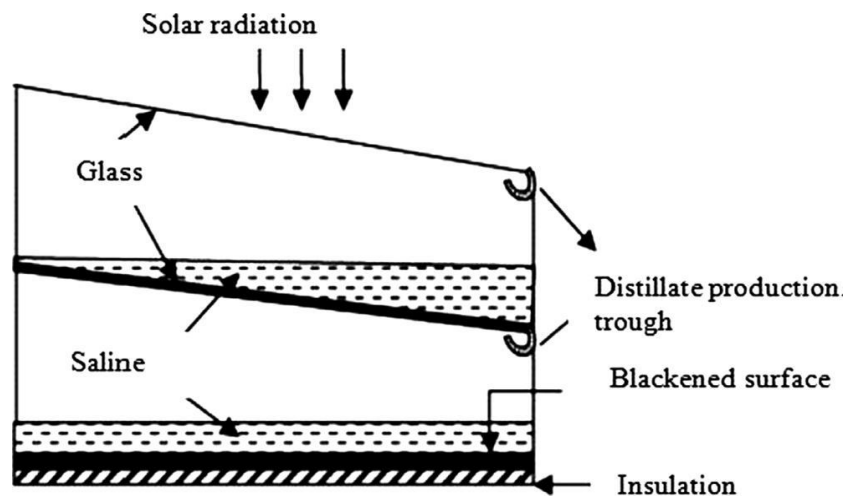


Figure 4-8 Representation of the cross section of a multi-effect solar still

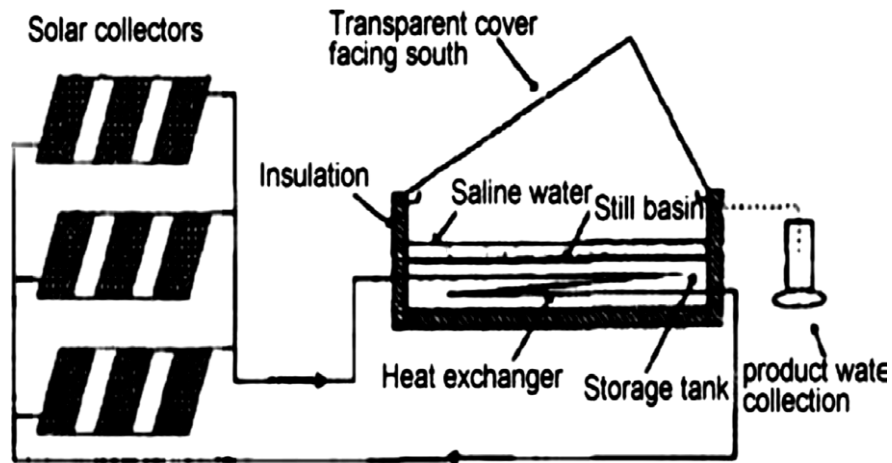


Figure 4-9 Schematic of a hybrid solar still coupled with solar collector

Additionally, various type of solar stills presented in the literature are; conventional, conical, vertical, single-slope with passive condenser, double condensing chamber, multi-wick, multiple-effect solar stills etc. A few schematic illustrations are presented below: (El-Bahi and Inan 1999) (Tiwari, Singh et al. 2003) (Anfas & Suneesh 2013) (Muftah, Alghoul et al. 2014)

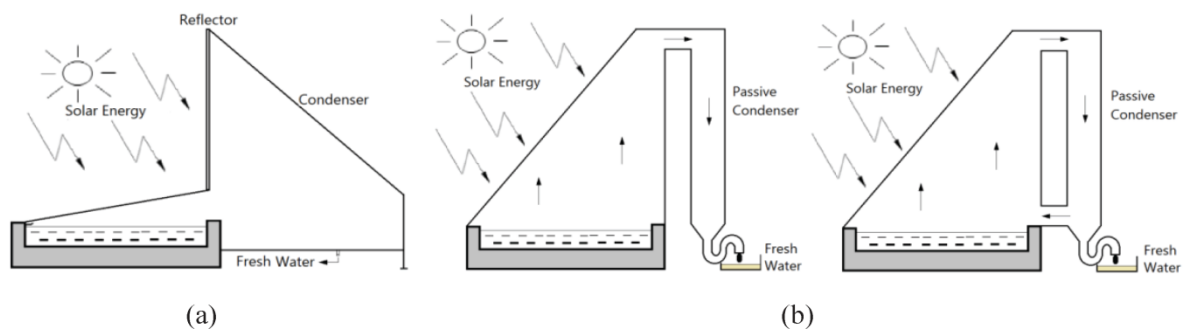


Figure 4-10 (a). Solar still with minimum inclination and outside condenser (b). Single slope still with passive condenser

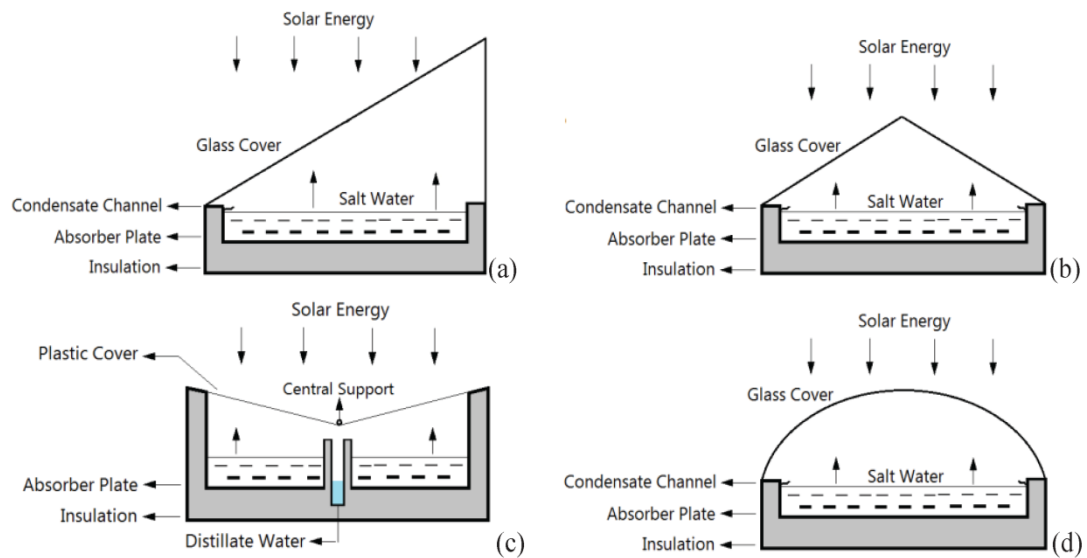


Figure 4-11 (a). Single-slope still (b). Double-slope still (c). V-type still (d). Hemi-spherical still

However, at present, there are only the single basin passive solar stills available in the market whereas all the other types mentioned above are mainly established through the research and projected in literature only. Consequently, the passive single basin solar stills will be focused only, further in this study. An overview on the related products and models that have been prototyped and exist in the market is given below:

4.2.5 Current status of solar stills:

4.2.5.1 Rainmaker™ 550 Solar Distiller

It is a single-slope solar still, manufactured with the use of advanced materials. It consists of a molded basin liner, enclosed in an insulation material and outer molded glass box. It has a basin area of 0.93 m². It costs 489\$ and produces 6 liters of freshwater per day during summer.



Figure 4-12 Representation of Solar Water Distiller (Rainmaker™ 550)

4.2.5.2 Rainkit™ 990

This solar water distiller is relatively cheap and simple. Also, it is double in size in comparison with the Rainmaker. A kit and material is shipped to the customer and can be assembled at home. It has a basin area of 1.70 m². It costs 245\$ and produces 11 liters of freshwater per day during summer.



Figure 4-13 Representation of Solar Water Distiller (Rainkit™ 990)

4.2.5.3 Watercone®

This simple, cheap and dashing solar still has the conical shape. It has a very smart basin area of 0.3m². It costs 25\$ and produces 1.7 liters of freshwater per day. And, the product is available in market according to the information given over website.



Figure 4-14 A solar still for solar seawater desalination (Watercone)

4.2.5.4 Eliodomestico

This very sustainable product is made of ceramic and no electricity or filters are required. Its working mechanism involves; solar radiations evaporate the water, then vapors are pressed down towards the bottom before condensing. It costs 50\$ and produces 5 liters of freshwater per day. The product is still not available in the market.



Figure 4-15 A solar household still for the developing countries (Eliodomestico)

4.3 Critical evaluation

4.3.1 Evaluation of existing products

Watercone and Eliodomestico are the most innovative, smart and the low cost amongst all the four solar stills. But, the Eliodomestico does not exist in the market indicating its missing potential. Therefore, Watercone, Rainmaker and Rainkit are the only three solar stills available for sale. The quality of product water has been tested, approved and permitted. Also, the quantity of produced freshwater is enough for the use of a small household. The existing patents of these designs are still valid.

Product Name	Yield (L/m ² /day)
Watercone	8.8
Rainkit™ 990	6.8
Rainmaker™ 550	6.5
Eliodomestico	5.0

Moreover, it is found cheaper to buy a solar still Instead of traveling to purchase bottled drinking water in dry, arid, remote, developing and under-developed regions perspective. Solar still saves roughly 150–200\$ a year per family rather than buying bottled water, as sated by Foster et al.

assuming the lifetime of a solar still a ten year, the energy cost of solar distilled water is around 0.03\$ per liter (Foster et al. 2005).

4.4 Large scale applications-case studies:

Implementation of solar distillation along the United States/Mexico borders;

Alike the dry regions of the developing world facing the deficiency and increasing demand of freshwater, the US-Mexico border communities adopted the low cost and efficient solution to meet their potable water needs. The Doña Ana County of New-Mexico, the El Paso County of Texas and the Ciudad Juárez County of Chihuahua city implemented the solar distillation technology to overcome this challenge. Over half a million of population in these counties having very limited infrastructure suffer from water issues such as very limited, contaminated with high amounts of salts and arsenic municipal water supplies that do not fit the national drinking water standards. Industrial pollution, infected systems, fertilizers and pesticides present in the runoff were the main sources of water contamination resulting in illness and diseases (NMSU 2000) (EPSEA, 2000) (Foster, Amos et al. 2005).

Distillation process was acknowledged the only solution to remove arsenic and obtain safe drinking water under the standard 62 of National Sanitation Foundation (NSF). In the past decade, solar distillation techniques have been adopted in these border cities and the developing world to get access to clean water. A pilot demonstration of 40 solar water distillation units (solar stills) of 3' × 8' length width order, mounted by the close collaboration of El Paso Solar Energy Association (EPSEA), the Southwest Technology Development Institute (SWTDI) and the New Mexico State University (NMSU) were distributed among colonia residents in Juarez-West Texas (Foster, Amos et al. 2005) (EPSEA, 2000) (NMSU 2000).

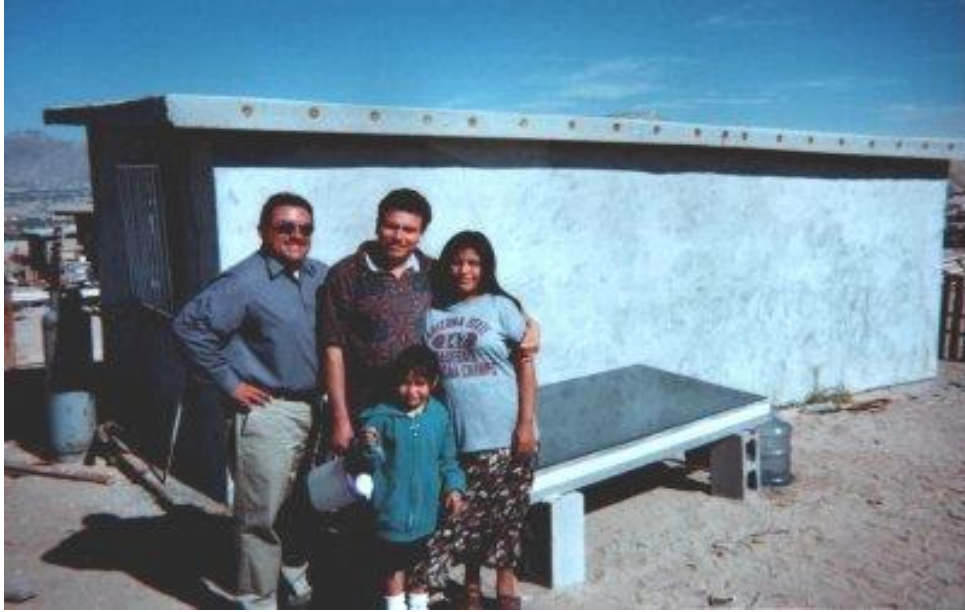


Figure 4-16 Representation of an installed solar still for the Marcos family in Juarez-Mexico (EPSEA, 2000)

Also, within the timeframe of two years (2000 - 2002), same practice of installing solar stills for freshwater generation was adopted by the 27 families in Chihuahua- Mexico and 80 families in New-Mexico and Texas (Foster et al. 2005). And studies have shown that these solar water distillation units effectively removed all biological impurities such as E-coli and Cryptosporidium, water borne pathogens, salts and heavy metals with the average water production of around 0.8 liter per sun hour per square meter (EPSEA, 2000) (Foster, Amos et al. 2005). However, in winter times the still's water production was found typically reduced. Moreover, at present, the El Paso Solar Energy Association (EPSEA) has initiated the implementation of solar stills in Australia, Mexico, South-Pacific and Guatemala. It is indisputable that the solar water distillation technology and solar stills is relatively cheap and practical way to address safe drinking water needs (Foster, Amos et al. 2005).

Solar water distillation technology has attained significant improvement over the last few years: beginning in the mid-1990s with the silicone lined solar stills transforming to aluminum and now comprising of ABS Plastic made by the company SolAqua. According to Foster et al. the solar water distillation technology has now evolved to large manufacturing units where the costs possibly will be reduced by a factor of three or even more (Foster, Amos et al. 2005). Regardless of the fact that the solar water distillation technology i.e. solar stills have a few drawbacks like does not produce optimum amounts of potable water to meet the demands in winter, it is a clean, most sustainable, acquiring minimal infrastructural resources and cheap technological solution that leaves a negligible carbon footprint on earth (Ray and Jain 2011) (Foster, Amos et al. 2005).

5 Discussion

Water reclamation and reuse by the application of passive solar driven technologies is a practical option, not only for the under-developed regions having relatively quite limited economic resources, but also for the technologically advanced rich countries. In current study, the existing three passive solar driven water treatment technologies were reviewed; solar pasteurization, solar water disinfection (SODIS) and solar water distillation. In pasteurization, water is treated by the solar heat at a specific temperature (Burch and Thomas 1998). And in SODIS, sun rays purify the water by a combination of solar heat and ultraviolet radiation effect. Whereas distillation process uses solar energy to decontaminate the water by evaporation and condensation in a closed system.

