UNIVERSITY OF GÄVLE

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT

# Desalination Needs and Appropriate technology for Sri Lanka

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| | **Master of Science Thesis-SEE**<br><br>**ASSESSMENT OF DESALINATION NEEDS AND APPROPRIATE TECHNOLGIES FOR SRI LANKA**<br><br>K.J.D.Buddhika Jagath Jayasekara<br>840228-P276 | |
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# Abstract

This study investigates the desalination needs and available technologies in Sri Lanka. Lack of rainfall, pollution due to agricultural chemicals, presence of fluoride, increasing demand, exploitation of ground water and brackishness have created scarcity of fresh pure water specially in near costal and dry zones in Sri Lanka. Due to Cronic Kidney Disease (CKD) around 500 people died in dry zones annually which is suspected to cause by Arsenic and Cadmium contain in ground water due to agriculture chemicals.

The available desalination methods are Reverse Osmosis (RO), Solar distillation and conventional methods. The cost for RO is Rs.0.10 cents per liter and solar distillation Rs.2.96 per liter. Although the price shows that the RO is better but due to high initial investment as a third world country it is very difficult to afford huge initial investment without government intervention. The experimental solar desalination units only produce nearly 5liters of potable water per day and directly impacted by availability of solar radiation.

The energy availability of Sri Lanka and future potable water demand predicted as 2188.3 Mn liters as maximum demand which will be in 2030, therefore by that time the government should have a proper plan to cater the demand and desalination plants need to be planned and built based on the demand of dry zones and specially agriculture areas.

The applicability of renewable energy for desalination in local arena was also simulated taking the Delf Reverse Osmosis plant for the simulation. Results show that the optimum design is combination of Solar PV and existing 100kW Diesel generator Set with Battery bank and converter.

# ACKNOWLEDGEMENTS

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# 1. Introduction

## Background

Sri Lanka is an island in the Indian Ocean which is located in between the latitudes of $5^0$ 55' N and $9^0$ 51' N and the longitudes of $79^0$ 41'E and $81^0$ 53' E by covering an area of 65610 $km^2$. The population of Sri Lanka is about 20.9 million in 2010 and 70% of them are living in rural areas [*NWSDB (2010)*]. The access to the safe water is about 81% in total population basis. A shortage of safe fresh water is a very crucial problem that is continuously increasing in Sri Lanka which mainly affects the coastal areas and dry zones.

According to current government policy guidelines, the country's vision is to achieve 94% of safe drinking water in total population basis in 2015 and 100% in 2020[*Ministry of Finance and Planning (2010)*].

The rural water supply is mainly based on ground water and in most urban areas pipe born water is available, which is sourced from rivers or natural water resources. However, in the dry zone and in coastal areas, the ground water is brackish and accessibility to natural potable water sources is very limited.

Due to the lack of pure fresh water, a large number of fluorosis has been identified in the areas of North Eastern and South Eastern provinces, dry climatic zone of the country. The chronic kidney disease, which is fast spreading in these areas, is also considered to be due to the consumption of brackish water for long time.

As a solution to this scarcity of pure fresh water, the desalination process can be used and the level of applicability needs to be explored considering Sri Lankan climate and socio-economic conditions. Presently, very limited studies have been published on this matter with respect to Sri Lankan scenario.

## Project objectives

- Identification of the water desalination needs in Sri Lanka (Communities, geographic limitations, health issues)

- Analyze the technologies available for desalination of water in Sri Lanka as well as in other countries.

- Determine the feasibility of utilizing renewable energy for desalination process for existing facility.

**Methodology**

This research was performed as follows:

I. Country climate was studied to identify the potable water resources based on the geography

II. The areas suffering from scarcity of water was identified based on the rainfall details, ground water and surface water availability

III. Desalination needs had been identified through studying the health impacts due to pollution of water and fluoride concentration.

IV. The available technologies for desalination were briefly studied in the worldwide

V. Technologies available in Sri Lanka are studied to find out the per liter cost for producing of potable water. Energy demand is also estimated for each technology

VI. Analyze the renewable energy application for the existing Reverse osmosis Plant by using Homer software.

# 2. Analysis of Desalination Needs

## 2.1. Climate

Sri Lanka has a number of climatic zones under the influence of monsoon circulation over South East Asia. Therefore, the climate is variable in Sri Lanka; especially the rainfall varies over different areas. Three major climate zones have been recognized according to the rainfall distribution as wet zone, dry zone and intermediate zone.

The wet zone includes the south west region and central hill country area which receives ample annual average rainfall of 2500 mm without pronounced dry period. The dry zone includes the Northern and Eastern part of the country which receives annual average rainfall of less than 1750 mm giving a significantly lengthy dry season from May to September every year. The Intermediate Zone receives annual rainfall of 1750 mm to 2500 mm with a short dry season.

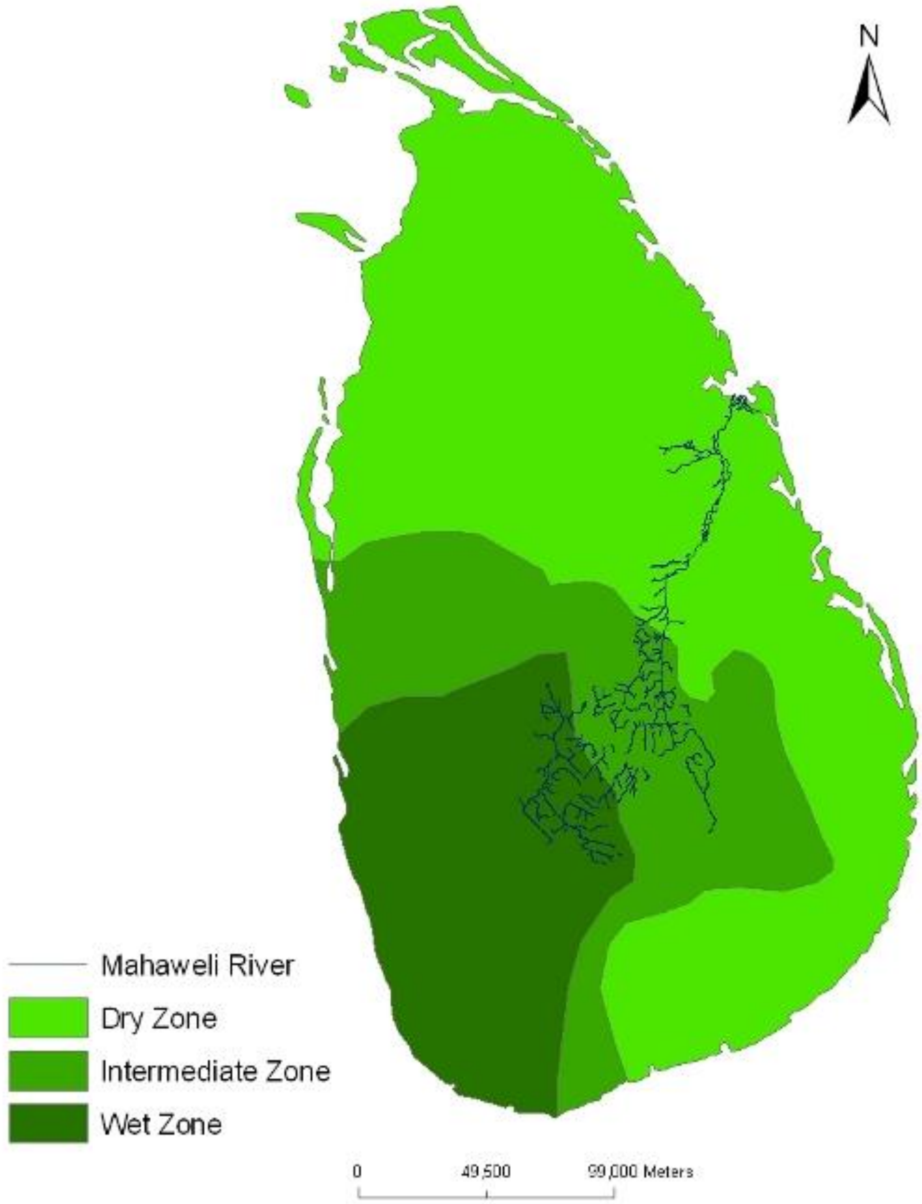


**Figure 1 Climate zones in Sri Lanka**

## 2.2. Water scarcity.

The areas that having average annual rainfall below the 2000 mm are suffering from the scarcity of fresh water and the available water is brackish. The *Mannar* district and a part of the *Hambanthota* district get an average of rainfall below 1000 mm and can be categorized as areas with severe water scarcity. Added to this unfavorable climatic condition, these areas do not have rivers or streams carrying significant amounts of water flows.

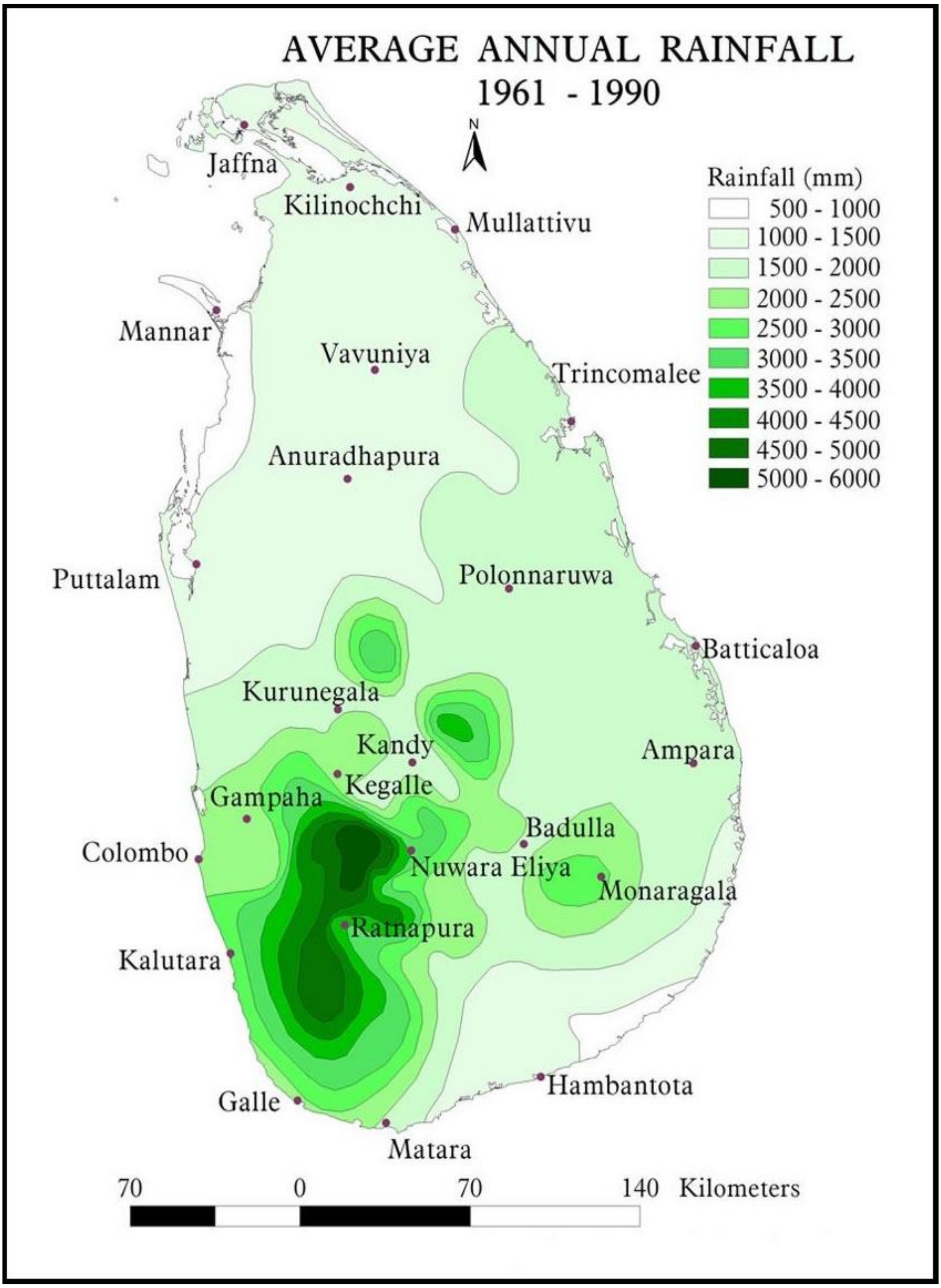


**Figure 2 Rainfall details**

If water replenishment from the rain is less than the ground extraction, there will be a scarcity. The over-extraction results in the drying out of the wells and it increases the brackish water concentration as well as salinity of the water.

The dry zone is the main contributor for the rice production in the country. The use of chemical fertilizer and other agrochemicals for weed and pest control are heavily used in these areas to maximize the yield. Therefore, chemical level of soil is high. This has resulted in high concentrations of heavy metal ions such as As, Cd, Cu and Zn in ground water, which is the source of drinking water. It is considered that Chronic Kidney Disease has been due to the continuous consumption of water with As and Cd.

## 2.3. Water resources

Mainly water resources of Sri Lanka can be categorized in to two main parts, namely surface and ground water.

**Surface water**

Surface water includes rivers, streams, lakes reservoirs, marshes and ponds. Source is rain water. It has been identified that 79% of the water of the Wet Zone and 51% from the Dry Zone is directly flows to the sea without any usage.

Table 1 Siri Lanka's water supply distribution among the different sources

| Population in 1998 | Urban 5.61 Mn | Rural 13.04Mn | Total 16.65 Mn |
|---|---|---|---|
| Served by piped water supply | 75% | 14% | 32% |
| Served by Dug Wells | 10% | 11% | 11% |
| Served by protected dug wells | 10% | 40% | 24% |
| Other | 5% | 35% | 33% |

(Source: MOFE, 2001)

**Ground water**

For the rural water supply, ground water is significant but in some part of country, such as dry zone and near coastal areas water quality is considerably low. The reasons for low quality are salinity, hardness, Fe, Mn, fluoride and agriculture chemicals.

The main source of ground water is rain water which seepage and collects to the ground.

10% to 30% of the rain fall is rest as ground water in other word 200mm-600mm per year has been converted to the ground water. It has been estimated that the ground water availability is as 7250 $m^3$ in the average of island wide.

Richest ground water resource is reported where the limestone aquifer are located. Jaffna peninsula and Puttalam district are having this limestone aquifers and it has been identified that the water potential goes up to 5 to 20 million cubic meters per year in that areas.

The ground water usage is comparatively increased in recent years for domestic and agricultural purposes. Mainly dug wells and tube well amount are getting high causing the ground water to low and increasing the contamination of water especially Mn and fluorides. About 40% of tube well has been abandoned due to fluoride problem.

In coastal areas, the increment of water extraction is above the sustainable level, causing the saline water coming in to the wells. For agriculture purposes some time huge amount of water extraction is done, It cause the increase of the salinity level of water in that area, creating scarcity of pure fresh water which use for drinking and domestic purposes.
Puttalam, Mannar, Paranthan, Kilinochchi, Anuradhapura and Mullativu areas are suffering from this shortage.