The pasteurization does solve a lot of water-borne disease problems and makes the water safe to drink, however water polluted with non-biological agents like heavy metals or toxic chemicals entail additional treatment to make the water clean (WHO). In SODIS, the ability of ultraviolet part of the sunlight to kill pathogens along with the heat (increased temperature) doubles its effectiveness to destroy micro-organisms and therewith improving the drinking water quality. And the solar distillation technology takes the advantage of its mechanism principle of vaporization; that the different chemicals have different evaporation temperatures and most of the potential contaminants present in water have higher evaporation points than that of water. So, when the raw water is heated, the pure water evaporates first leaving the contaminants behind in the still's basin (Vigneswaran 2009) (Etchepare and van der Hoek 2015) (Pisani, Lahnsteiner et al. 2006) (du Pisani 2006) (Burch and Thomas 1998).

Since, solar pasteurization is a thermal method in which the temperature attained from solar radiations is the only mean to purify water while in SODIS impurities are removed by the combined effect of temperature and ultraviolet radiations of specific wavelength. Therefore, SODIS is relatively considered more efficient and recommended, but nevertheless solar distillation is the most effective and perfect technology for water decontamination amongst the three because of the evaporation and condensation process mechanisms that remove all the impurities present in feed water. Moreover, pasteurization and SODIS remove only biological contaminants such as bacteria, viruses, protozoa and worms and do not address other pollutants found in water i.e. chemicals, pesticides or heavy metals. While the distillation eradicates completely and efficiently the biological, chemical and organic contaminants by the effective way of using sun's radiations to distill the water (Burch & Karen 1998) (Chittaranjan & Ravi 2011) (Meierhoffer & Wegelin 2002) (Caslake et al. 2004).

Solar pasteurization removes only the microbial contaminants such as E. coli, rotavirus, worms, protozoa cysts, salmonella typhi, hepatitis virus etc. It does kill or inactivates the pathogens depending upon the exposure (time and temperature) of contaminated water to solar radiations.

And, the mechanism involved in bringing the water up to the required temperature range ($\approx 65^{\circ}\text{C}$) varies. Regardless of the temperature-time regime, the solar pasteurization requires less energy than the other two under discussion technologies. Moreover, it requires the smallest amount of energy per volumes of production in comparison to the technologies considered. Depending on the site-specific conditions, it also requires similarly the low maintenance. However, alike solar distillation, the volumes of product freshwater per unit area are quite low. The disadvantages of this technology include; it is challenging to observe, understand and deliver the temperature-time mechanism involved, yet It could be suggested to users to confirm visually that the water has been adequately heated or boiled. In addition, the environmental constraints such as the circumstances of unabundant sunshine can make this technology impractical. However, this technology has been broadly accepted and practiced in water treatment.

SODIS is a simple, low cost and sustainable solution for water treatment at household level. It disinfects small quantities of water having low turbidity. As pathogens such as bacteria and viruses, being too small micro-organisms can easily and readily be treated with ultraviolet (UV) radiations. Whereas protozoa and worms are larger microbes and resistant to sun rays. Turbidity in water lets the viruses and bacteria to escape during ultraviolet treatments. Thus turbidity must be reduced by means such as filtering the water before applying the ultraviolet techniques such as SODIS (Burch & Karen 1998). However, it can supply fresh water at the household level and is recommended as a viable method by the WHO. It is easy to understand and afford, even the poorest can afford as it only requires sunlight and plastic bottles. Since it does not require large infrastructure, it is a self-help technology. The main drawbacks to SODIS are: It is not feasible in cloudy weather or unfavorable climatic conditions as it requires sufficient sunshine. It can treat only the small and less contaminated volumes of water and is reluctant to change the chemical quality of water. The SODIS is already working in numerous developing countries (SANDEC / EAWAG, 2002).

The solar water distillation has the capability to remove heavy metals, salts, arsenic, nitrates, pathogens and various other contaminants. Laboratory tests have shown that the solar stills can even remove the carcinogenic pollutants present in water. Since it does not comprise of moving parts, the maintenance of a still is quite simple and cheap compared to the pasteurization and SODIS i.e. the only required maintenance is to seldom clean the basin for the removal of residue. This technology is and would be readily accepted due to its simple and small scale of operation. The mechanism of evaporation and condensation can easily be delivered and grasped. As a result of the witnesses of freshwater delivery every day, the community will be desiring for larger stills. The shortcomings of this technology include: It requires relatively more amounts of solar radiations for lengthier periods of time than solar pasteurization and SODIS. The yield is low because of the slow evaporation rate. Moreover, since the still has a glass cover that tends to be large as per site-specific requirements, the capital cost can be high.

Also, the risks of environmental damages such as from weather, animals etc. can be significant. A sufficient research has been conducted and made available over the solar water distillation technology and is being practiced in various countries for water treatment such as desalination through distillation (Burch & Karen 1998) (*Chittaranjan & Ravi 2011*) (*Meierhoffer & Wegelin 2002*) (*Caslake et al. 2004*) (Etchepare and van der Hoek 2015).

In context of economic aspects of the passive solar driven water treatment technologies; the costs, affordability and willingness to pay are the central considerations for their employment, use and sustainability. All the three technologies entail an approach for the cost recovery in order to be sustainable. Besides, the results of the risk assessment conducted by Etchepare and van der Hoek over the reuse of greywater and human health showed that it does not pose any potential risk, even if being used for the whole life as potable (Etchepare and van der Hoek 2015)

6 Conclusion:

The solar water distillation is acknowledged as the best amongst the discussed three passive solar driven water treatment technologies. Its competence to remove almost all type of potential water contaminants cannot be neglected, though there are several design, operational and environmental limitations associated with the presentation of this technology such as high capital cost, low yield, weather and climatic constraints. However, the selection process of a technology for water purification should always be based on the local circumstances.

7 Proposed solutions

Overall, all the three discussed technologies are not fully developed, the marked potential is missing and there is further room for research and development. The only and insufficient theoretical research work and the missing laboratory or experimentation part has resulted in the lack of applicable market product. However, various parameters have been tested in the existing technologies to develop and commercialize the products. Similarly, in the case of passive solar water distillation, the solar stills are simple in design and fabrication but have low efficiency and production. To improve its distillate productivity, the scientists have carried out sufficient research and proposed various modifications for instance, the inclined designs with wick, shallow water depths, use of different energy storage materials and improvements in the condensing cover and cooling patterns can significantly enhance the still's output (Telkes 1953, 1959, Cooper 1969, Lawand 1969, Gomkale and Datta 1973, Howe and Tleimat 1974, Hirschmann 1975, Malik, Tiwari et al. 1982, Tiwari and Garg 1984, Kumar and Tiwari 1996, Fath 1998, El-Bahi and Inan 1999, El-Bahi and Inan 1999, Müller-Holst, Engelhardt et al. 1999, You, Tseng et al. 1999, Chaibi 2000, Van der Bruggen and Vandecasteele 2002, 2003, Al-Hinai 2003, Al-Kharabsheh, Yogi et al. 2003, Bouchekima 2003, Bouchekima 2003, Fath, El-Samanoudy et al. 2003, Tiwari, Singh et al. 2003, Al-Hayeka and Badran 2004, Khedim, Schwarzer et al. 2004, Khedim, Schwarzer et al. 2004, Foster, Amos et al. 2005, du Pisani 2006, Tiwari and Tiwari 2006, Badran and Abu-Khader 2007, Scrivani, El Asmar et al. 2007, Dimri, Sarkar et al. 2008, Kalidasa Murugavel, Chockalingam et al. 2008, Khawaji, Kutubkhanah et al. 2008, Qiblawey and Banat 2008, Abdallah, Abu-Khader et al. 2009, Arjunan, Aybar et al. 2009, Khalifa and Hamood 2009, Tiwari, Dimri et al. 2009, Kabeel, Hamed et al. 2010, Kalidasa Murugavel, Sivakumar et al. 2010, Kaushal and Varun 2010, Sampathkumar, Arjunan et al. 2010, Balan, Chandrasekaran et al. 2011, Kabeel and El-Agouz 2011, Kalidasa Murugavel and Srithar 2011, Ray and Jain 2011, Velmurugan and Srithar 2011, Compain 2012, El-Ghonemy 2012, Ansari, Asbik et al. 2013, Arunkumar, Denkenberger et al. 2013, Bhardwaj, ten Kortenaar et al. 2013, Kalidasa Murugavel, Anburaj et al. 2013, Manikandan, Shanmugasundaram et al. 2013, Omara, Eltawil et al. 2013, Rajaseenivasan, Murugavel et al. 2013, Ranjan and Kaushik 2013, Sivakumar and Ganapathy Sundaram 2013, Xiao, Wang et al. 2013, Zarasvand Asadi, Suja et al. 2013, 2014, Muftah, Alghoul et al. 2014, Muthu Manokar, Kalidasa Murugavel et al. 2014, Muthu Manokar, Kalidasa Murugavel et al. 2014, review, Alghoul et al. 2014, Chaichan and Kazem 2015, Durkaieswaran and Murugavel 2015, El-Sebaai and El-Bialy 2015, Elango, Gunasekaran et al. 2015, Ghaffour, Bundschuh et al. 2015, Gugulothu, Somanchi et al. 2015, Ibrahim, Allam et al. 2015, Manchanda and Kumar 2015, Prakash and Velmurugan 2015, Shashikanth, Khadka et al. 2015, Subramani and Jacangelo 2015, Sukkasi and Terdthaichairat 2015, Vishwanath Kumar, Kumar et al. 2015, Yadav and Sudhakar 2015, Abujazar, Fatihah et al. 2016, Dsilva Winfred Rufuss, Iniyani et al. 2016, Kabeel, Omara et al. 2016, KALITA, DEWAN et al. 2016, Kaviti, Yadav et al. 2016, Lyu, Chen et al. 2016, Shafii, Shahmohamadi et al. 2016, Sharshir, Yang et al. 2016).

The conclusions drawn from the current study and my proposed solutions to improve the still's performance are:

- External reflectors such as lens and mirrors should be tested with different designs of still to enhance the concentration and absorption of solar radiations
- The condensing part of still should be improved; the use of a separate condenser, providing the condenser with cooling i.e. the use of fans driven by solar panel and use of Peltier condensing module:

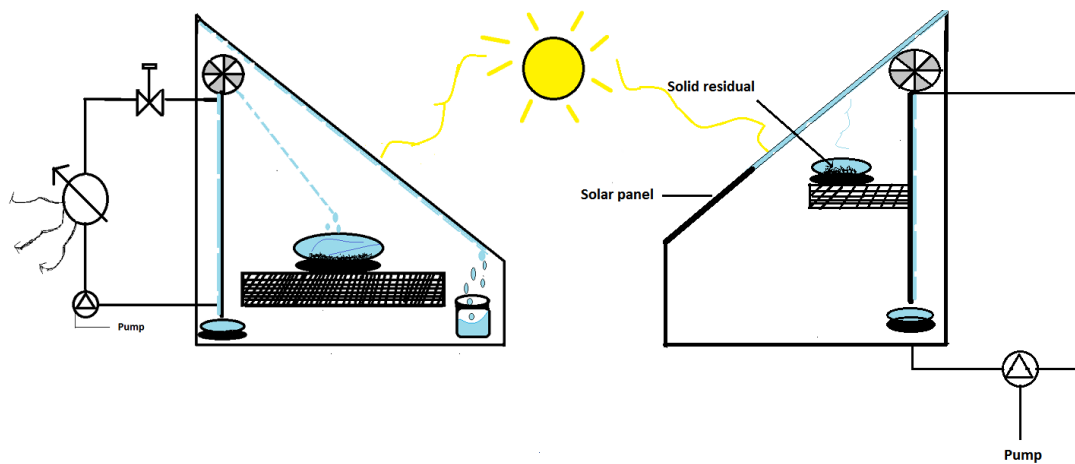


Figure: A schematic of the proposed solution

From my viewpoint, testing a combination of different parameters can brand a new, simple and more practical design of the passive solar still. Therefore, more efforts are crucial for the improvement in existing designs and performance parameters to make this environment friendly technique more useful for humanity.

8 Future Perspectives:

Passive solar driven water treatment is a naturally operated technique for the freshwater production from contaminated water resources using plentiful and free available solar energy. Due to the water and energy scarcity, there is strong need to utilize renewable energy sources. From the future perspectives, passive solar water treatment is considered as the efficient method. The main disadvantage of passive solar driven systems is the low product output. Though a number of different combination of parameters have been tested in the existing technologies to increase the productivity, there is great need of work to improve the performance at reasonable cost so far.

From the Windhoek practice, it is obvious that the treated water can effectively be reused for potable purposes and that, it is a feasible option for the arid countries if the associated cultural and management issues are overcome. However, the selection of a method for providing clean water should be based on local conditions, and the selection process should include a variety of social factors as well as the technical and cost factors explored here.