## 2.4. Health Risk related to the pure water quality

Five to six liters of potable water per day is considered as adequate for elderly person to satisfy both cooking and drinking purposes, one to two liters for drinking and other four liters for cooking purpose. Contaminated water consumption can lead to diseases some of which could lead to death. Some of the major health problems related to the consumption of contaminated water in Siri Lanka are described below.

### 2.4.1 Chronic kidney disease (CKD)

The North Central Province is one of the main paddy cultivation area in Sri Lanka. The chronic kidney disease (CKD) is common severe health issue in this area and in some village 3-4% of population is suffering from this disease. In the Anuradhapura district, which is part of north central province, 30% out of total mortalities are being accounted by CKD. The hospital statistics revealed that more than 8000 people undergone treatments. The cost for the treatment is high and most patients are farmers who cannot afford the cost.

One of the root causes for CKD has been identified as high Arsenic level in the water. The pesticides and other chemicals used in Agriculture remain in the ground causing arsenic deposition in to the ground. The populations who depend on the surface water have not been effected to the CKD. In this reason dwellers are not willing to consume the ground water and further some other people in other agriculture areas got fear and refrain from consuming ground water.

Figure 3 Some symptoms of arsenic toxicity source:. The Sundayleader

With reference to the World Health Organization investigation and evaluation of Chronic Kidney Disease of Uncertain Aetiology in Sri Lanka, the concentration of arsenic in urine in people with CKD was above levels known to cause oxidative injury to the kidney. In people with CKD from the endemic area, concentrations of **As** in urine and in finger nails were higher than those reported in people living in unexposed or low exposure environments. Total **As** level in urine is associated with chronic kidney disease in a dose response relationship especially when the level is greater than 10.74 µg/g. Co-exposure to As is likely to aggravate the effect of Cd on the kidney making the changes more significant than expose to Cd alone.

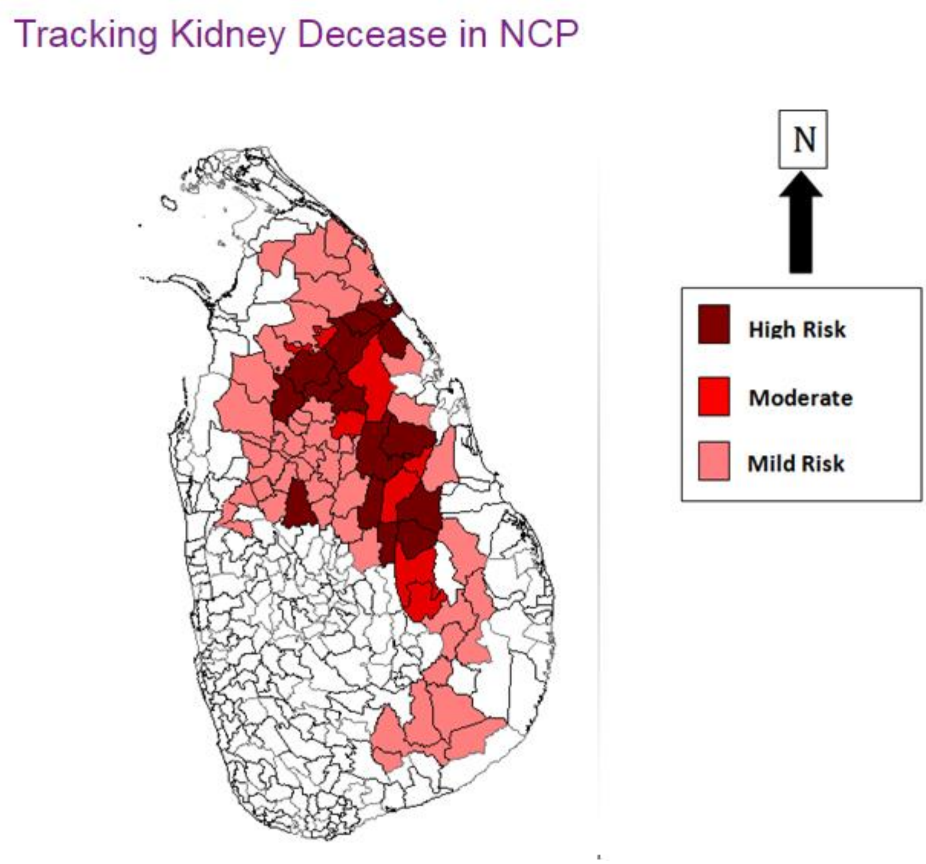


Figure 4 CKD affected areas (http://www.presidentialtaskforce.gov.lk/en/kidney.html)

As per the Map, the all severely affected area lies in dry zones and paddy cultivation areas.

### 2.4.2 Skeleton and Dental Problem

Table 2 Impact of fluoride on health

| Concentration of fluoride (mg/L) | Impact on health |
|---|---|
| Nil | Limited growth and fertility |
| 0.0-0.5 | Dental Caries |
| 0.5-1.5 | Promote dental health, prevent decay |
| 1.5-4.0 | Dental fluorosis |
| 4.0-10 | Dental/Skelton fluorosis |
| >10 | Crippling fluorosis |

Over a one million people and children are at a risk of dental fluorosis. To prevent this, only treatment is to reduce fluoride intake in long time basis.

In dry zones of Sri Lanka, the fluoride concentration is up to 10 mg per liter in the ground water. According to the above table 2 and figure 5, the dry zone has high risk for dental and skeletal fluorosis.

The low concentration of fluoride is good for health and increase the health of teeth and skeleton but excessively disclose to the fluoride can give severe adverse effects.

## Dental fluorosis

Figure 5 Dental Fluorosis

The mottling of dental enamel which is caused by exposure to the high concentration of fluoride is called as dental fluorosis. The risk of over exposure is affected age between three months to eight years.

In the beginning, the effect is unnoticeable and in cause of the time discoloration and or browning is visible and enamel get eroded and may be pitted, rough and hard to clean. The effect is permanent and or may be getting darker with the age.

The Dean Index is to classification of the dental fluorosis which introduced by dean in 18th century.

Table 3 Deans Index

Dean's Index

| Classification | Criteria – description of enamel |
|---|---|
| Normal | Smooth, glossy, pale creamy-white translucent surface |
| Questionable | A few white flecks or white spots |
| Very Mild | Small opaque, paper white areas covering less than 25% of the tooth surface |
| Mild | Opaque white areas covering less than 50% of the tooth surface |
| Moderate | All tooth surfaces affected; marked wear on biting surfaces; brown stain may be present |
| Severe | All tooth surfaces affected; discrete or confluent pitting; brown stain present |

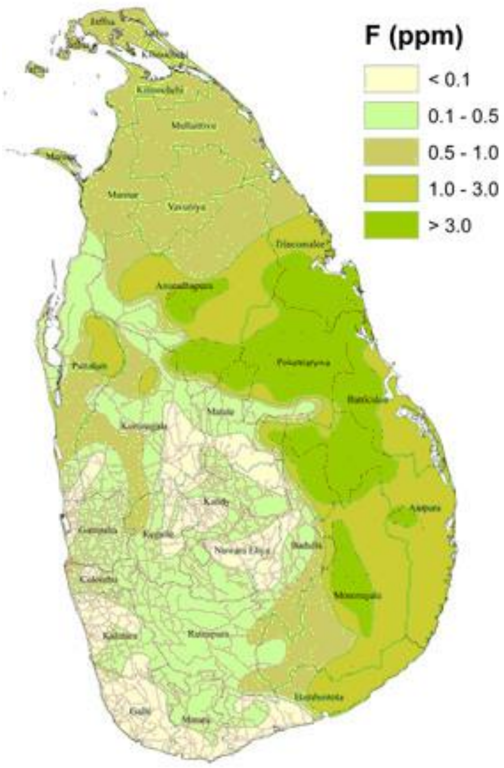


**Figure 6 Fluoride contamination in the ground water in different parts of Sri Lanka**

As per the figure 5, it can be observed that the high concentration of the fluoride is limited in to dry zones.

With reference to the research of *(1999), Dental fluorosis incidence in rural children residing in a high fluoride area in the dry zone of Sri Lanka*, the higher dental fluorosis scores children who are consuming water with high fluoride concentrations. According to the data they observed that 64 percent of the sample to be using fluoridated toothpaste which is another significant factor act together with drinking water. Samples of food items commonly consumed by these children and vegetables grown in their own gardens were analyzed to find the fluoride content. The data revealed most samples, in certain vegetables that grown in this area are contain high fluoride content. The hot and dry climate presence in this area may influence to the higher water consumption causing more fluoride intake.

### Skeletal Fluorosis

If the level of fluoride exposure continues to increase, a severe disease which affects to the bone which is known as skeleton fluorosis can occur. It can even affect the neurological system creating more complications. Same as mild fluorosis, this also increases with the increase of fluoride intake. Most of the time, this symptoms are visible in between the age of 30 to 50 years. Although skeleton fluorosis is not much attention in Sri Lanka, many people living in dry zone are suffering with bone disease that related to the skeleton fluorosis. Still no detail research have been carried out in dry zone and it need to be emphasized the need of such research.

## 2.6. Current situation of pure water supply in Sri Lanka and solutions

**Distributing potable water**

In Anuradhapura district which is not only highly fluoride area but also suffering from Chronic Kidney Disease, the National Water Supply and Drainage Board introduced a distributing of fresh pure water by using trucks and store in the tanks of 100 liters capacity for common usage of villagers.

Figure 7 Water distribution Anuradhapura Sri Lanka

Difficulties and Limitation

This is not a sustainable solution for the community water supply, Water distribution cannot be controlled and this is first come first serve basis.

**Brick filter to filtration of the fluoride**

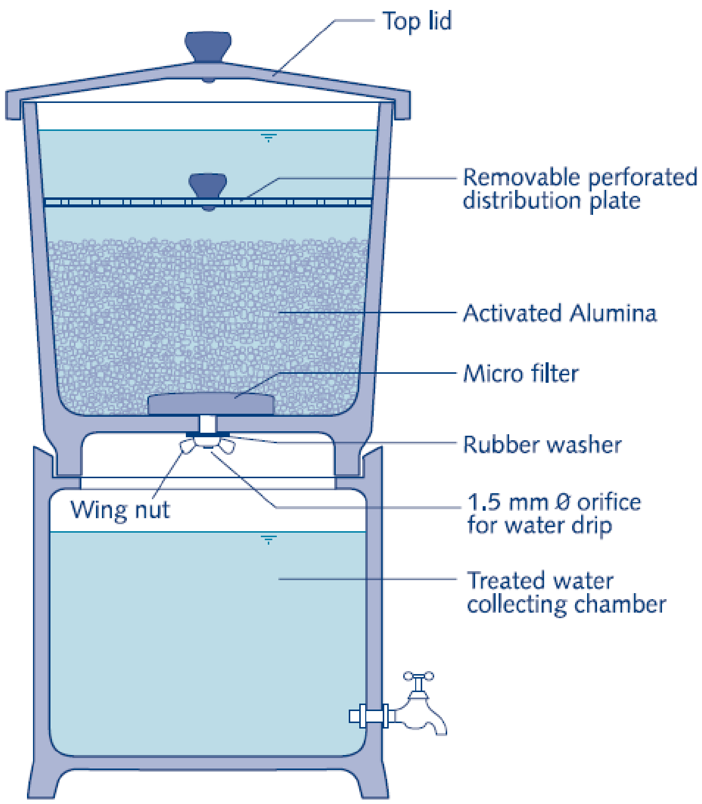


Figure 8 Brick filter

Freshly fired brick pieces are used for the removal of Fluoride in domestic defluoridation units. The brick bed in the unit is layered on the top with charred coconut shells and pebbles. Water is passed through the unit in an up flow mode. The performance of domestic units has been evaluated in rural areas.

This is not effective for high scale production commonly use in house hold item. Filtration efficiency varies from 85% to 25% for the time being from the beginning.

**Disadvantages and limitations**

The research for size and quantity of brick pieces not clearly done yet and people who have been using do not know about the refilling after use.

The quality cannot be measured domestically since they have no technology as well as the money to do that.

**Rain water Harvesting**

New research has been conducted related to this scenario, as example community water supply and sanitation project introduced rain water harvesting as an option for domestic water needs in several districts.

Lanka water Harvesting Forum (LRWHF) is an NGO which is promoting rain water harvesting in Sri Lanka. To promote the concept they use publications, media, awareness programs as well as training.

In 1998, the president directly involved to harvesting and after requesting, the National Water Supply and Drainage Board constructed 73 rainwater harvesting system in Kandy, Yatinuwara.

Presently there are twenty three institutions that have been involving in to this and nearly 32000 projects are in the operation.

**Figure 9 Rainwater harvesting Unit**

### Difficulties and limitations

The harvesting is only seasonal and this will not be good solution for Dry zone scenario because the water problem arises on the dry season.

The water may be infected with microbial activities and may be stagnate. So prevention method should be introduced in such cases.

### Fire wood Hearth Distiller

This is also popular in rural areas in Sri Lanka, especially in dry zone. This is made by using the clay and improved and modified version of "Anagi Uduna". The 73% of total energy produced from the combustion of fire woods have been utilized by the instrument to produce distilled water and distinct advantage of this is usage of waste heat from the cooking. Nearly 1kg of fire wood can produce 1.1 liters of drinking water and research revealed that normal house hold use 8kg of fire wood for daily cooking needs and hence the hearth can produce 9-10 Liters of water.

Figure 10 Fire wood Hearth Distiller

### Difficulties and Limitations

As the steam leaving the boiler (distiller) is not superheated, distilled water may contain trace amounts of the original water impurities.

Certain pesticides, volatile solvents and volatile organic compounds (VOCs) such as benzene and toluene, with boiling points close to or below that of water, vaporize along with the water as it is boiled in the boiler Such compounds will not be completely removed unless another process is used prior to condensation.

The boiling process generally deactivates microorganisms. If the distiller is idle for an extended period, bacteria can be activated and grown again.

In this chapter we have identified the desalination need for Sri Lanka by studying its geographic location, climate, rainfall information's, surface water and ground water distribution, different zones and locally available solutions for producing fresh water from brackish and fluoride ground water.

Also we have identified that the available solutions are not sustainable in large scale production.

As pointed out in the paper of Water for Drinking and cooking by Nihal Ferdinando. The Ground water should be treated by using advanced appropriate technology such as reverse osmosis, Membrane desalination, flash desalination and absorption techniques. It is much convenient if advanced portable units are introduced for community operation.

The government and privet sector involvement should be for this endeavor and promoting appropriate technologies is a must.

From next chapter on wards we will discuss in detail about the available technologies for desalination and among them, identify the sustainable appropriate technologies for Sri Lanka.

# 3. Future Water demand

3.1. Water demand Expectation in future.

The future potable water demand expectation is not so far predicted by government by or researchers. But we can predict it in indirect method by using population growth where we assumed population growth in only depend with potable water to get rough idea about future water demand.

Below data is referred from " A population projection of Sri Lanka" by W.indralal de silva.