9 References:

(EU 2000). European Commission, Directorate-General for the Environment. The EU water framework directive. file:///C:/Users/Mubasher/Downloads/KH0414216ENC_002.pdf

UNDP (United Nations Development Program) 2015, The Millennium Development Goal 7; http://www.un.org/millenniumgoals/pdf/Goal_7_fs.pdf. Fact Sheet. Retrieved 03.04.2016

UN-DESA; Transforming our world: the 2030 Agenda for Sustainable Development. <https://sustainabledevelopment.un.org/post2015/transformingourworld>. Retrieved 03.04.2016

The Millennium Development Goals Report 2015, United Nations. New York; <http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2015/English2015.pdf>. Retrieved 04.04.2016

UNEP (United Nations Environment Program) 2002, Global Water Resources. http://www.unep.org/training/programmes/Instructor%20Version/Part_2/Activities/Economics_of_Ecosystems/Water/Supplemental/Global_Water_Resources.pdf. Accessed 06.04.2016

UN-Water, World Water Development Report 2016; <http://www.unwater.org/publications/world-water-development-report/en/>. Retrieved 04.04.2016

UNESCO- Division of Water Sciences; United Nations World Water Assessment Program. <http://www.unesco.org/water/wwap>. Retrieved 07.04.2016

WBCSD (World Business Council for Sustainable Development) Water Facts and Trends 2009. <http://www.wbcd.org/Pages/EDocument/EDocumentDetails.aspx?ID=137&NoSearchContextKey=true>. Accessed 07.04.2016

(FAO 2003): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Review of World Water Resources by Country. Water Report. ISSN 1020-1203. ISBN 92-5-104899-1

UNESCO 2016; WWAP (United Nations World Water Assessment Program). The United Nations World Water Development Report 2016: Water and Jobs. Paris. Accessed 08.04.2016

FAO 2012; (Food and Agriculture Organization of the United Nations). Coping with water scarcity: <http://www.fao.org/docrep/016/i3015e/i3015e.pdf>. Accessed 08.04.2016

UNEP (United Nations Environment Program) 2000s. Trends in global water use by sector - Vital Water Graphics - UNEP. http://www.unwater.org/downloads/Water_facts_and_trends.pdf. Accessed 09.04.2016

UNEP (United Nations Environment Program) 2000. Trends in global water use by sector. GRID-Arendal, Norway. <http://www.grida.no/publications/vg/caspian/page/3229.aspx>

WWC 2000: (World Water Council). World Water Vision Chapter 2- The Use of Water Today <http://www.worldwatercouncil.org/fileadmin/wwc/Library/WWVision/Chapter2.pdf>. Accessed 09.04.2016

FAO 2012; (Food and Agriculture Organization of the United Nations). Coping with water scarcity: <http://www.fao.org/docrep/016/i3015e/i3015e.pdf>. Accessed 09.04.2016

(FAO 2003): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Review of World Water Resources by Country. Water Report. ISSN 1020-1203. ISBN 92-5-104899-1

IVAR 2016; Product Data Sheet for IVAR drinking water / Langevatn, Norway. <http://www.ivar.no/getfile.php/1366376/IVAR%20Dokumenter/Produktdatablad%20IVAR%2021767.pdf>. Accessed 20.04.2016

EPA: Contaminant Candidate List (CCL) and Regulatory Determination. Types of Drinking Water Contaminants. <https://www.epa.gov/ccl/types-drinking-water-contaminants>. Accessed 20.04.2016

UNICEF/WHO: Guidelines for drinking water quality- fourth edition http://www.unicef.org/cholera/Chapter_4_prevention/01_WHO_Guidelines_for_drinking_water_quality.pdf. Accessed 20.04.2016

DWQR 2016: Drinking Water Quality Regulator for Scotland- National Water Quality Ten Key Parameters. <http://dwqr.scot/public-supply/national-water-quality/ten-key-parameters/> Accessed 20.04.2016

(AWWA 1999) American Water Works Association. Water quality and treatment: A handbook of community water supplies, 5th ed. Water Quality and Treatment Handbook.pdf. Accessed 22.04.2016

de Koning, J., D. Bixio, A. Karabelas, M. Salgot and A. Schäfer (2008). "Characterisation and assessment of water treatment technologies for reuse." Desalination 218(1-3): 92-104.

(APHA 1998): APHA, AWWA; WEF; American Public Health Association, American Water Works Association, Water Environment Federation. Standard Methods for the Examination of Water and Wastewater, 20th edition. APHA, Washington, D.C. http://www.mwa.co.th/download/file_upload/SMWW_1000-3000.pdf

(WHO 2000): World Health Organization. The World Health Report 2000. Global Water Supply and Sanitation Assessment. Geneva. http://www.who.int/water_sanitation_health/diseases/diarrhoea/en/.

(CDC 2012): Centers for Disease Control and Prevention, Atlanta, USA. Waterborne Diseases. http://www.cdc.gov/healthywater/wash_diseases.html. Accessed 28.04.2016

(CDC 2015): Centers for Disease Control and Prevention, Atlanta, USA. Global Water, Sanitation, & Hygiene (WASH). Accessed 28.04.2016

(Pisani, Lahnsteiner et al. 2006): Pisani, Petrus L. Lahnsteiner, J and G. Lempert. Direct Reclamation of potable water at Windhoek's Goreangab reclamation plant. Desalination 188(2006) 79-88. Water management in Windhoek, Namibia. Water Science & Technology. 55(2007) 441-448.

(WRA, 2007): WaterReuse Association, Alexandria, VA. Innovative Applications in Water Reuse and Desalination. Case studies by James Crook. WRA-103.pdf. Accessed 12.06.2016

(Vigneswaran & Sundaravadivel 2009): Wastewater Recycling, Reuse, and Reclamation - Vol. I. ISBN: 1905839243, 9781905839247. EOLSS Publications, 2009

(McKenzie 2005): Caigan McKenzie. Guidelines for Water Reuse. National Environmental Services Center (NESC). <http://www.nesc.wvu.edu/ndwc/articles/OT/WI05/reuse.pdf>. Accessed 04.05.2016

(EU 2014): European Union. Institute for Environment and Sustainability. Water Reuse in Europe - Relevant guidelines, needs for and barriers to innovation. ISSN: 18319424. <http://publications.jrc.ec.europa.eu/repository/handle/JRC92582>

(OECD/IEA, 2006): INTERNATIONAL ENERGY AGENCY. Organization for Economic Co-operation and Development. ENVIRONMENT DIRECTORATE INTERNATIONAL ENERGY AGENCY. BARRIERS TO TECHNOLOGY DIFFUSION: THE CASE OF SOLAR THERMAL TECHNOLOGIES. https://www.iea.org/publications/freepublications/publication/solar_thermal.pdf. JT03216489. Accessed 16.05.2016

(Burch & Karen 1998): Burch, J. (Jay), Thomas, Karen E. National Renewable Energy Laboratory (U.S.). An overview of water disinfection in developing countries and the potential for solar thermal water pasteurization. <http://www.nrel.gov/docs/legosti/fy98/23110.pdf>. NREL/TP-550-23110

(SCI 2009): Solar Cookers International Cookit. Water pasteurization indicator. Wikia Inc. www.solarcooking.org. http://solarcooking.wikia.com/wiki/Water_Pasteurization_Indicator. Accessed 23.05.2016

(Metcalf R, 2009): The microbiology of solar water pasteurization, with applications in East Africa. Solar Cookers International. [New-Methods-of-Water-Pasteurisation.pdf](#). Accessed 23.05.2016

(EU 2000). European Commission, Directorate-General for the Environment. The EU water framework directive. file:///C:/Users/Mubasher/Downloads/KH0414216ENC_002.pdf

UNDP (United Nations Development Program) 2015, The Millennium Development Goal 7; http://www.un.org/millenniumgoals/pdf/Goal_7_fs.pdf. Fact Sheet. Retrieved 03.04.2016

UN-DESA; Transforming our world: the 2030 Agenda for Sustainable Development. <https://sustainabledevelopment.un.org/post2015/transformingourworld>. Retrieved 03.04.2016

The Millennium Development Goals Report 2015, United Nations. New York; <http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2015/English2015.pdf>. Retrieved 04.04.2016

UNEP (United Nations Environment Program) 2002, Global Water Resources. http://www.unep.org/training/programmes/Instructor%20Version/Part_2/Activities/Economics_of_Ecosystems/Water/Supplemental/Global_Water_Resources.pdf. Accessed 06.04.2016

UN-Water, World Water Development Report 2016; <http://www.unwater.org/publications/world-water-development-report/en/>. Retrieved 04.04.2016

UNESCO- Division of Water Sciences; United Nations World Water Assessment Program. <http://www.unesco.org/water/wwap>. Retrieved 07.04.2016

WBCSD (World Business Council for Sustainable Development) Water Facts and Trends 2009. <http://www.wbcd.org/Pages/EDocument/EDocumentDetails.aspx?ID=137&NoSearchContextKey=true>. Accessed 07.04.2016

(FAO 2003): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Review of World Water Resources by Country. Water Report. ISSN 1020-1203. ISBN 92-5-104899-1

Abujazar, M. S. S., S. Fatihah, A. R. Rakmi and M. Z. Shahrom (2016). "The effects of design parameters on productivity performance of a solar still for seawater desalination: A review." *Desalination* 385: 178-193.

McGuigan, K. G., R. M. Conroy, H.-J. Mosler, M. d. Preez, E. Ubomba-Jaswa and P. Fernandez-Ibañez (2012). "Solar water disinfection (SODIS): A review from bench-top to roof-top." *Journal of Hazardous Materials* 235–236: 29-46.

Seneviratne, M. (2006). *Water Conservation — A Priority for Business*-Chapter 1, Elsevier Ltd.

Seneviratne, M. (2007). *Practical Approach to Water Conservation for Commercial and Industrial Facilities*. Kidlington, GBR, Elsevier Science & Technology.

UNESCO 2016; WWAP (United Nations World Water Assessment Program). *The United Nations World Water Development Report 2016: Water and Jobs*. Paris. Accessed 08.04.2016

FAO 2012; (Food and Agriculture Organization of the United Nations). *Coping with water scarcity*: <http://www.fao.org/docrep/016/i3015e/i3015e.pdf>. Accessed 08.04.2016

UNEP (United Nations Environment Program) 2000s. *Trends in global water use by sector - Vital Water Graphics* - UNEP. http://www.unwater.org/downloads/Water_facts_and_trends.pdf

Accessed 09.04.2016

UNEP (United Nations Environment Program) 2000. *Trends in global water use by sector*. GRID-Arendal, Norway. <http://www.grida.no/publications/vg/caspian/page/3229.aspx>

WWC 2000: (World Water Council). *World Water Vision Chapter 2- The Use of Water Today* <http://www.worldwatercouncil.org/fileadmin/wwc/Library/WWVision/Chapter2.pdf>. Accessed 09.04.2016

FAO 2012; (Food and Agriculture Organization of the United Nations). *Coping with water scarcity*: <http://www.fao.org/docrep/016/i3015e/i3015e.pdf>. Accessed 09.04.2016

(FAO 2003): *FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Review of World Water Resources by Country*. Water Report. ISSN 1020-1203. ISBN 92-5-104899-1

IVAR 2016; *Product Data Sheet for IVAR drinking water / Langevatn*, Norway. <http://www.ivar.no/getfile.php/1366376/IVAR%20Dokumenter/Produktdatablad%20IVAR%2021767.pdf>. Accessed 20.04.2016

EPA: *Contaminant Candidate List (CCL) and Regulatory Determination. Types of Drinking Water Contaminants*. <https://www.epa.gov/ccl/types-drinking-water-contaminants>. Accessed 20.04.2016

UNICEF/WHO: Guidelines for drinking water quality- fourth edition
http://www.unicef.org/cholera/Chapter_4_prevention/01_WHO_Guidelines_for_drinking_water_quality.pdf. Accessed 20.04.2016

DWQR 2016: Drinking Water Quality Regulator for Scotland- National Water Quality Ten Key Parameters. <http://dwqr.scot/public-supply/national-water-quality/ten-key-parameters/>
Accessed 20.04.2016

(AWWA 1999) American Water Works Association. Water quality and treatment: A handbook of community water supplies, 5th ed. Water Quality and Treatment Handbook.pdf. Accessed 22.04.2016

de Koning, J., D. Bixio, A. Karabelas, M. Salgot and A. Schäfer (2008). "Characterisation and assessment of water treatment technologies for reuse." *Desalination* 218(1–3): 92-104.

(APHA 1998): APHA, AWWA; WEF; American Public Health Association, American Water Works Association, Water Environment Federation. Standard Methods for the Examination of Water and Wastewater, 20th edition. APHA, Washington, D.C.
http://www.mwa.co.th/download/file_upload/SMWW_1000-3000.pdf

(WHO 2000): World Health Organization. The World Health Report 2000. Global Water Supply and Sanitation Assessment. . Geneva.
http://www.who.int/water_sanitation_health/diseases/diarrhoea/en/.

(CDC 2012): Centers for Disease Control and Prevention, Atlanta, USA. Waterborne Diseases.
http://www.cdc.gov/healthywater/wash_diseases.html. Accessed 28.04.2016

(CDC 2015): Centers for Disease Control and Prevention, Atlanta, USA. Global Water, Sanitation, & Hygiene (WASH). Accessed 28.04.2016

(FAO 2003): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Review of World Water Resources by Country. Water Report. ISSN 1020-1203. ISBN 92-5-104899-1

(USGS 2016): United States' Geological Survey. Runoff.
<http://water.usgs.gov/edu/runoff.html>. Accessed 19.04.2016

(FAO 2011): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Rainwater harvesting.
https://www.viawater.nl/files/documents/fao_-_water_harvesting.pdf. Accessed 19.04.2016

(AWWA 2010): American Water Works Association. WHITE PAPER ON GRAYWATER. Water Reuse Association, Alexandria. GraywaterFinal Report2010 for the US - AWWA.pdf. Accessed 19.04.2016

(EMMERSON 1998): Every Drop is Precious: Greywater as an Alternative Resource. QUEENSLAND PARLIAMENTARY LIBRARY, BRISBANE. July 1998.ISSN 1325-1341. <http://www.parliament.qld.gov.au/documents/explore/ResearchPublications/researchBulletins/rb0498ge.pdf>. ISBN 0 7242 7838 9. Accessed 20.04.2016

(Wiley 2014): John Wiley & Sons, Ltd. Water Efficiency in Buildings: Theory and Practice. Alternative Water Technologies. ISBN: 978-1-118-45657-6

Bixio, D., C. Thoeye, J. De Koning, D. Joksimovic, D. Savic, T. Wintgens and T. Melin (2006). "Integrated Concepts in Water RecyclingWastewater reuse in Europe." *Desalination* 187(1): 89-101.

Etchepare, R. and J. P. van der Hoek (2015). "Health risk assessment of organic micropollutants in greywater for potable reuse." *Water Research* 72: 186-198.

Khawaji, A. D., I. K. Kutubkhanah and J.-M. Wie (2008). "European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort 22 –25 April 2007, Halkidiki, GreeceAdvances in seawater desalination technologies." *Desalination* 221(1): 47-69.

Van der Bruggen, B. and C. Vandecasteele (2002). "Distillation vs. membrane filtration: overview of process evolutions in seawater desalination." *Desalination* 143(3): 207-218.

Wang, Z., Z. Fan, L. Xie and S. Wang (2006). "International Congress on Membranes and Membrane ProcessesStudy of integrated membrane systems for the treatment of wastewater from cooling towers." *Desalination* 191(1): 117-124.

You, S.-H., D.-H. Tseng, G.-L. Guo and J.-J. Yang (1999). "The potential for the recovery and reuse of cooling water in Taiwan." *Resources, Conservation and Recycling* 26(1): 53-70.