**Table 4 The population growth prediction in"000"**

| Period | High | Standard | Low |
|---|---|---|---|
| 2016 | 21573 | 21186 | 20682 |
| 2021 | 22162 | 21580 | 20897 |
| 2026 | 22580 | 21804 | 20924 |
| 2031 | 22888 | 21883 | 20776 |
| 2036 | 23122 | 21841 | 20493 |
| 2041 | 23282 | 21712 | 20102 |
| 2046 | 23334 | 21465 | 19601 |
| 2051 | 23278 | 21104 | 18992 |
| 2056 | 23175 | 20656 | 18267 |
| 2061 | 23036 | 28145 | 17476 |
| 2066 | 22867 | 19590 | 16631 |
| 2071 | 22707 | 19030 | 15778 |
| 2076 | 22570 | 18480 | 14947 |
| 2081 | 22462 | 17914 | 14139 |
| 2086 | 22369 | 17416 | 13367 |
| 2091 | 22282 | 16910 | 12632 |
| 2096 | 22221 | 16437 | 11936 |
| 2101 | 22216 | 16012 | 11292 |

Research conducted on water use by different researchers have suggested water demand rates that vary from 20 to 50 liters per capita day (lpcd).

These figures are taken as the basic minimum lifeline values for human survival. However, in certain cases the lifeline values have been quoted as high as 100 lpcd. So in here we assumed it to the 100lpcd.

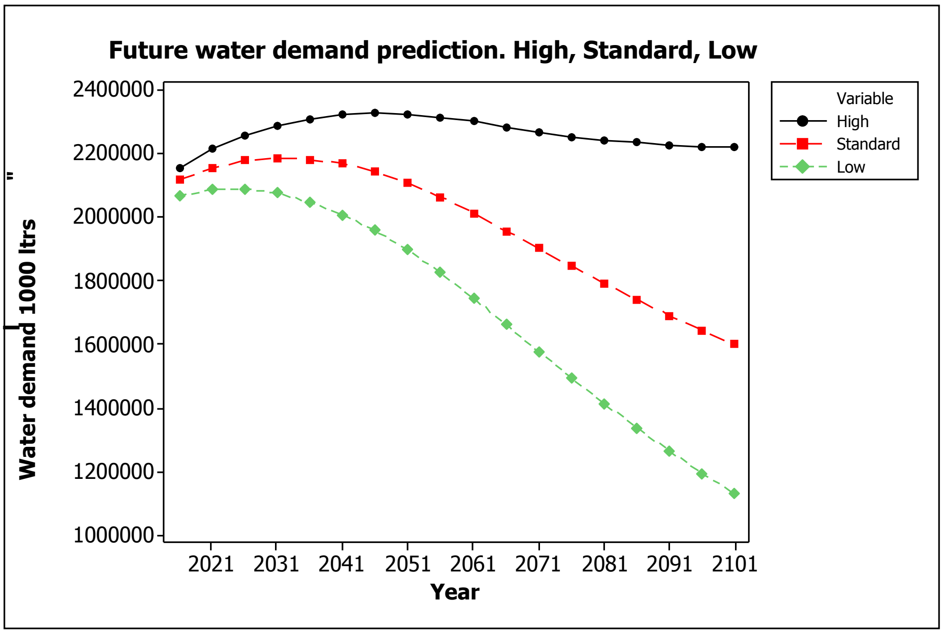


**Figure 11 Future Water Demand Prediction**

According to data predicted, 2031 will be the highest population and simultaneously higher water demand which is predicted as 2188300000 L (2188.3 Mn liters) subsequently 798729.5 million liter per annum or 798.7295 million $m^3$ per annum. Therefore we have to cater the demand on 2031 and Planning should be done in order to achieve that.

**Role of desalination for future water demand**

The role of desalination will be significant in future to cater the demand of water due to changing weather conditions as well as population growth. The existing water sources are getting polluted due to industrial and agricultural chemicals will also impact to increase the desalination needs as we discussed in chapter one.

The water supply basically need to be safe, reliable, adequate and continuous supply. The desalination will be satisfy that requirements but with a considerable amount of cost. Sri Lanka is a third worlds country therefor application of renewable energy is must for the const controlling purpose since srilanka is not producing any fossil fuels but imports.

# 3. The available desalination technologies in worldwide and Sri Lanka

Desalination generally refers to the process, which reduces the measure of dissolved particles in the water that fed to the process. It is known that usually seawater tastes extremely salty and it cannot be drunk or used for domestic purposes like washing and cooking in typical circumstances. If there is a possibility to reduce the salt concentration, the resulting water can be used for domestic purposes.

All waters, which are found in nature, contain dissolved particles such as sodium chloride, magnesium sulphate, calcium bicarbonate and a variety of other natural substances. Water that does not contain any dissolved matter tastes "flat" and unpleasant. Similarly, if the concentration of dissolved matter is too high, as an example seawater the water will tastes unpleasant. For usual drinking water supplies, the condition has to be in between these two extremes. Table 4 below shows the palatability of water with different concentrations of dissolved particles expressed as milligrams per liter (mg/l) or otherwise parts per million (ppm)

**Table 5 The palatability of water according to its concentration of total dissolved solids (WHO, 1984)**

| Palatability | Dissolved Particles (mg/l) |
|---|---|
| Excellent | <300 mg/l |
| Good | 300 - 600 mg/l |
| Fair | 600 - 900 mg/l |
| Poor | 900 - 1,200 mg/l |
| Unacceptable | >1,200 mg/l |

Table 6 Total dissolved solids and water types

| Description | Total Dissolved Solids (mg/l) |
|---|---|
| Potable water | <1,000 |
| Mildly brackish waters | 1,000 to 5,000 |
| Moderately brackish | 5,000 to 15,000 |
| Heavily brackish waters | 15,000 to 35,000 |
| Average sea water | 35,000 |

There is a wide variety in total dissolved solids in some seas and evaporative lakes, for instance, the Arabian Gulf has an average of dissolved solids content 48,000 mg/l and in Mono Lake in California, and there is 100,000 mg/l (National Research Council, 2004). The salinity of the Dead Sea is almost 250,000 mg/L. It is level about seven times as high as that of the ocean, while the surface salinity in the Arctic Ocean (to be precise the top 50 meters) can be as low as 20,000 mg/L (Johnson & Polyakov, 2001). The salinity is nearly 32500 mg/L in Indian Ocean where Sri Lanka is located. Water produced by desalination processes can be directly used (e.g, for makeup water in power plant boilers) or it may be mixed with water containing some dissolved particles and can be used for drinking purposes, irrigation, or other uses. Desalinated water is considered purer than the standards specified for drinking water thus if the water is intended for civic use, it can be mixed with water that includes higher levels of total dissolved substances. Pure desalination water is acidic and is consequently corrosive so it should be given additional treatment before being pumped to supply in order to produce noncorrosive slightly alkaline water.

## 3.1 Methods of desalinations of brackish or seawater

When the salt water freezes in winter seasons the ice which forms on the surface is fresh water. The freezing process force out the salts from the water therefore melting this ice will produce fresh water. This gives one method to create fresh water from seawater, a technique known as "Freeze Desalination". This process need heat energy and is one of a group of processes termed "Thermal Desalination".

Generally every desalination processes use technology of chemical engineering in which a saline water stream is supplied to the process equipment, energy as heat, pressure or electricity is applied, and two outputs are produced, a flow of desalinated (fresh) water and a flow of concentrated brine which must be disposed.

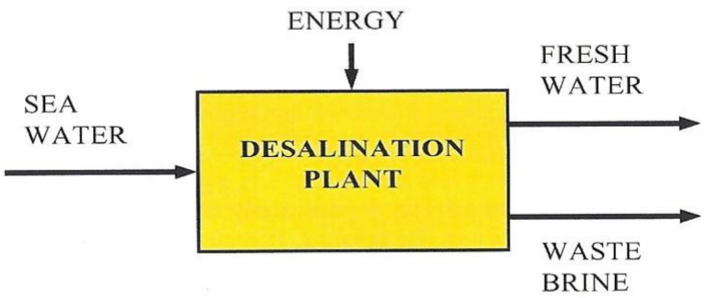


Figure 12 General scheme of desalination process

We can use two main groups of processes to reduce the concentration of dissolved particles in briny or seawater. They are thermal processes and membrane processes.