(Cooley et al. 2006): Heather Cooley, Peter Gleick, Gary Wolff. *Desalination, With a Grain of Salt: A California Perspective*. Pacific Institute for Studies in Development, Environment, and Security, California. ISBN: 1-893790-13-4

(USGS 2013): U.S. Geological Survey. *Ground Water and Surface Water a Single Resource*. By T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley. <http://pubs.water.usgs.gov/cir1139>. ISBN 0–607–89339–7. Accessed 20.04.2016

(Chen & Chu 2009): Chen Jining and Chu Junying. *Point Sources of Pollution: Local Effects and Control – Volume 1. Municipal Wastewater Reuse*. ISBN: 978-1-84826-167-9

(Metcalf & Eddy 1999): Metcalf and Eddy, Incorporated. 1991. Wastewater Engineering: Treatment Disposal and Reuse. New York: McGraw-Hill. Accessed 20.04.2016

(EPA 1981): Process Design Manual for Land Treatment of Municipal Wastewater. EPA 625/1-81-013. Cincinnati, Ohio: U. S. Environmental Protection Agency. Accessed 23.04.2016

(Anderson & Meng 2011): Paul R. Anderson and Yi Meng. ISTC; Illinois Sustainable Technology Center. Assessing Opportunities for Municipal Wastewater Reuse in the Metropolitan Chicago Area. Accessed 23.04.2016

(FAO 2003): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Review of World Water Resources by Country. Water Report. ISSN 1020-1203. ISBN 92-5-104899-1. Accessed 18.04.2016

(UNEP 2010): United Nations Environment Program. Clearing the Waters; A focus on water quality solutions. http://www.unep.org/PDF/Clearing_the_Waters.pdf. Accessed 18.04.2016

(UWEC 2004): University of Wisconsin-Eau Claire, USA, 2004. Surface water drawdown. <http://academic.evergreen.edu/g/grossmaz/LENONTM/>. Accessed 18.04.2016

(FAO 1991): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS - Rome, 1991. Natural Resources Management and Environment Department. Water harvesting (AGL/MISC/17/91). Accessed 19.04.2016

(UWEC 2004): University of Wisconsin-Eau Claire, USA, 2004. Traditional Water Harvesting. <http://academic.evergreen.edu/g/grossmaz/palmbajp/>. Accessed 19.04.2016

(Chittaranjan & Ravi 2011): Chittaranjan Ray and Ravi Jain. Drinking Water Treatment; Focusing on Appropriate Technology and Sustainability. ISBN 978-94-007-1103-7. DOI 10.1007/978-94-007-1104-4

(Hajian, Niknam et al. 2014): Mohammadhadi Hajian, Ramin Niknam, Mostafa Tasbandi and Morteza Tasbandi. The International Journal of Plant, Animal and Environmental Sciences [IJPAAES]. APPLICATION OF TREATED URBAN WASTE WATER CONSIDERING ENVIRONMENTAL AND ECONOMICAL ASPECTS; CASE STUDY: WASTE WATER TREATMENT PLANT OF KERMAN, IRAN. ISSN 2231-4490.

(Pisani, Lahnsteiner et al. 2006): Pisani, Petrus L. Lahnsteiner, J and G. Lempert. Direct Reclamation of potable water at Windhoek's Goreangab reclamation plant. Desalination 188(2006) 79-88. Water management in Windhoek, Namibia. Water Science & Technology. 55(2007) 441-448.

(FAC, 2012): Florida Administrative Code, Department of Environmental Protection 2012. Chapter 62-610 reuse of reclaimed water and land application – Florida. <http://www.dep.state.fl.us/legal/rules/wastewater/62-610.pdf>. Accessed 11.06.2016

(EPA, 2012): Environmental Protection Agency, United States. Guidelines for Water Reuse. EPA/600/R-12/618. <http://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf> (Accessed 10.06.2016)

(FDEP, 2015): Florida Department of Environmental Protection 2015. Reuse Inventory and Reuse Program http://www.dep.state.fl.us/water/reuse/docs/inventory/2014_reuse-report.pdf (Accessed 10.06.2016)

Christopher J. Martinez and Mark W. Clark, 2015. Document No. AE448. Publication Date: July 2009- Revised November 2015. Department of Soil and Water Science; University of Florida. <http://edis.ifas.ufl.edu>. (Accessed 10.06.2016)

Al-Jasser, A. O. (2011). "Saudi wastewater reuse standards for agricultural irrigation: Riyadh treatment plants effluent compliance." *Journal of King Saud University - Engineering Sciences* 23(1): 1-8.

Angelakis, A., T. Asano, E. Diamadopoulos, G. Tchobanoglous, T. Asano and A. D. Levine (1996). "Wastewater Reclamation and Reuse 1995Wastewater reclamation, recycling and reuse: past, present, and future." *Water Science and Technology* 33(10): 1-14.

Angelakis, A., T. Asano, E. Diamadopoulos, G. Tchobanoglous, J. Haarhoff and B. Van der Merwe (1996). "Wastewater Reclamation and Reuse 1995Twenty-five years of wastewater reclamation in Windhoek, Namibia." *Water Science and Technology* 33(10): 25-35.

Bouwer, H. (1996). "Issues in artificial recharge." *Water Science and Technology* 33(10–11): 381-390.

Bouwer, H. (2000). "Integrated water management: emerging issues and challenges." *Agricultural Water Management* 45(3): 217-228.

du Pisani, P. L. (2006). "Integrated Concepts in Water RecyclingDirect reclamation of potable water at Windhoek's Goreangab reclamation plant." *Desalination* 188(1): 79-88.

Englande Jr, A. J., P. Krenkel and J. Shamas (2015). *Wastewater Treatment & Water Reclamation* ☆. Reference Module in Earth Systems and Environmental Sciences, Elsevier.

Geselbracht, J. and D. Evans-Walker (2005). "Water Reclamation and Reuse." *Water Environment Research* 77(6): 1571-1609.

Huertas, E., M. Salgot, J. Hollender, S. Weber, W. Dott, S. Khan, A. Schäfer, R. Messalem, B. Bis, A. Aharoni and H. Chikurel (2008). "Key objectives for water reuse concepts." *Desalination* 218(1–3): 120-131.

Kellis, M., I. Kalavrouziotis and P. Gikas (2013). REVIEW OF WASTEWATER REUSE IN THE MEDITERRANEAN COUNTRIES, FOCUSING ON REGULATIONS AND POLICIES FOR MUNICIPAL AND INDUSTRIAL APPLICATIONS. *Glob. Nest. J.* 15: 333-350.

Kruzic, A. P. and S. K. Liehr (2008). "Natural treatment and onsite systems." *Water Environment Research* 80(10): 1206-1224.

Okun, D. A. (2000). "WATER RECLAMATION AND UNRESTRICTED NONPOTABLE REUSE: A New Tool in Urban Water Management." *Annual Review of Public Health* 21(1): 223.

Salgot, M., E. Huertas, S. Weber, W. Dott and J. Hollender (2006). "Integrated Concepts in Water Recycling Wastewater reuse and risk: definition of key objectives." *Desalination* 187(1): 29-40.

Smith, R. G. (1995). "Water reclamation and reuse." *Water Environment Research* 67(4): 488-495.

Vigneswaran, S. (2009). *Wastewater Recycling, Reuse, and Reclamation - Vol. I.*

Wade Miller, G. (2006). "Integrated Concepts in Water Recycling Integrated concepts in water reuse: managing global water needs." *Desalination* 187(1): 65-75.

(Karabelas J. Anastasios et al. 2002): Anastasios J. Karabelas, K. Katsoufidou, Dimitris Christos Sioutopoulos. UPGRADING AND REUSE OF EFFLUENTS FROM MUNICIPAL WASTE-WATER TREATMENT PLANTS – CURRENT TRENDS. HYDRORAMA 2002, 3rd International Forum Integrated Water Management: The Key to Sustainable Water Resources Athens.

(Laura & Bernd 2014): Laura Alcalde Sanz, Bernd Manfred Gawlik. *Water Reuse in Europe Relevant guidelines, needs for and barriers to innovation.* European Commission, Joint Research Centre, Institute for Environment and Sustainability. ISBN 978-92-79-44399-2 (PDF), ISSN 1831-9424, doi:10.2788/29234

(Vigneswaran & Sundaravadivel, 2004): S.Vigneswaran, M.Sundaravadivel, RECYCLE AND REUSE OF DOMESTIC WASTEWATER, in *Wastewater Recycle, Reuse, and Reclamation*, [Ed. Saravanamuthu (Vigi) Vigneswaran], in *Encyclopedia of Life Support Systems (EOLSS)*, Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK.

(EPWU 2015): El Paso Water Utilities (EPWU). El Paso, TX. Reclaimed Water. http://www.epwu.org/reclaimed_water/. Accessed 12.06.2016

(WRA, 2007): WaterReuse Association, Alexandria, VA. Innovative Applications in Water Reuse and Desalination. Case studies by James Crook. WRA-103.pdf. Accessed 12.06.2016

(WRA, 2004): WaterReuse Association, Alexandria, VA. Innovative Applications in Water Reuse and Desalination. Case studies by James Crook. WRA-101.pdf. Accessed 12.06.2016

(US EPA): Guide lines for Water Re use. US EPA Office of Technology Transfer and Regulatory Support. EPA/625/R-92/004. September 1992 & Municipal Wastewater Reuse: Selected Readings on Water Reuse. Office of Water (WH-595) EPA 430/09-91-002. September, 1991.

(EPWU 2014): El Paso Water Utilities. El Paso Water Utilities- Public Service Board. El Paso Water Utilities - Bureau of Reclamation. Water SMART: "Development of Feasibility Studies under Title XVI, Water Reclamation and Reuse Program for FY 2014". <http://www.usbr.gov/watersmart/title/docs/apps/ElPasoWaterUtilities.pdf>

(US OCWD): United States' Orange County Water District- California. <http://www.ocwd.com/gwrs/>. <http://www.ocwd.com/media/4267/gwrs-technical-brochure-r.pdf>

(US OCWD): United States' Orange County Water District- California. http://www.ocwd.com/media/3849/ocwd_fact-sheet_v34-final.pdf

(Burch & Karen 1998): Burch, J. (Jay), Thomas, Karen E. National Renewable Energy Laboratory, U.S.A. An overview of water disinfection in developing countries and the potential for solar.

(Chittaranjan & Ravi 2011): Chittaranjan Ray and Ravi Jain. Drinking Water Treatment; Focusing on Appropriate Technology and Sustainability. ISBN 978-94-007-1103-7. DOI 10.1007/978-94-007-1104-4

Brame, J., Q. Li and P. J. J. Alvarez (2011). "Nanotechnology-enabled water treatment and reuse: emerging opportunities and challenges for developing countries." Trends in Food Science & Technology 22(11): 618-624.

Burch, J. D. and K. E. Thomas (1998). "Water disinfection for developing countries and potential for solar thermal pasteurization." Solar Energy 64(1-3): 87-97.

de Koning, J., D. Bixio, A. Karabelas, M. Salgot and A. Schäfer (2008). "Characterisation and assessment of water treatment technologies for reuse." Desalination 218(1-3): 92-104.

Englande Jr, A. J., P. Krenkel and J. Shamas (2015). Wastewater Treatment & Water Reclamation☆. Reference Module in Earth Systems and Environmental Sciences, Elsevier.

Kivaisi, A. K. (2001). "The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review." *Ecological Engineering* 16(4): 545-560.

Kruzic, A. P. and S. K. Liehr (2008). "Natural treatment and onsite systems." *Water Environment Research* 80(10): 1206-1224.

Li, Q., S. Mahendra, D. Y. Lyon, L. Brunet, M. V. Liga, D. Li and P. J. J. Alvarez (2008). "Antimicrobial nanomaterials for water disinfection and microbial control: Potential applications and implications." *Water Research* 42(18): 4591-4602.

Qu, X., P. J. J. Alvarez and Q. Li (2013). "Applications of nanotechnology in water and wastewater treatment." *Water Research* 47(12): 3931-3946.

Uribe, I. O., A. Mosquera-Corral, J. L. Rodicio and S. Esplugas (2015). "Advanced technologies for water treatment and reuse." *AIChE Journal* 61(10): 3146-3158.

Westerhoff, P., G. Song, K. Hristovski and M. A. Kiser (2011). "Occurrence and removal of titanium at full scale wastewater treatment plants: implications for TiO₂ nanomaterials." *J Environ Monit* 13(5): 1195-1203.

Wiesner, M., Q. Li, J. Burgess, R. Kaegi and D. Dixon (2013). "Progress towards the responsible application of nanotechnology for water treatment." *Water Research* 47(12): 3865.

(Lemley, Wagenet et al. 1995): ANN LEMLEY, LINDA WAGENET AND BARBERA KNEEN. Activated Carbon Treatment of Drinking Water- Fact sheet 3 December 1995. CCEWQ-03-ActivatedCarbonWtrTrt.pdf. Accessed 28.04.2016

(EPA 2016): Environmental Protection Agency U.S. Granular Activated Carbon. <https://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?treatmentProcessId=2074826383>. Accessed 28.04.2016

(Burch & Karen 1998): Burch, J. (Jay), Thomas, Karen E. National Renewable Energy Laboratory (U.S.). An overview of water disinfection in developing countries and the potential for solar

(EPA 2016): Environmental Protection Agency U.S. Drinking Water Treatability Database. <https://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?treatmentProcessId=1934681921>. Conventional Treatment. Accessed 28.04.2016

(WHO 1996): World Health Organization. 1996. Water Sanitation and Health. http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_13.pdf. Coagulation, flocculation and clarification. Accessed 28.04.2016

(WHO 2007): World Health Organization. 2007. Water Treatment. http://www.who.int/water_sanitation_health/dwq/S12.pdf

(Shankar & Kumar 2012): Shankar P, Kumar S. Solar distillation – A parametric review. VSRD International Journal of Mechanical, Automobile & Production Engineering. 2012;2(1):17–33.

Abdallah, S., M. M. Abu-Khader and O. Badran (2009). "Effect of various absorbing materials on the thermal performance of solar stills." *Desalination* 242(1): 128-137.

Al-Hinai, H. e. a. (2003). Effect of climatic, design and operational parameters on the yield of a simple solar still: Al-Hinai, H. et al. *Energy Conversion and Management* , 2002, 43, (13), 1639–1650. 44: 87-87.

Badran, O. and M. Abu-Khader (2007). "Evaluating thermal performance of a single slope solar still." *Wärme- und Stoffübertragung* 43(10): 985-995.

Balan, R., J. Chandrasekaran, S. Shanmugan, B. Janarthanan and S. Kumar (2011). "Review on passive solar distillation." *Desalination and Water Treatment* 28(1-3): 217-238.

Burch, J. D. and K. E. Thomas (1998). "Water disinfection for developing countries and potential for solar thermal pasteurization." *Solar Energy* 64(1–3): 87-97.

Chaichan, M. T. and H. A. Kazem (2015). "Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM)." *Case Studies in Thermal Engineering* 5: 151-159.

Compain, P. (2012). Solar energy for water desalination. 1st International Symposium on Innovation and Technology in the Phosphate Industry, SYMPHOS 2011, Marrakesh.