### 3.1.1 Thermal processes

Distillation is the simplest example of a thermal process. Saline water is heated to produce steam from the seawater, which is then condensed to generate water with a low dissolved salts concentration. This condensed water can then be used for domestic and industrial purposes or for irrigation. Several methods of distillation are currently used for desalination:

- Multi-stage flash evaporation/distillation (MSF)
- Low temperature thermal desalination (LTTD)
- Vapour compression distillation (VCD)
- Multiple-effect evaporation/distillation (MED) also known as long-tube vertical distillation (LTV)
- Solar desalination
- Membrane distillation
- Vapour reheat flash distillation

These three thermal processes use thermal energy to freeze and then melt the ice formed during the freezing stage:-

- Secondary refrigerant freezing
- Vacuum freezing
- Clathrate or hydrate formation process (not strictly a freezing process)

### 3.1.2 Membrane processes

Three membrane processes are currently in use:

- Reverse osmosis (RO)
- Forward osmosis (FO)
- Electro dialysis (ED or EDR)

### 3.1.3 Other processes

Other available desalination processes include:

- Ion exchange (IEX)
- Capacitive deionization using IEX membranes (qv. Voltea)
- Thermally regenerated IEX (Sirotherm, Bolto 1984; Chandra, 2009)
- Solar thermal ionic desalination (qv. Saltworks Technologies Inc)
- Solar desalination

Some of the IEX processes listed above are in the demonstration stage yet and still not widely used. Therefore, those methods are not studied any further in this report because report scope is limited to research appropriate technologies for Sri Lanka.

## 3.5 Pretreatment of feed water to desalination plants

The water fed to a desalination plant will generally consist of other impurities other than dissolved particles such as sludge, algae, bacteria and other forms of small plant and animal species. An especially important form of impurity is the Transparent Exo polymer Particles (TEP), which was, only identified relatively recently (Alldredge, 1993). TEPs are produced from dissolved polymers exuded by phytoplankton and bacteria, are found in the sea and fresh water in concentrations of 28 to 5000 ppm, and vary in size from 2-200 micrometers. They generally exist in many different structures from amorphous blobs, filaments, clouds, sheets or clumps and occasionally recognizable as remains from wrecked plankton (Berman, 2005). TEPs can be an important source of nutrition for microorganisms including bacteria.

These impurities, and mostly TEPs, can have an undesirable effect on desalination processes by polluting surfaces and blocking membranes. This can be particularly harmful in the case of reverse osmosis (RO) by allowing biofilms (Films of bacteria) to extend on the surfaces of membranes resulting in a drop of the flow rates. This can reduce the effective life of the membranes and cause an increase in the cost of operation. Thus, it is necessary to include a pre- treatment phase in desalination plants as shown in Figure 11below.

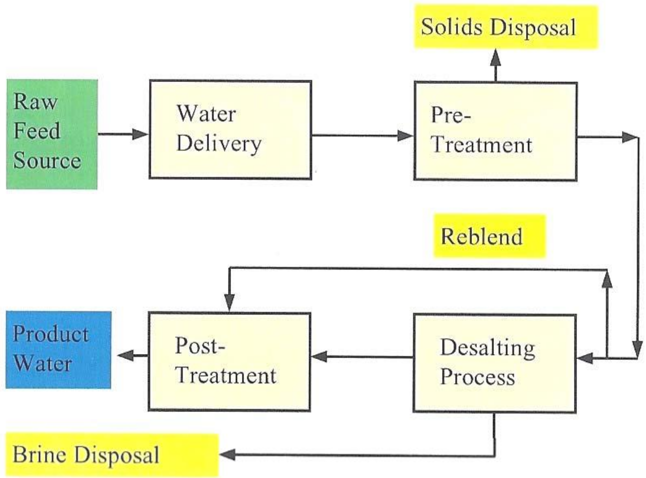


**Figure 13 Simplified flow diagram of the desalination process**

In general pretreatment will consist of some form of coagulation process which cause the particulate impurities, especially TEPs, agglomerate into larger particles which can be removed, for instance by filtration.

## 3.6 Post treatment of the produced desalinated water

Thermal desalination processes produce water, which includes a very low dissolved content although they produce distilled water. As mentioned earlier, water devoid of dissolved substances tastes "flat" and unpleasant, therefor some dissolved solids and air must be added back to the desalinated water, if the water is to be used for drinking purposes. This task is generally completed by blending a proportion of the feed water with the desalinated water (Figure 02), aerating the water and adding some chemicals to decrease its corrosiveness. Disinfection will be required prior to the water can be put into the water mains supply network.

Membrane processes decrease the salt content of water but do not reduce it to the low levels as distillation processes therefore reblending is generally not required, even though some form of posttreatment may still be required such as reaeration, corrosion control as well as disinfection.

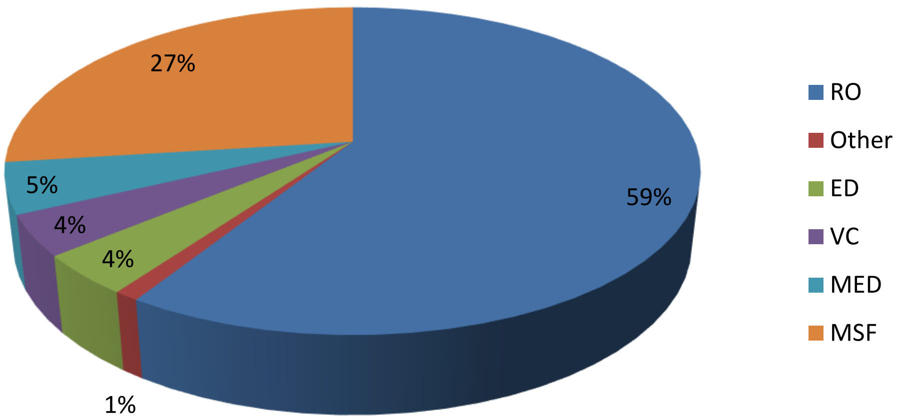


**Figure 14 Percentage of production of world desalinated water from the diverse processes (based on Cooley et al, 2006 & Awerbuch 2009)**

## 3.6 What are the ranges of concentrations to which different desalination processes can be applied?

Seawater is shown in Table 6 as having an average dissolved substances concentration of 35,000 mg/l but this can be different quite considerably as shown in Table No 7 .

**Table 7 Different salinities in seawaters**

| Sea | Approximate Salinity in mg/l |
|---|---|
| Red Sea | 40,000 |
| Mediterranean Sea | 38,000 |
| Average seawater | 35,000 |
| Black Sea | 18,000 |
| Baltic Sea | 8,000 |

The ranges of concentration of dissolved particles in the water which different processes can be applied economically are shown in Table 4 below.

Table 8 Range of concentrations to which different desalination processes can be applied.

| Process | Concentration Range in mg/liter |
|---|---|
| Ion exchange | 10 – 800 |
| Reverse Osmosis | 50 - 50,000 |
| Electro dialysis | 200 - 10,000 |
| Distillation processes | 20,000 - 100,000 |

## 3.8. Explanation of thermal desalination processes

**. Multi stage flash evaporation/distillation (MSF)**

In multi stage flash evaporation, the saline water, mainly sea or brackish water is heated and evaporated. Then the pure water is produced by condensing the vapour. When the water is heated in a vessel both the pressure and temperature increase and the heated water passes to another chamber at a lower pressure, which causes vapour to be produced. The vapour is led off and condensed to pure water using the cold seawater, which feeds the first heating stage.

Then the concentrated brine is directed to a second chamber which is lower pressure and further water evaporation takes place and condensed as before. The process is repeated all the way through a series of vessels or chambers until atmospheric pressure is reached. N ormally, a MSF plant may contain about 4 to 40 stages. Multi-stage flash evaporation is considered the most reliable, and is possibly the most widely used of the three major distillation processes. This principle is shown in Figure 13 below, which shows just three stages while in commercial plant many more stages are used.

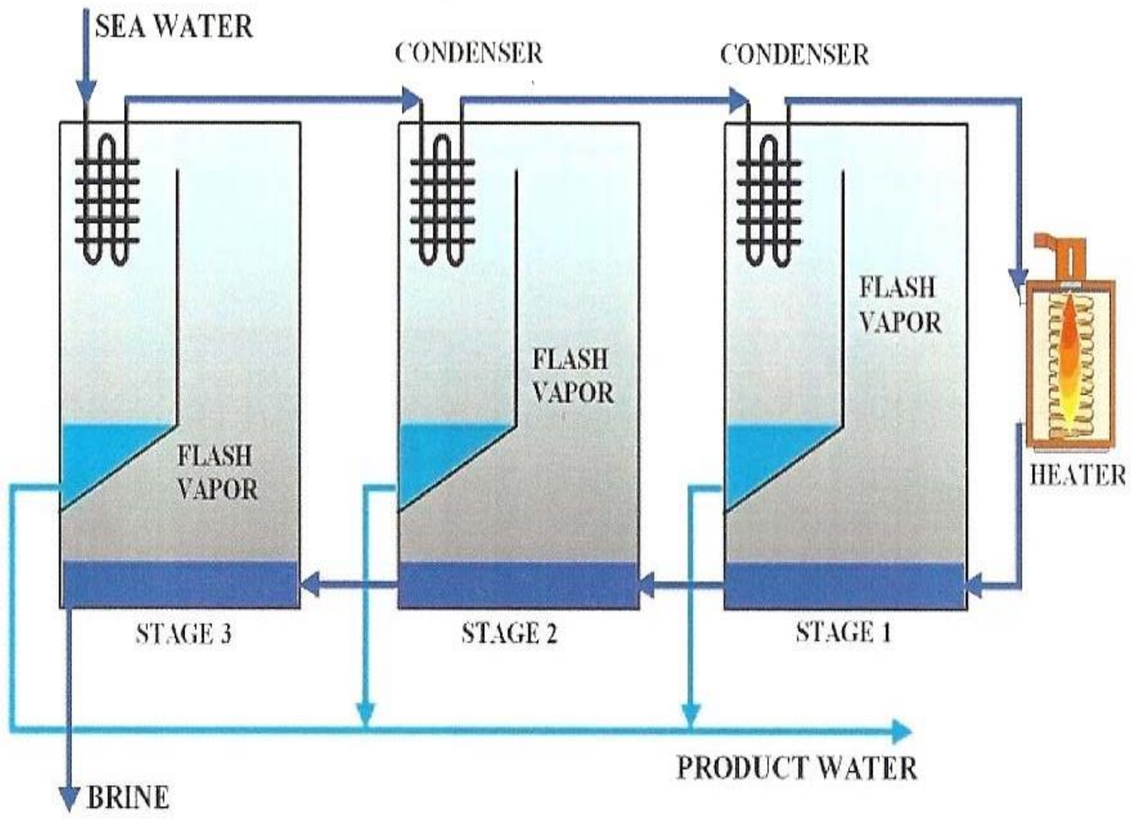


**Figure 15 Simplified illustration of the multi-stage flash evaporation process**

## 2. Multiple effect evaporation/distillation (MED)

Multiple effect distillation (MED) is also known as long tube vertical distillation (LTV). I t is similar to multi-stage flash evaporation in principle, except that steam is used to heat up the seawater in the first stage and the resulting vapour is used in successive stages to evaporate the water. The seawater/brine is used to cool and condense the vapour in each consecutive stage therefore the temperature steadily falls across each stage of the process.

As in multi stage flash evaporation, several stages are used in commercial plants. At the time, it began operating the MED process is used for the largest desalination plant in the world in Jubail, Saudi Arabia, producing over 800,000 $m^3$/day. The first plant began operating in April 2009. The principle of Multiple-effect distillation is shown below in the Figure 14.

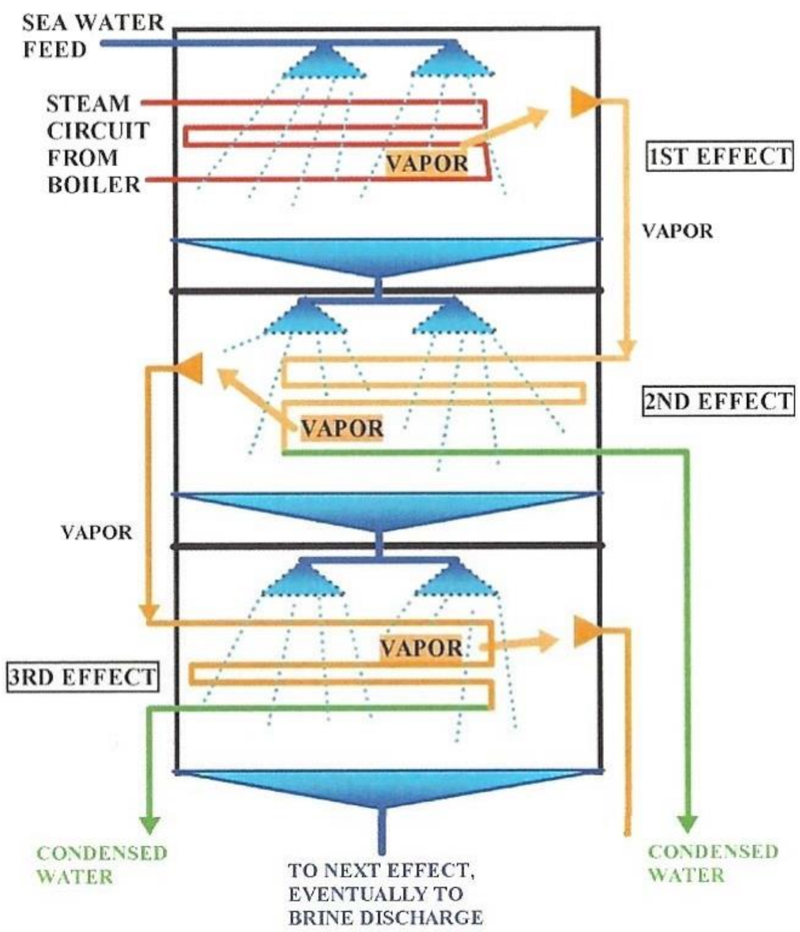


Figure 16 Simplified diagram of the multiple effect distillation process

### 3.9 Vapour compression distillation (VCD)

Steam is produced from the seawater using a heat source and the vapour is then compressed by means of a compressor. Bec au se of this compression, the temperature and pressure of the steam is increased, to be precise the work done in compressing the vapour is changed into heat. The incoming seawater is used to cool the compressed steam and the seawater is heated further generating more steam. The theory is shown in Figure 15 below.

Vapour compression distillation is usually used when the requisite for desalinated fresh water is comparatively small such as in small communities, holiday resorts or in ships. VCD was the second most commonly used process for desalination in Australia in 2002 after reverse osmosis accounting for about 18% of Australia's national desalination capacity (URS Australia, 2002). Yet, since then there has been a rapid expansion in the use of reverse osmosis, majorly for the large plants which are coming on line.