Cooper, P. I. (1969). "Digital simulation of transient solar still processes." *Solar Energy* 12(3): 313-331.

Delyannis, E. (2003). "Historic background of desalination and renewable energies." *Solar Energy* 75(5): 357-366.

El-Bahi, A. and D. Inan (1999). "A solar still with minimum inclination, coupled to an outside condenser." *Desalination* 123(1): 79-83.

Fath, H. E. S. (1998). "Solar distillation: a promising alternative for water provision with free energy, simple technology and a clean environment." *Desalination* 116(1): 45-56.

Foster, R. E., W. Amos and S. Eby (2005). Ten years of solar distillation application along the US-Mexico border. Solar World Congress, International Solar Energy Society Orlando, Florida, Citeseer.

Gude, V. G., N. Nirmalakhandan and S. Deng (2010). "Renewable and sustainable approaches for desalination." *Renewable and Sustainable Energy Reviews* 14(9): 2641-2654.

Joyce, T. M., K. G. McGuigan, M. Elmore-Meegan and R. M. Conroy (1996). "Inactivation of fecal bacteria in drinking water by solar heating." *Applied and Environmental Microbiology* 62(2): 399-402.

Kalidasa Murugavel, K., P. Anburaj, R. Samuel Hanson and T. Elango (2013). "Progresses in inclined type solar stills." *Renewable and Sustainable Energy Reviews* 20: 364-377.

Kalidasa Murugavel, K., K. K. S. K. Chockalingam and K. Srithar (2008). "Progresses in improving the effectiveness of the single basin passive solar still." *Desalination* 220(1-3): 677-686.

Kalidasa Murugavel, K., S. Sivakumar, J. Riaz Ahamed, K. K. S. K. Chockalingam and K. Srithar (2010). "Single basin double slope solar still with minimum basin depth and energy storing materials." *Applied Energy* 87(2): 514-523.

Kalidasa Murugavel, K. and K. Srithar (2011). "Performance study on basin type double slope solar still with different wick materials and minimum mass of water." *Renewable Energy* 36(2): 612-620.

KALITA, P., A. DEWAN and S. BORAH (2016). "A review on recent developments in solar distillation units." *Sadhana* 41(2): 203-223.

Kalogirou, S. A. (2004). "Solar thermal collectors and applications." *Progress in Energy and Combustion Science* 30(3): 231-295.

Manchanda, H. and M. Kumar (2015). "A comprehensive decade review and analysis on designs and performance parameters of passive solar still." *Renewables: Wind, Water, and Solar* 2(1): 1-24.

McGuigan, K. G., R. M. Conroy, H.-J. Mosler, M. d. Preez, E. Ubomba-Jaswa and P. Fernandez-Ibañez (2012). "Solar water disinfection (SODIS): A review from bench-top to roof-top." *Journal of Hazardous Materials* 235-236: 29-46.

- Muftah, A. F., M. A. Alghoul, A. Fudholi, M. M. Abdul-Majeed and K. Sopian (2014). "Factors affecting basin type solar still productivity: A detailed review." *Renewable and Sustainable Energy Reviews* 32: 430-447.
- Müller-Holst, H., M. Engelhardt and W. Schölkopf (1999). "Small-scale thermal seawater desalination simulation and optimization of system design." *Desalination* 122(2–3): 255-262.
- Muthu Manokar, A., K. Kalidasa Murugavel and G. Esakkimuthu (2014). "Different parameters affecting the rate of evaporation and condensation on passive solar still - A review." *Renewable and Sustainable Energy Reviews* 38: 309-322.
- Prakash, P. and V. Velmurugan (2015). "Parameters influencing the productivity of solar stills – A review." *Renewable and Sustainable Energy Reviews* 49: 585-609.
- Ray, C. and R. Jain (2011). *Drinking Water Treatment*. Dordrecht, Springer.
- Sampathkumar, K., T. V. Arjunan, P. Pitchandi and P. Senthilkumar (2010). "Active solar distillation—A detailed review." *Renewable and Sustainable Energy Reviews* 14(6): 1503-1526.
- Schmid, P., M. Kohler, R. Meierhofer, S. Luzi and M. Wegelin (2008). "Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water?" *Water Research* 42(20): 5054-5060.
- Şen, Z. (2004). "Solar energy in progress and future research trends." *Progress in Energy and Combustion Science* 30(4): 367-416.
- Shannon, M. A., P. W. Bohn, M. Elimelech, J. G. Georgiadis, B. J. Marinas and A. M. Mayes (2008). "Science and technology for water purification in the coming decades." *Nature* 452(7185): 301-310.
- Shatat, M., M. Worall and S. Riffat (2013). "Opportunities for solar water desalination worldwide: Review." *Sustainable Cities and Society* 9: 67-80.
- Sukkasi, S. and W. Terdthaichairat (2015). "Improving the efficacy of solar water disinfection by incremental design innovation." *Clean Technologies and Environmental Policy* 17(7): 2013-2027.
- Tiwari, G. N. (2015). *Solar Energy Technology Advances*. Hauppauge, US, Nova.
- Tiwari, G. N., V. Dimri and A. Chel (2009). "Parametric study of an active and passive solar distillation system: Energy and exergy analysis." *Desalination* 242(1–3): 1-18.

Tiwari, G. N., H. N. Singh and R. Tripathi (2003). "Present status of solar distillation." *Solar Energy* 75(5): 367-373.

Velmurugan, V. and K. Srithar (2011). "Performance analysis of solar stills based on various factors affecting the productivity—A review." *Renewable and Sustainable Energy Reviews* 15(2): 1294-1304.

Vidan, A., D. Shoag, P. Kalt, C. Birzer, H. Evans, A. Liew, M. Padovan and M. Watchman (2014). "Humanitarian Technology: Science, Systems and Global Impact 2014, HumTech2014A Solar Disinfection Water Treatment System for Remote Communities." *Procedia Engineering* 78: 250-258.

(Argaw 2003): By N. Argaw. NREL: National Renewable Energy Laboratory. Renewable Energy in Water and Wastewater Treatment. Applications. NREL/SR-500-30383.<http://www.nrel.gov/docs/fy03osti/30383.pdf>. <http://www.osti.gov/bridge>. Accessed 28.04.2016

(WHO/UNICEF 2011): WHO/UNICEF- Joint Monitoring Program – Drinking Water Equity, Safety and Sustainability: Thematic Report on Drinking Water 2011, WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation (JMP). WHO/UNICEF, New York.

(Andreatta 2007): Andreatta, Dale. A Summary of Water Pasteurization Techniques. S.E.A. Ltd, Columbus. ANDREATTA 2007 A Summary of Water Pasteurization Techniques.pdf.

(Meierhoffer & Wegelin 2002): Meierhoffer R and Wegelin M. Solar water disinfection, a guide for the application of SODIS. Swiss Federal Institute of Environmental Science and Technology (EAWAG). Department of Water and Sanitation in Developing Countries (SANDEC). SANDEC, Dübendorf

(Caslake et al. 2004): Caslake L, Connolly D, Menon V, Duncanson C, Rojas R, Tavakoli J. Disinfection of contaminated water by using solar irradiation. *Appl Environ Microbiol* 70(2):1145–1151

(Burch & Karen 1998): Burch, J. (Jay), Thomas, Karen E. National Renewable Energy Laboratory (U.S.). An overview of water disinfection in developing countries and the potential for solar thermal water pasteurization. <http://www.nrel.gov/docs/legosti/fy98/23110.pdf>. NREL/TP-550-23110.

(Rainmaker™ 550): Solar Water Distiller. SolAqua. <http://www.solaqua.com/info.html>. Accessed 06.05.2016

(Rainkit™ 990): &Kit Plans. <http://solaqua.stores.yahoo.net/solaquakit2.html>

(Watercone): <http://www.watercone.com/contact.html>. Accessed: 06.05.2016

Eliodomestico: <http://www.gabrielediamanti.com/projects/eliodomestico>. Accessed: 06.05.2016

(Delyannis, 2003): Historic background of desalination and renewable energies. *Solar Energy*

(Talbert et al. 1970): Talbert, S.G., Eibling, J.A., Lof, G.O.G., 1970. Manual on solar distillation of saline water. R&D Progress Report No.546, US Department of the Interior. <http://www.ircwash.org/sites/default/files/215.1-70MA.pdf>. Accessed 23.05.2016

(Ward et al. 2000): Ward, R.C. and Robinson, M. Principles of hydrology; 4th edition. McGraw Hill- London.

(Anfas & Suneesh 2013): Anfas Mukram T, Suneesh P U. Experimental analysis of active solar still with air pump and external boosting mirrors. *International Journal of Innovative Research in Science, Engineering and Technology*. 2013;2(7):3084–904.

(EPSEA, 2000): El Paso Solar Energy Association. Solar Stills. Solar Water Purification Project. <http://www.epsea.org/stills.html>. <http://solar.nmsu.edu/publications/1437ISESpaper05.pdf>. <http://www.epsea.org/pdf/borderpact.pdf>. EPSEA Still Cutaway. Accessed 23.04.2016

(NMSU 2000): Renewable Energy: Solar Water Distillers. Juarez, Mexico- Border Pact project. the New Mexico State University. College of Agricultural, Consumer, and Environmental Sciences. Accessed 23.04.2016

(Chittaranjan & Ravi 2011): Chittaranjan Ray and Ravi Jain. Drinking Water Treatment; Focusing on Appropriate Technology and Sustainability. ISBN 978-94-007-1103-7. DOI 10.1007/978-94-007-1104-4

(Hajian, Niknam et al. 2014): Mohammadhadi Hajian, Ramin Niknam, Mostafa Tasbandi and Morteza Tasbandi. The International Journal of Plant, Animal and Environmental Sciences [IJPAES]. APPLICATION OF TREATED URBAN WASTE WATER CONSIDERING ENVIRONMENTAL AND ECONOMICAL ASPECTS; CASE STUDY: WASTE WATER TREATMENT PLANT OF KERMAN, IRAN. ISSN 2231-4490.

(1959). "An introduction to solar distillation : De Jong, Tim, Proc. Am. Soc. Civil Engr. J. Sanit. Eng. Div. SA4, Paper 1704, July 1958. 40 p. Illus." *Solar Energy* 3(1): 63.

(2003). "Effect of climatic, design and operational parameters on the yield of a simple solar still." *Fuel and Energy Abstracts* 44(2): 87.

- (2014). *Solar Desalination*. Hoboken, NJ, USA, Hoboken, NJ, USA: John Wiley & Sons, Inc.
- Abdallah, S., M. M. Abu-Khader and O. Badran (2009). "Effect of various absorbing materials on the thermal performance of solar stills." *Desalination* 242(1): 128-137.
- Abujazar, M. S. S., S. Fatihah, A. R. Rakmi and M. Z. Shahrom (2016). "The effects of design parameters on productivity performance of a solar still for seawater desalination: A review." *Desalination* 385: 178-193.
- Al-Hayeka, I. and O. O. Badran (2004). "The effect of using different designs of solar stills on water distillation." *Desalination* 169(2): 121-127.
- Al-Hinai, H. e. a. (2003). Effect of climatic, design and operational parameters on the yield of a simple solar still: Al-Hinai, H. et al. *Energy Conversion and Management* , 2002, 43, (13), 1639–1650. 44: 87-87.
- Al-Jasser, A. O. (2011). "Saudi wastewater reuse standards for agricultural irrigation: Riyadh treatment plants effluent compliance." *Journal of King Saud University - Engineering Sciences* 23(1): 1-8.
- Al-Kharabsheh, S., Yogi and D. Goswami (2003). "Analysis of an innovative water desalination system using low-grade solar heat." *Desalination* 156(1–3): 323-332.
- Angelakis, A., T. Asano, E. Diamadopoulos, G. Tchobanoglous, T. Asano and A. D. Levine (1996). "Wastewater Reclamation and Reuse 1995Wastewater reclamation, recycling and reuse: past, present, and future." *Water Science and Technology* 33(10): 1-14.
- Angelakis, A., T. Asano, E. Diamadopoulos, G. Tchobanoglous, J. Haarhoff and B. Van der Merwe (1996). "Wastewater Reclamation and Reuse 1995Twenty-five years of wastewater reclamation in Windhoek, Namibia." *Water Science and Technology* 33(10): 25-35.
- Ansari, O., M. Asbik, A. Bah, A. Arbaoui and A. Khmou (2013). "Desalination of the brackish water using a passive solar still with a heat energy storage system." *Desalination* 324: 10-20.
- Arjunan, T. V., H. Ş. Aybar and N. Nedunchezian (2009). "Status of solar desalination in India." *Renewable and Sustainable Energy Reviews* 13(9): 2408-2418.
- Arunkumar, T., D. Denkenberger, A. Ahsan and R. Jayaprakash (2013). "The augmentation of distillate yield by using concentrator coupled solar still with phase change material." *Desalination* 314: 189-192.
- Badran, O. and M. Abu-Khader (2007). "Evaluating thermal performance of a single slope solar still." *Wärme- und Stoffübertragung* 43(10): 985-995.

- Balan, R., J. Chandrasekaran, S. Shanmugan, B. Janarthanan and S. Kumar (2011). "Review on passive solar distillation." *Desalination and Water Treatment* 28(1-3): 217-238.
- Bhardwaj, R., M. V. ten Kortenaar and R. F. Mudde (2013). "Influence of condensation surface on solar distillation." *Desalination* 326: 37-45.
- Bixio, D., C. Thoeye, J. De Koning, D. Joksimovic, D. Savic, T. Wintgens and T. Melin (2006). "Integrated Concepts in Water Recycling Wastewater reuse in Europe." *Desalination* 187(1): 89-101.
- Boucekima, B. (2003). "A small solar desalination plant for the production of drinking water in remote arid areas of southern Algeria." *Desalination* 159(2): 197-204.
- Boucekima, B. (2003). "A solar desalination plant for domestic water needs in arid areas of South Algeria." *Desalination* 153(1-3): 65-69.
- Bouwer, H. (1996). "Issues in artificial recharge." *Water Science and Technology* 33(10-11): 381-390.
- Bouwer, H. (2000). "Integrated water management: emerging issues and challenges." *Agricultural Water Management* 45(3): 217-228.
- Brame, J., Q. Li and P. J. J. Alvarez (2011). "Nanotechnology-enabled water treatment and reuse: emerging opportunities and challenges for developing countries." *Trends in Food Science & Technology* 22(11): 618-624.
- Burch, J. D. and K. E. Thomas (1998). "Water disinfection for developing countries and potential for solar thermal pasteurization." *Solar Energy* 64(1-3): 87-97.
- Chaibi, M. T. (2000). "An overview of solar desalination for domestic and agriculture water needs in remote arid areas." *Desalination* 127(2): 119-133.
- Chaichan, M. T. and H. A. Kazem (2015). "Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM)." *Case Studies in Thermal Engineering* 5: 151-159.
- Compain, P. (2012). *Solar energy for water desalination. 1st International Symposium on Innovation and Technology in the Phosphate Industry, SYMPHOS 2011, Marrakesh.*
- Cooper, P. I. (1969). "Digital simulation of transient solar still processes." *Solar Energy* 12(3): 313-331.

- de Koning, J., D. Bixio, A. Karabelas, M. Salgot and A. Schäfer (2008). "Characterisation and assessment of water treatment technologies for reuse." *Desalination* 218(1–3): 92-104.
- Delyannis, E. (2003). "Historic background of desalination and renewable energies." *Solar Energy* 75(5): 357-366.
- Dimri, V., B. Sarkar, U. Singh and G. N. Tiwari (2008). "Effect of condensing cover material on yield of an active solar still: an experimental validation." *Desalination* 227(1–3): 178-189.
- Dsilva Winfred Rufuss, D., S. Iniyar, L. Suganthi and P. A. Davies (2016). "Solar stills: A comprehensive review of designs, performance and material advances." *Renewable and Sustainable Energy Reviews* 63: 464-496.
- du Pisani, P. L. (2006). "Integrated Concepts in Water Recycling Direct reclamation of potable water at Windhoek's Goreangab reclamation plant." *Desalination* 188(1): 79-88.
- Durkaieswaran, P. and K. K. Murugavel (2015). "Various special designs of single basin passive solar still – A review." *Renewable and Sustainable Energy Reviews* 49: 1048-1060.
- El-Bahi, A. and D. Inan (1999). "Analysis of a parallel double glass solar still with separate condenser." *Renewable Energy* 17(4): 509-521.
- El-Bahi, A. and D. Inan (1999). "A solar still with minimum inclination, coupled to an outside condenser." *Desalination* 123(1): 79-83.
- El-Ghonemy, A. M. K. (2012). "Water desalination systems powered by renewable energy sources: Review." *Renewable and Sustainable Energy Reviews* 16(3): 1537-1556.
- El-Sebaili, A. A. and E. El-Bialy (2015). "Advanced designs of solar desalination systems: A review." *Renewable and Sustainable Energy Reviews* 49: 1198-1212.
- Elango, C., N. Gunasekaran and K. Sampathkumar (2015). "Thermal models of solar still—A comprehensive review." *Renewable and Sustainable Energy Reviews* 47: 856-911.
- Englande Jr, A. J., P. Krenkel and J. Shamas (2015). *Wastewater Treatment & Water Reclamation* ☆. Reference Module in Earth Systems and Environmental Sciences, Elsevier.
- Etchepare, R. and J. P. van der Hoek (2015). "Health risk assessment of organic micropollutants in greywater for potable reuse." *Water Research* 72: 186-198.
- Fath, H. E. S. (1998). "Solar distillation: a promising alternative for water provision with free energy, simple technology and a clean environment." *Desalination* 116(1): 45-56.

- Fath, H. E. S., M. El-Samanoudy, K. Fahmy and A. Hassabou (2003). "Thermal-economic analysis and comparison between pyramid-shaped and single-slope solar still configurations." *Desalination* 159(1): 69-79.
- Foster, R. E., W. Amos and S. Eby (2005). Ten years of solar distillation application along the US-Mexico border. Solar World Congress, International Solar Energy Society Orlando, Florida, Citeseer.
- Geselbracht, J. and D. Evans-Walker (2005). "Water Reclamation and Reuse." *Water Environment Research* 77(6): 1571-1609.
- Ghaffour, N., J. Bundschuh, H. Mahmoudi and M. F. A. Goosen (2015). "Renewable energy-driven desalination technologies: A comprehensive review on challenges and potential applications of integrated systems." *Desalination* 356: 94-114.
- Gomkale, S. D. and R. L. Datta (1973). "Some aspects of solar distillation for water purification." *Solar Energy* 14(4): 387-392.
- Gude, V. G., N. Nirmalakhandan and S. Deng (2010). "Renewable and sustainable approaches for desalination." *Renewable and Sustainable Energy Reviews* 14(9): 2641-2654.
- Gugulothu, R., N. S. Somanchi, D. Vilasagarapu and H. B. Banoth (2015). "Solar Water Distillation Using Three Different Phase Change Materials." *Materials Today: Proceedings* 2(4-5): 1868-1875.
- Hirschmann, J. R. (1975). "Solar distillation in Chile." *Desalination* 17(1): 31-67.
- Howe, E. D. and B. W. Tleimat (1974). "Twenty years of work on solar distillation at the University of California." *Solar Energy* 16(2): 97-105.
- Huertas, E., M. Salgot, J. Hollender, S. Weber, W. Dott, S. Khan, A. Schäfer, R. Messalem, B. Bis, A. Aharoni and H. Chikurel (2008). "Key objectives for water reuse concepts." *Desalination* 218(1-3): 120-131.
- Ibrahim, A. G. M., E. E. Allam and S. E. Elshamarka (2015). "A modified basin type solar still: Experimental performance and economic study." *Energy* 93, Part 1: 335-342.
- Joyce, T. M., K. G. McGuigan, M. Elmore-Meegan and R. M. Conroy (1996). "Inactivation of fecal bacteria in drinking water by solar heating." *Applied and Environmental Microbiology* 62(2): 399-402.
- Kabeel, A. E. and S. A. El-Agouz (2011). "Review of researches and developments on solar stills." *Desalination* 276(1-3): 1-12.

- Kabeel, A. E., A. M. Hamed and S. A. El-Agouz (2010). "Cost analysis of different solar still configurations." *Energy* 35(7): 2901-2908.
- Kabeel, A. E., Z. M. Omara, F. A. Essa and A. S. Abdullah (2016). "Solar still with condenser – A detailed review." *Renewable and Sustainable Energy Reviews* 59: 839-857.
- Kalidasa Murugavel, K., P. Anburaj, R. Samuel Hanson and T. Elango (2013). "Progresses in inclined type solar stills." *Renewable and Sustainable Energy Reviews* 20: 364-377.
- Kalidasa Murugavel, K., K. K. S. K. Chockalingam and K. Srithar (2008). "Progresses in improving the effectiveness of the single basin passive solar still." *Desalination* 220(1–3): 677-686.
- Kalidasa Murugavel, K., S. Sivakumar, J. Riaz Ahamed, K. K. S. K. Chockalingam and K. Srithar (2010). "Single basin double slope solar still with minimum basin depth and energy storing materials." *Applied Energy* 87(2): 514-523.
- Kalidasa Murugavel, K. and K. Srithar (2011). "Performance study on basin type double slope solar still with different wick materials and minimum mass of water." *Renewable Energy* 36(2): 612-620.
- KALITA, P., A. DEWAN and S. BORAH (2016). "A review on recent developments in solar distillation units." *Sadhana* 41(2): 203-223.
- Kalogirou, S. A. (2004). "Solar thermal collectors and applications." *Progress in Energy and Combustion Science* 30(3): 231-295.
- Kaushal, A. and Varun (2010). "Solar stills: A review." *Renewable and Sustainable Energy Reviews* 14(1): 446-453.
- Kaviti, A. K., A. Yadav and A. Shukla (2016). "Inclined solar still designs: A review." *Renewable and Sustainable Energy Reviews* 54: 429-451.
- Kellis, M., I. Kalavrouziotis and P. Gikas (2013). REVIEW OF WASTEWATER REUSE IN THE MEDITERRANEAN COUNTRIES, FOCUSING ON REGULATIONS AND POLICIES FOR MUNICIPAL AND INDUSTRIAL APPLICATIONS. *Glob. Nest. J.* 15: 333-350.
- Khalifa, A. J. N. and A. M. Hamood (2009). "Performance correlations for basin type solar stills." *Desalination* 249(1): 24-28.
- Khawaji, A. D., I. K. Kutubkhanah and J.-M. Wie (2008). "European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort 22 –25 April 2007, Halkidiki, GreeceAdvances in seawater desalination technologies." *Desalination* 221(1): 47-69.

- Khedim, A., K. Schwarzer, C. Faber and C. Muller (2004). "Decentralized production of potable water with solar energy." *Desalination* 168: 13-20.
- Khedim, A., K. Schwarzer, C. Faber and C. Müller (2004). "Production décentralisée de l'eau potable à l'énergie solaire." *Desalination* 168: 13-20.
- Kivaisi, A. K. (2001). "The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review." *Ecological Engineering* 16(4): 545-560.
- Kruzic, A. P. and S. K. Liehr (2008). "Natural treatment and onsite systems." *Water Environment Research* 80(10): 1206-1224.
- Kumar, S. and G. N. Tiwari (1996). "Estimation of convective mass transfer in solar distillation systems." *Solar Energy* 57(6): 459-464.
- Lawand, T. A. (1969). "Description of a large solar distillation plant in the West Indies." *Solar Energy* 12(4): 509-512.
- Li, Q., S. Mahendra, D. Y. Lyon, L. Brunet, M. V. Liga, D. Li and P. J. J. Alvarez (2008). "Antimicrobial nanomaterials for water disinfection and microbial control: Potential applications and implications." *Water Research* 42(18): 4591-4602.
- Lyu, S., W. Chen, W. Zhang, Y. Fan and W. Jiao (2016). "Wastewater reclamation and reuse in China: Opportunities and challenges." *Journal of Environmental Sciences* 39: 86-96.
- Malik, M. A. S., G. N. Tiwari, A. Kumar and M. S. Sodha (1982). *Solar distillation*.
- Manchanda, H. and M. Kumar (2015). "A comprehensive decade review and analysis on designs and performance parameters of passive solar still." *Renewables: Wind, Water, and Solar* 2(1): 1-24.
- Manikandan, V., K. Shanmugasundaram, S. Shanmugan, B. Janarthanan and J. Chandrasekaran (2013). "Wick type solar stills: A review." *Renewable and Sustainable Energy Reviews* 20: 322-335.
- McGuigan, K. G., R. M. Conroy, H.-J. Mosler, M. d. Preez, E. Ubomba-Jaswa and P. Fernandez-Ibañez (2012). "Solar water disinfection (SODIS): A review from bench-top to roof-top." *Journal of Hazardous Materials* 235–236: 29-46.
- Muftah, A. F., M. A. Alghoul, A. Fudholi, M. M. Abdul-Majeed and K. Sopian (2014). "Factors affecting basin type solar still productivity: A detailed review." *Renewable and Sustainable Energy Reviews* 32: 430-447.

- Müller-Holst, H., M. Engelhardt and W. Schölkopf (1999). "Small-scale thermal seawater desalination simulation and optimization of system design." *Desalination* 122(2–3): 255-262.
- Muthu Manokar, A., K. Kalidasa Murugavel and G. Esakkimuthu (2014). "Different parameters affecting the rate of evaporation and condensation on passive solar still - A review." *Renewable and Sustainable Energy Reviews* 38: 309-322.
- Muthu Manokar, A., K. Kalidasa Murugavel and G. Esakkimuthu (2014). "Different parameters affecting the rate of evaporation and condensation on passive solar still – A review." *Renewable and Sustainable Energy Reviews* 38: 309-322.
- Okun, D. A. (2000). "WATER RECLAMATION AND UNRESTRICTED NONPOTABLE REUSE: A New Tool in Urban Water Management." *Annual Review of Public Health* 21(1): 223.
- Omara, Z. M., M. A. Eltawil and E. A. ElNashar (2013). "A new hybrid desalination system using wicks/solar still and evacuated solar water heater." *Desalination* 325: 56-64.
- Prakash, P. and V. Velmurugan (2015). "Parameters influencing the productivity of solar stills – A review." *Renewable and Sustainable Energy Reviews* 49: 585-609.
- Qiblawey, H. M. and F. Banat (2008). "Solar thermal desalination technologies." *Desalination* 220(1–3): 633-644.
- Qu, X., P. J. J. Alvarez and Q. Li (2013). "Applications of nanotechnology in water and wastewater treatment." *Water Research* 47(12): 3931-3946.
- Rajaseenivasan, T., K. K. Murugavel, T. Elango and R. S. Hansen (2013). "A review of different methods to enhance the productivity of the multi-effect solar still." *Renewable and Sustainable Energy Reviews* 17: 248-259.
- Ranjan, K. R. and S. C. Kaushik (2013). "Energy, exergy and thermo-economic analysis of solar distillation systems: A review." *Renewable and Sustainable Energy Reviews* 27: 709-723.
- Ray, C. and R. Jain (2011). *Drinking Water Treatment*. Dordrecht, Springer.
- review, F. a. b. t. s. s. p. A. d., M. A. Alghoul, A. Fudholi, M. M. Abdul-Majeed and K. Sopian (2014). "Factors affecting basin type solar still productivity: A detailed review." *Renewable and Sustainable Energy Reviews* 32: 430-447.
- Salgot, M., E. Huertas, S. Weber, W. Dott and J. Hollender (2006). "Integrated Concepts in Water Recycling Wastewater reuse and risk: definition of key objectives." *Desalination* 187(1): 29-40.

- Sampathkumar, K., T. V. Arjunan, P. Pitchandi and P. Senthilkumar (2010). "Active solar distillation—A detailed review." *Renewable and Sustainable Energy Reviews* 14(6): 1503-1526.
- Schmid, P., M. Kohler, R. Meierhofer, S. Luzi and M. Wegelin (2008). "Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water?" *Water Research* 42(20): 5054-5060.
- Scrivani, A., T. El Asmar and U. Bardi (2007). "Solar trough concentration for fresh water production and waste water treatment." *Desalination* 206(1–3): 485-493.
- Şen, Z. (2004). "Solar energy in progress and future research trends." *Progress in Energy and Combustion Science* 30(4): 367-416.
- Seneviratne, M. (2006). *Water Conservation — A Priority for Business-Chapter 1*, Elsevier Ltd.
- Seneviratne, M. (2007). *Practical Approach to Water Conservation for Commercial and Industrial Facilities*. Kidlington, GBR, Elsevier Science & Technology.
- Shafii, M. B., M. Shahmohamadi, M. Faegh and H. Sadrhosseini (2016). "Examination of a novel solar still equipped with evacuated tube collectors and thermoelectric modules." *Desalination* 382: 21-27.
- Shannon, M. A., P. W. Bohn, M. Elimelech, J. G. Georgiadis, B. J. Marinas and A. M. Mayes (2008). "Science and technology for water purification in the coming decades." *Nature* 452(7185): 301-310.
- Sharshir, S. W., N. Yang, G. Peng and A. E. Kabeel (2016). "Factors affecting solar stills productivity and improvement techniques: A detailed review." *Applied Thermal Engineering* 100: 267-284.
- Shashikanth, M., B. Khadka, Y. Lekhana, P. M. S. Kiran, N. Alaparathi and S. Veerammneni (2015). "Solar Water Distillation Using Energy Storage Material." *Procedia Earth and Planetary Science* 11: 368-375.
- Shatat, M., M. Worall and S. Riffat (2013). "Opportunities for solar water desalination worldwide: Review." *Sustainable Cities and Society* 9: 67-80.
- Sivakumar, V. and E. Ganapathy Sundaram (2013). "Improvement techniques of solar still efficiency: A review." *Renewable and Sustainable Energy Reviews* 28: 246-264.
- Smith, R. G. (1995). "Water reclamation and reuse." *Water Environment Research* 67(4): 488-495.

- Subramani, A. and J. G. Jacangelo (2015). "Emerging desalination technologies for water treatment: A critical review." *Water Research* 75: 164-187.
- Sukkasi, S. and W. Terdthaichairat (2015). "Improving the efficacy of solar water disinfection by incremental design innovation." *Clean Technologies and Environmental Policy* 17(7): 2013-2027.
- Telkes, M. (1953). "Fresh Water from Sea Water by Solar Distillation." *Industrial & Engineering Chemistry* 45(5): 1108-1114.
- Tiwari, A. K. and G. N. Tiwari (2006). "Effect of water depths on heat and mass transfer in a passive solar still: in summer climatic condition." *Desalination* 195(1–3): 78-94.
- Tiwari, G. N. (2015). *Solar Energy Technology Advances*. Hauppauge, US, Nova.
- Tiwari, G. N., V. Dimri and A. Chel (2009). "Parametric study of an active and passive solar distillation system: Energy and exergy analysis." *Desalination* 242(1–3): 1-18.
- Tiwari, G. N. and H. P. Garg (1984). "Studies on various designs of solar distillation systems." *Solar & Wind Technology* 1(3): 161-165.
- Tiwari, G. N., H. N. Singh and R. Tripathi (2003). "Present status of solar distillation." *Solar Energy* 75(5): 367-373.
- Uribe, I. O., A. Mosquera-Corral, J. L. Rodicio and S. Esplugas (2015). "Advanced technologies for water treatment and reuse." *AIChE Journal* 61(10): 3146-3158.
- Van der Bruggen, B. and C. Vandecasteele (2002). "Distillation vs. membrane filtration: overview of process evolutions in seawater desalination." *Desalination* 143(3): 207-218.
- Velmurugan, V. and K. Srithar (2011). "Performance analysis of solar stills based on various factors affecting the productivity—A review." *Renewable and Sustainable Energy Reviews* 15(2): 1294-1304.
- Vidan, A., D. Shoag, P. Kalt, C. Birzer, H. Evans, A. Liew, M. Padovan and M. Watchman (2014). "Humanitarian Technology: Science, Systems and Global Impact 2014, HumTech2014A Solar Disinfection Water Treatment System for Remote Communities." *Procedia Engineering* 78: 250-258.
- Vigneswaran, S. (2009). *Wastewater Recycling, Reuse, and Reclamation - Vol. I*.
- Vishwanath Kumar, P., A. Kumar, O. Prakash and A. K. Kaviti (2015). "Solar stills system design: A review." *Renewable and Sustainable Energy Reviews* 51: 153-181.

Wade Miller, G. (2006). "Integrated Concepts in Water Recycling Integrated concepts in water reuse: managing global water needs." *Desalination* 187(1): 65-75.

Wang, Z., Z. Fan, L. Xie and S. Wang (2006). "International Congress on Membranes and Membrane Processes Study of integrated membrane systems for the treatment of wastewater from cooling towers." *Desalination* 191(1): 117-124.

Westerhoff, P., G. Song, K. Hristovski and M. A. Kiser (2011). "Occurrence and removal of titanium at full scale wastewater treatment plants: implications for TiO₂ nanomaterials." *J Environ Monit* 13(5): 1195-1203.

Wiesner, M., Q. Li, J. Burgess, R. Kaegi and D. Dixon (2013). "Progress towards the responsible application of nanotechnology for water treatment." *Water Research* 47(12): 3865.

Xiao, G., X. Wang, M. Ni, F. Wang, W. Zhu, Z. Luo and K. Cen (2013). "A review on solar stills for brine desalination." *Applied Energy* 103: 642-652.

Yadav, S. and K. Sudhakar (2015). "Different domestic designs of solar stills: A review." *Renewable and Sustainable Energy Reviews* 47: 718-731.

You, S.-H., D.-H. Tseng, G.-L. Guo and J.-J. Yang (1999). "The potential for the recovery and reuse of cooling water in Taiwan." *Resources, Conservation and Recycling* 26(1): 53-70.

Zarasvand Asadi, R., F. Suja, M. H. Ruslan and N. a. A. Jalil (2013). "The application of a solar still in domestic and industrial wastewater treatment." *Solar Energy* 93: 63-71.

(Karabelas J. Anastasios et al. 2002): Anastasios J. Karabelas, K. Katsoufidou, Dimitris Christos Sioutopoulos. UPGRADING AND REUSE OF EFFLUENTS FROM MUNICIPAL WASTE-WATER TREATMENT PLANTS – CURRENT TRENDS. HYDRORAMA 2002, 3rd International Forum Integrated Water Management: The Key to Sustainable Water Resources Athens.

(Laura & Bernd 2014): Laura Alcalde Sanz, Bernd Manfred Gawlik. Water Reuse in Europe Relevant guidelines, needs for and barriers to innovation. European Commission, Joint Research Centre, Institute for Environment and Sustainability. ISBN 978-92-79-44399-2 (PDF), ISSN 1831-9424, doi:10.2788/29234

(Vigneswaran & Sundaravadivel 2009): Wastewater Recycling, Reuse, and Reclamation - Vol. I. ISBN: 1905839243, 9781905839247. EOLSS Publications, 2009

(EU 2014): European Union. Institute for Environment and Sustainability. Water Reuse in Europe - Relevant guidelines, needs for and barriers to innovation. ISSN: 18319424. <http://publications.jrc.ec.europa.eu/repository/handle/JRC92582>

(McKenzie 2005): Caigan McKenzie. Guidelines for Water Reuse. National Environmental Services Center (NESC). <http://www.nesc.wvu.edu/ndwc/articles/OT/WI05/reuse.pdf>. Accessed 04.05.2016

S.Vigneswaran,M.Sundaravadivel, (2004), RECYCLE AND REUSE OF DOMESTIC WASTEWATER, in Wastewater Recycle,Reuse,and Reclamation, [Ed. Saravanamuthu (Vigi Vigneswaran)], in Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford ,UK.

(FAO 2003): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Review of World Water Resources by Country. Water Report. ISSN 1020-1203. ISBN 92-5-104899-1. Accessed 18.04.2016

(UNEP 2010): United Nations Environment Program. Clearing the Waters; A focus on water quality solutions. http://www.unep.org/PDF/Clearing_the_Waters.pdf. Accessed 18.04.2016

(UWEC 2004): University of Wisconsin-Eau Claire, USA, 2004. Surface water drawdown. <http://academic.evergreen.edu/g/grossmaz/LENONTM/>. Accessed 18.04.2016

(FAO 1991): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS - Rome, 1991. Natural Resources Management and Environment Department. Water harvesting (AGL/MISC/17/91). Accessed 19.04.2016

(UWEC 2004): University of Wisconsin-Eau Claire, USA, 2004. Traditional Water Harvesting. <http://academic.evergreen.edu/g/grossmaz/palmbajp/>. Accessed 19.04.2016

FAO 2003): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Review of World Water Resources by Country. Water Report. ISSN 1020-1203. ISBN 92-5-104899-1

(USGS 2016): United States' Geological Survey. Runoff. <http://water.usgs.gov/edu/runoff.html>. Accessed 19.04.2016

(FAO 2011): FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Rainwater harvesting.https://www.viawater.nl/files/documents/fao_-_water_harvesting.pdf. Accessed 19.04.2016

(AWWA 2010): American Water Works Association. WHITE PAPER ON GRAYWATER. Water Reuse Association, Alexandria. GraywaterFinal Report2010 for the US - AWWA.pdf. Accessed 19.04.2016

(EMMERSON 1998): Every Drop is Precious: Greywater as an Alternative Resource. QUEENSLAND PARLIAMENTARY LIBRARY, BRISBANE. July 1998.ISSN 1325-1341.

<http://www.parliament.qld.gov.au/documents/explore/ResearchPublications/researchBulletins/rb0498ge.pdf>. ISBN 0 7242 7838 9. Accessed 20.04.2016

(Wiley 2014): John Wiley & Sons, Ltd. *Water Efficiency in Buildings: Theory and Practice. Alternative Water Technologies*. ISBN: 978-1-118-45657-6

Bixio, D., C. Thoeye, J. De Koning, D. Joksimovic, D. Savic, T. Wintgens and T. Melin (2006). "Integrated Concepts in Water Recycling Wastewater reuse in Europe." *Desalination* 187(1): 89-101.

Etchepare, R. and J. P. van der Hoek (2015). "Health risk assessment of organic micropollutants in greywater for potable reuse." *Water Research* 72: 186-198.

Khawaji, A. D., I. K. Kutubkhanah and J.-M. Wie (2008). "European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort 22 –25 April 2007, Halkidiki, Greece Advances in seawater desalination technologies." *Desalination* 221(1): 47-69.

Van der Bruggen, B. and C. Vandecasteele (2002). "Distillation vs. membrane filtration: overview of process evolutions in seawater desalination." *Desalination* 143(3): 207-218.

Wang, Z., Z. Fan, L. Xie and S. Wang (2006). "International Congress on Membranes and Membrane Processes Study of integrated membrane systems for the treatment of wastewater from cooling towers." *Desalination* 191(1): 117-124.

You, S.-H., D.-H. Tseng, G.-L. Guo and J.-J. Yang (1999). "The potential for the recovery and reuse of cooling water in Taiwan." *Resources, Conservation and Recycling* 26(1): 53-70.

(Cooley et al. 2006): Heather Cooley, Peter Gleick, Gary Wolff. *Desalination, With a Grain of Salt: A California Perspective*. Pacific Institute for Studies in Development, Environment, and Security, California. ISBN: 1-893790-13-4

(USGS 2013): U.S. Geological Survey. *Ground Water and Surface Water a Single Resource*. By T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley. <http://pubs.water.usgs.gov/cir1139>. ISBN 0–607–89339–7. Accessed 20.04.2016

(Chen & Chu 2009): Chen Jining and Chu Junying. *Point Sources of Pollution: Local Effects and Control – Volume 1. Municipal Wastewater Reuse*. ISBN: 978-1-84826-167-9

(Metcalf & Eddy 1999): Metcalf and Eddy, Incorporated. 1991. *Wastewater Engineering: Treatment Disposal and Reuse*. New York: McGraw-Hill. Accessed 20.04.2016

(EPA 1981): *Process Design Manual for Land Treatment of Municipal Wastewater*. EPA 625/1-81-013. Cincinnati, Ohio: U. S. Environmental Protection Agency. Accessed 23.04.2016

(Anderson & Meng 2011): Paul R. Anderson and Yi Meng. ISTC; Illinois Sustainable Technology Center. Assessing Opportunities for Municipal Wastewater Reuse in the Metropolitan Chicago Area. Accessed 23.04.2016

(Burch & Karen 1998): Burch, J. (Jay), Thomas, Karen E. National Renewable Energy Laboratory (U.S.). An overview of water disinfection in developing countries and the potential for solar thermal water pasteurization. <http://www.nrel.gov/docs/legosti/fy98/23110.pdf>. NREL/TP-550-23110.

(Chittaranjan & Ravi 2011): Chittaranjan Ray and Ravi Jain. Drinking Water Treatment; Focusing on Appropriate Technology and Sustainability. ISBN 978-94-007-1103-7. DOI 10.1007/978-94-007-1104-4

(SANDEC / EAWAG, 2002): Department of Water & Sanitation in Developing Countries at Swiss Federal Institute for Environmental Science and Technology. SANDEC Report No 06/02. <http://www.sodis.ch/>. ISBN Nr.: 3-906484-24-6.

Burch, J. D. and K. E. Thomas (1998). "Water disinfection for developing countries and potential for solar thermal pasteurization." *Solar Energy* 64(1–3): 87-97.

Etchepare, R. and J. P. van der Hoek (2015). "Health risk assessment of organic micropollutants in greywater for potable reuse." *Water Research* 72: 186-198.

(1959). "An introduction to solar distillation : De Jong, Tim, Proc. Am. Soc. Civil Engr. J. Sanit. Eng. Div. SA4, Paper 1704, July 1958. 40 p. Illus." *Solar Energy* 3(1): 63.

(2003). "Effect of climatic, design and operational parameters on the yield of a simple solar still." *Fuel and Energy Abstracts* 44(2): 87.

(2014). *Solar Desalination*. Hoboken, NJ, USA, Hoboken, NJ, USA: John Wiley & Sons, Inc.

Abdallah, S., M. M. Abu-Khader and O. Badran (2009). "Effect of various absorbing materials on the thermal performance of solar stills." *Desalination* 242(1): 128-137.

Abujazar, M. S. S., S. Fatihah, A. R. Rakmi and M. Z. Shahrom (2016). "The effects of design parameters on productivity performance of a solar still for seawater desalination: A review." *Desalination* 385: 178-193.

Al-Hayeka, I. and O. O. Badran (2004). "The effect of using different designs of solar stills on water distillation." *Desalination* 169(2): 121-127.

- Al-Hinai, H. e. a. (2003). Effect of climatic, design and operational parameters on the yield of a simple solar still: Al-Hinai, H. et al. *Energy Conversion and Management* , 2002, 43, (13), 1639–1650. 44: 87-87.
- Al-Kharabsheh, S., Yogi and D. Goswami (2003). "Analysis of an innovative water desalination system using low-grade solar heat." *Desalination* 156(1–3): 323-332.
- Ansari, O., M. Asbik, A. Bah, A. Arbaoui and A. Khmou (2013). "Desalination of the brackish water using a passive solar still with a heat energy storage system." *Desalination* 324: 10-20.
- Arjunan, T. V., H. Ş. Aybar and N. Nedunchezian (2009). "Status of solar desalination in India." *Renewable and Sustainable Energy Reviews* 13(9): 2408-2418.
- Arunkumar, T., D. Denkenberger, A. Ahsan and R. Jayaprakash (2013). "The augmentation of distillate yield by using concentrator coupled solar still with phase change material." *Desalination* 314: 189-192.
- Badran, O. and M. Abu-Khader (2007). "Evaluating thermal performance of a single slope solar still." *Wärme- und Stoffübertragung* 43(10): 985-995.
- Balan, R., J. Chandrasekaran, S. Shanmugan, B. Janarthanan and S. Kumar (2011). "Review on passive solar distillation." *Desalination and Water Treatment* 28(1-3): 217-238.
- Bhardwaj, R., M. V. ten Kortenaar and R. F. Mudde (2013). "Influence of condensation surface on solar distillation." *Desalination* 326: 37-45.
- Boucekima, B. (2003). "A small solar desalination plant for the production of drinking water in remote arid areas of southern Algeria." *Desalination* 159(2): 197-204.
- Boucekima, B. (2003). "A solar desalination plant for domestic water needs in arid areas of South Algeria." *Desalination* 153(1–3): 65-69.
- Chaibi, M. T. (2000). "An overview of solar desalination for domestic and agriculture water needs in remote arid areas." *Desalination* 127(2): 119-133.
- Chaichan, M. T. and H. A. Kazem (2015). "Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM)." *Case Studies in Thermal Engineering* 5: 151-159.
- Compain, P. (2012). *Solar energy for water desalination*. 1st International Symposium on Innovation and Technology in the Phosphate Industry, SYMPHOS 2011, Marrakesh.

- Cooper, P. I. (1969). "Digital simulation of transient solar still processes." *Solar Energy* 12(3): 313-331.
- Dimri, V., B. Sarkar, U. Singh and G. N. Tiwari (2008). "Effect of condensing cover material on yield of an active solar still: an experimental validation." *Desalination* 227(1–3): 178-189.
- Dsilva Winfred Rufuss, D., S. Iniyar, L. Suganthi and P. A. Davies (2016). "Solar stills: A comprehensive review of designs, performance and material advances." *Renewable and Sustainable Energy Reviews* 63: 464-496.
- du Pisani, P. L. (2006). "Integrated Concepts in Water Recycling Direct reclamation of potable water at Windhoek's Goreangab reclamation plant." *Desalination* 188(1): 79-88.
- Durkaieswaran, P. and K. K. Murugavel (2015). "Various special designs of single basin passive solar still – A review." *Renewable and Sustainable Energy Reviews* 49: 1048-1060.
- El-Bahi, A. and D. Inan (1999). "Analysis of a parallel double glass solar still with separate condenser." *Renewable Energy* 17(4): 509-521.
- El-Bahi, A. and D. Inan (1999). "A solar still with minimum inclination, coupled to an outside condenser." *Desalination* 123(1): 79-83.
- El-Ghonemy, A. M. K. (2012). "Water desalination systems powered by renewable energy sources: Review." *Renewable and Sustainable Energy Reviews* 16(3): 1537-1556.
- El-Sebaai, A. A. and E. El-Bialy (2015). "Advanced designs of solar desalination systems: A review." *Renewable and Sustainable Energy Reviews* 49: 1198-1212.
- Elango, C., N. Gunasekaran and K. Sampathkumar (2015). "Thermal models of solar still—A comprehensive review." *Renewable and Sustainable Energy Reviews* 47: 856-911.
- Fath, H. E. S. (1998). "Solar distillation: a promising alternative for water provision with free energy, simple technology and a clean environment." *Desalination* 116(1): 45-56.
- Fath, H. E. S., M. El-Samanoudy, K. Fahmy and A. Hassabou (2003). "Thermal-economic analysis and comparison between pyramid-shaped and single-slope solar still configurations." *Desalination* 159(1): 69-79.
- Foster, R. E., W. Amos and S. Eby (2005). Ten years of solar distillation application along the US-Mexico border. Solar World Congress, International Solar Energy Society Orlando, Florida, Citeseer.

- Ghaffour, N., J. Bundschuh, H. Mahmoudi and M. F. A. Goosen (2015). "Renewable energy-driven desalination technologies: A comprehensive review on challenges and potential applications of integrated systems." *Desalination* 356: 94-114.
- Gomkale, S. D. and R. L. Datta (1973). "Some aspects of solar distillation for water purification." *Solar Energy* 14(4): 387-392.
- Gugulothu, R., N. S. Somanchi, D. Vilasagarapu and H. B. Banoth (2015). "Solar Water Distillation Using Three Different Phase Change Materials." *Materials Today: Proceedings* 2(4-5): 1868-1875.
- Hirschmann, J. R. (1975). "Solar distillation in Chile." *Desalination* 17(1): 31-67.
- Howe, E. D. and B. W. Tleimat (1974). "Twenty years of work on solar distillation at the University of California." *Solar Energy* 16(2): 97-105.
- Ibrahim, A. G. M., E. E. Allam and S. E. Elshamarka (2015). "A modified basin type solar still: Experimental performance and economic study." *Energy* 93, Part 1: 335-342.
- Kabeel, A. E. and S. A. El-Agouz (2011). "Review of researches and developments on solar stills." *Desalination* 276(1-3): 1-12.
- Kabeel, A. E., A. M. Hamed and S. A. El-Agouz (2010). "Cost analysis of different solar still configurations." *Energy* 35(7): 2901-2908.
- Kabeel, A. E., Z. M. Omara, F. A. Essa and A. S. Abdullah (2016). "Solar still with condenser – A detailed review." *Renewable and Sustainable Energy Reviews* 59: 839-857.
- Kalidasa Murugavel, K., P. Anburaj, R. Samuel Hanson and T. Elango (2013). "Progresses in inclined type solar stills." *Renewable and Sustainable Energy Reviews* 20: 364-377.
- Kalidasa Murugavel, K., K. K. S. K. Chockalingam and K. Srithar (2008). "Progresses in improving the effectiveness of the single basin passive solar still." *Desalination* 220(1-3): 677-686.
- Kalidasa Murugavel, K., S. Sivakumar, J. Riaz Ahamed, K. K. S. K. Chockalingam and K. Srithar (2010). "Single basin double slope solar still with minimum basin depth and energy storing materials." *Applied Energy* 87(2): 514-523.
- Kalidasa Murugavel, K. and K. Srithar (2011). "Performance study on basin type double slope solar still with different wick materials and minimum mass of water." *Renewable Energy* 36(2): 612-620.

- KALITA, P., A. DEWAN and S. BORAH (2016). "A review on recent developments in solar distillation units." *Sadhana* 41(2): 203-223.
- Kaushal, A. and Varun (2010). "Solar stills: A review." *Renewable and Sustainable Energy Reviews* 14(1): 446-453.
- Kaviti, A. K., A. Yadav and A. Shukla (2016). "Inclined solar still designs: A review." *Renewable and Sustainable Energy Reviews* 54: 429-451.
- Khalifa, A. J. N. and A. M. Hamood (2009). "Performance correlations for basin type solar stills." *Desalination* 249(1): 24-28.
- Khawaji, A. D., I. K. Kutubkhanah and J.-M. Wie (2008). "European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort 22 –25 April 2007, Halkidiki, Greece Advances in seawater desalination technologies." *Desalination* 221(1): 47-69.
- Khedim, A., K. Schwarzer, C. Faber and C. Muller (2004). "Decentralized production of potable water with solar energy." *Desalination* 168: 13-20.
- Khedim, A., K. Schwarzer, C. Faber and C. Müller (2004). "Production décentralisée de l'eau potable à l'énergie solaire." *Desalination* 168: 13-20.
- Kumar, S. and G. N. Tiwari (1996). "Estimation of convective mass transfer in solar distillation systems." *Solar Energy* 57(6): 459-464.
- Lawand, T. A. (1969). "Description of a large solar distillation plant in the West Indies." *Solar Energy* 12(4): 509-512.
- Lyu, S., W. Chen, W. Zhang, Y. Fan and W. Jiao (2016). "Wastewater reclamation and reuse in China: Opportunities and challenges." *Journal of Environmental Sciences* 39: 86-96.
- Malik, M. A. S., G. N. Tiwari, A. Kumar and M. S. Sodha (1982). *Solar distillation*.
- Manchanda, H. and M. Kumar (2015). "A comprehensive decade review and analysis on designs and performance parameters of passive solar still." *Renewables: Wind, Water, and Solar* 2(1): 1-24.
- Manikandan, V., K. Shanmugasundaram, S. Shanmugan, B. Janarthanan and J. Chandrasekaran (2013). "Wick type solar stills: A review." *Renewable and Sustainable Energy Reviews* 20: 322-335.

- Muftah, A. F., M. A. Alghoul, A. Fudholi, M. M. Abdul-Majeed and K. Sopian (2014). "Factors affecting basin type solar still productivity: A detailed review." *Renewable and Sustainable Energy Reviews* 32: 430-447.
- Müller-Holst, H., M. Engelhardt and W. Schölkopf (1999). "Small-scale thermal seawater desalination simulation and optimization of system design." *Desalination* 122(2–3): 255-262.
- Muthu Manokar, A., K. Kalidasa Murugavel and G. Esakkimuthu (2014). "Different parameters affecting the rate of evaporation and condensation on passive solar still - A review." *Renewable and Sustainable Energy Reviews* 38: 309-322.
- Muthu Manokar, A., K. Kalidasa Murugavel and G. Esakkimuthu (2014). "Different parameters affecting the rate of evaporation and condensation on passive solar still – A review." *Renewable and Sustainable Energy Reviews* 38: 309-322.
- Omara, Z. M., M. A. Eltawil and E. A. ElNashar (2013). "A new hybrid desalination system using wicks/solar still and evacuated solar water heater." *Desalination* 325: 56-64.
- Prakash, P. and V. Velmurugan (2015). "Parameters influencing the productivity of solar stills – A review." *Renewable and Sustainable Energy Reviews* 49: 585-609.
- Qiblawey, H. M. and F. Banat (2008). "Solar thermal desalination technologies." *Desalination* 220(1–3): 633-644.
- Rajaseenivasan, T., K. K. Murugavel, T. Elango and R. S. Hansen (2013). "A review of different methods to enhance the productivity of the multi-effect solar still." *Renewable and Sustainable Energy Reviews* 17: 248-259.
- Ranjan, K. R. and S. C. Kaushik (2013). "Energy, exergy and thermo-economic analysis of solar distillation systems: A review." *Renewable and Sustainable Energy Reviews* 27: 709-723.
- Ray, C. and R. Jain (2011). *Drinking Water Treatment*. Dordrecht, Springer.
- review, F. a. b. t. s. s. p. A. d., M. A. Alghoul, A. Fudholi, M. M. Abdul-Majeed and K. Sopian (2014). "Factors affecting basin type solar still productivity: A detailed review." *Renewable and Sustainable Energy Reviews* 32: 430-447.
- Sampathkumar, K., T. V. Arjunan, P. Pitchandi and P. Senthilkumar (2010). "Active solar distillation—A detailed review." *Renewable and Sustainable Energy Reviews* 14(6): 1503-1526.
- Scrivani, A., T. El Asmar and U. Bardi (2007). "Solar trough concentration for fresh water production and waste water treatment." *Desalination* 206(1–3): 485-493.

- Shafii, M. B., M. Shahmohamadi, M. Faegh and H. Sadrhosseini (2016). "Examination of a novel solar still equipped with evacuated tube collectors and thermoelectric modules." *Desalination* 382: 21-27.
- Sharshir, S. W., N. Yang, G. Peng and A. E. Kabeel (2016). "Factors affecting solar stills productivity and improvement techniques: A detailed review." *Applied Thermal Engineering* 100: 267-284.
- Shashikanth, M., B. Khadka, Y. Lekhana, P. M. S. Kiran, N. Alaparathi and S. Veerammneni (2015). "Solar Water Distillation Using Energy Storage Material." *Procedia Earth and Planetary Science* 11: 368-375.
- Sivakumar, V. and E. Ganapathy Sundaram (2013). "Improvement techniques of solar still efficiency: A review." *Renewable and Sustainable Energy Reviews* 28: 246-264.
- Subramani, A. and J. G. Jacangelo (2015). "Emerging desalination technologies for water treatment: A critical review." *Water Research* 75: 164-187.
- Sukkasi, S. and W. Terdthaichairat (2015). "Improving the efficacy of solar water disinfection by incremental design innovation." *Clean Technologies and Environmental Policy* 17(7): 2013-2027.
- Telkes, M. (1953). "Fresh Water from Sea Water by Solar Distillation." *Industrial & Engineering Chemistry* 45(5): 1108-1114.
- Tiwari, A. K. and G. N. Tiwari (2006). "Effect of water depths on heat and mass transfer in a passive solar still: in summer climatic condition." *Desalination* 195(1-3): 78-94.
- Tiwari, G. N., V. Dimri and A. Chel (2009). "Parametric study of an active and passive solar distillation system: Energy and exergy analysis." *Desalination* 242(1-3): 1-18.
- Tiwari, G. N. and H. P. Garg (1984). "Studies on various designs of solar distillation systems." *Solar & Wind Technology* 1(3): 161-165.
- Tiwari, G. N., H. N. Singh and R. Tripathi (2003). "Present status of solar distillation." *Solar Energy* 75(5): 367-373.
- Van der Bruggen, B. and C. Vandecasteele (2002). "Distillation vs. membrane filtration: overview of process evolutions in seawater desalination." *Desalination* 143(3): 207-218.
- Velmurugan, V. and K. Srithar (2011). "Performance analysis of solar stills based on various factors affecting the productivity—A review." *Renewable and Sustainable Energy Reviews* 15(2): 1294-1304.

Vishwanath Kumar, P., A. Kumar, O. Prakash and A. K. Kaviti (2015). "Solar stills system design: A review." *Renewable and Sustainable Energy Reviews* 51: 153-181.

Xiao, G., X. Wang, M. Ni, F. Wang, W. Zhu, Z. Luo and K. Cen (2013). "A review on solar stills for brine desalination." *Applied Energy* 103: 642-652.

Yadav, S. and K. Sudhakar (2015). "Different domestic designs of solar stills: A review." *Renewable and Sustainable Energy Reviews* 47: 718-731.

You, S.-H., D.-H. Tseng, G.-L. Guo and J.-J. Yang (1999). "The potential for the recovery and reuse of cooling water in Taiwan." *Resources, Conservation and Recycling* 26(1): 53-70.

Zarasvand Asadi, R., F. Suja, M. H. Ruslan and N. a. A. Jalil (2013). "The application of a solar still in domestic and industrial wastewater treatment." *Solar Energy* 93: 63-71.

(Burch & Karen 1998): Burch, J. (Jay), Thomas, Karen E. National Renewable Energy Laboratory (U.S.). An overview of water disinfection in developing countries and the potential for solar thermal water pasteurization. <http://www.nrel.gov/docs/legosti/fy98/23110.pdf>. NREL/TP-550-23110.