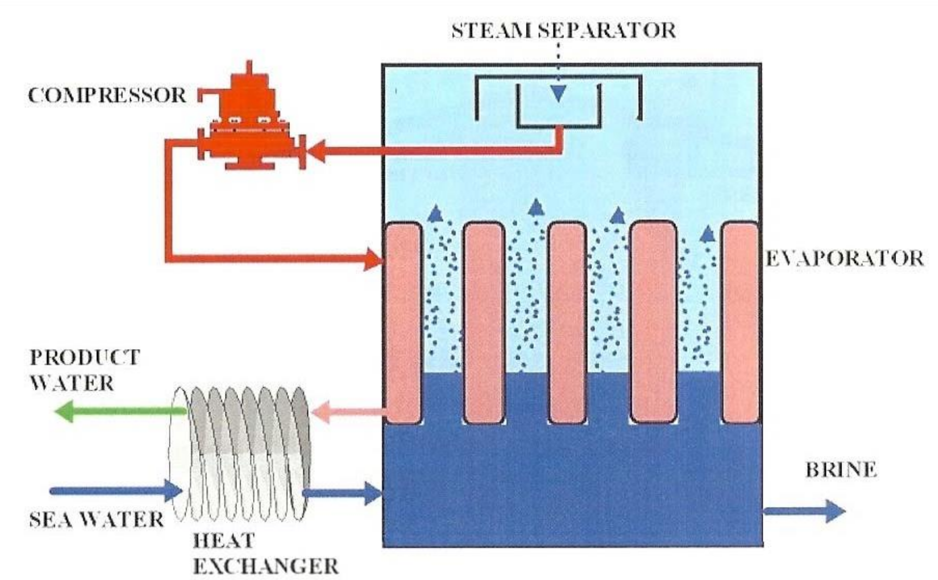


Figure 17 Vapour phase compression desalination diagram

## 3.10 Solar desalination

Formerly solar distillation was a technology that is simple and suitable only for small outputs and it has been practiced for a long time. Here the heat energy from the sun is utilized to heat the seawater in a glass covered tank resulting part of the water to evaporate. That vapour is then condensed on a glass cover and the resultant fresh water is collected as shown in the diagram in Figure 16 below. This is a low cost system and is not suitable for large scale production of water. Troubles can occur from the growth of algae on the underside of the glass cover, and fine sealing is required or else the vapour and heat can escape reducing the efficiency of the system.

A well maintained solar plant still generates about 8 liters for every square meter of glass, thus the area required for about 4 people would be 130-260 square meters.

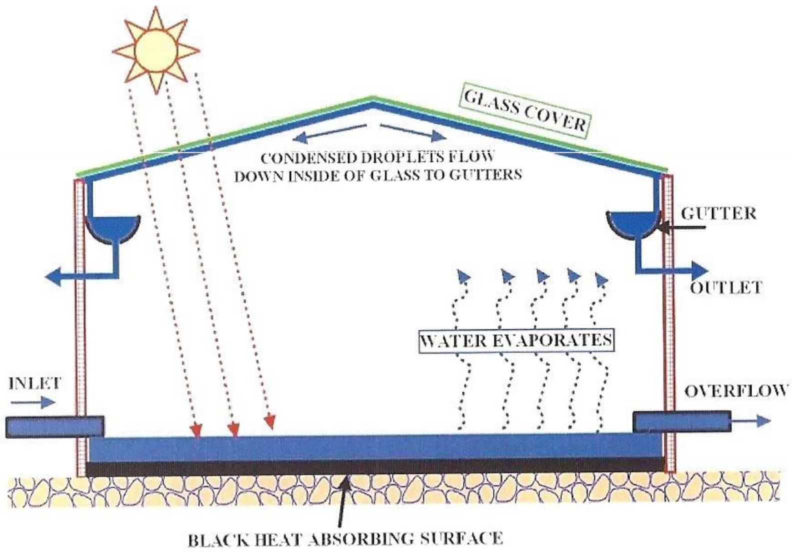


Figure 18 : Diagram of a solar distillation system

However, in recent years, there has been considerable development in large scale solar systems for power generation, both thermal and photovoltaic. Thermal power stations offer an opportunity for solar desalination but despite extensive R&D in Australia, the USA and Spain, where a pilot plant is producing 72 $m^3$/day, (Blanco et al, 2008), there are no large-scale plants yet in operation. Concern over global warming has either generated considerable interest in the use of solar energy (now frequently referred to as concentrated solar power or CSP) for desalination processes, directly, as in the case of solar distillation, or using humidification.

In recent years, there has been rapid growth in the use of solar energy in desalination, for example the use of photovoltaic cells to generate electricity for RO plants and in the use of solar energy for the called multiple effect humidification (MEH) process. A MEH pilot-plant has been installed in Jeddah, Saudi Arabia, which successfully produces 5$m^3$/day of desalinated water (Müller-Holst, 2007).

## 3.11 Vacuum freeze desalination (VFD)

As previously discussed, when saline water freezes, the salts dissolved in the water are excluded from the ice. Cooled saline water is sprayed into a vacuum chamber at a pressure of about 0.004 atmospheres. Some of the water flashes off as vapour removing more heat from the water causing ice to form. The ice floats on the brine and is washed with fresh water, melted and the fresh water (which is less dense than the brine) flows out of the washer melter as shown in the diagram in Figure17. In theory, freeze desalination has a lower energy requirement than other thermal processes and little susceptibility to the scaling problems, which can affect distillation processes. Although a few small plants have been built in the last 40 years the process has not yet been commercially developed (URS Australia, 2002)

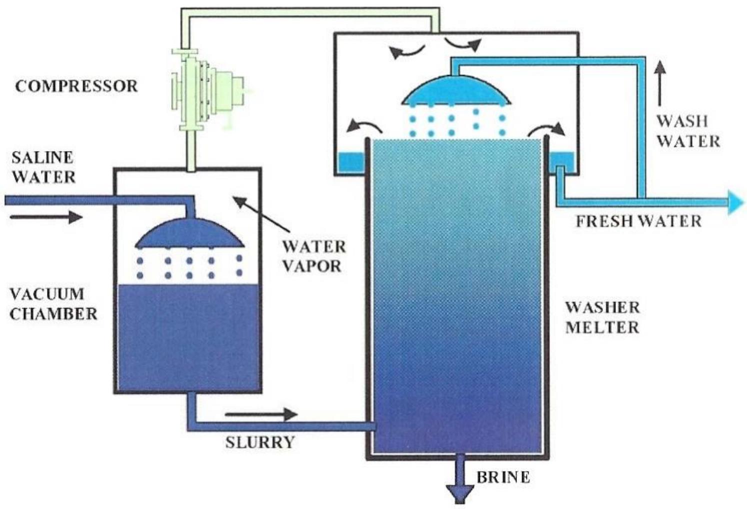


Figure 19 Vacuum freeze desalination schematic diagram

## 3.12 Secondary refrigerant freezing (SRF)

In this variant of freeze desalination, a liquid hydrocarbon refrigerant such as butane, which will not mix with water, is vaporized when in direct contact with the saline water consequently producing slurry of ice in brine. The vaporized refrigerant is taken off , compressed ,cooled in the melter and recycled to the freezer/crystallizer. The slurry of ice is taken off, washed and passed to the melter. The advantage claimed for secondary refrigerant freeze desalination is an even lower energy requirement than for freeze desalination, and low susceptibility to scaling and corrosion. The SRF process was considered by the Water Resources Board as a possible method for supplementing water supplies in England and Wales in the 1970s but despite some development work, it never achieved commercialization.

## 3.13 Clathrate or hydrate formation process

In this process, the brackish water is mixed with a hydrocarbon to generate hydrates or clathrates. A hydrocarbon molecule is included in a "cage" of water molecules in a clathrate making a solid ice phase as shown in Figure 18. The figure shows a methane ($CH_4$) molecule held in a "cage" of molecules of water ($H_2O$). The "cage" or hydrate generates ice which like crystals, which do not include a bit of the salts present in the seawater where in the hydrate produces.

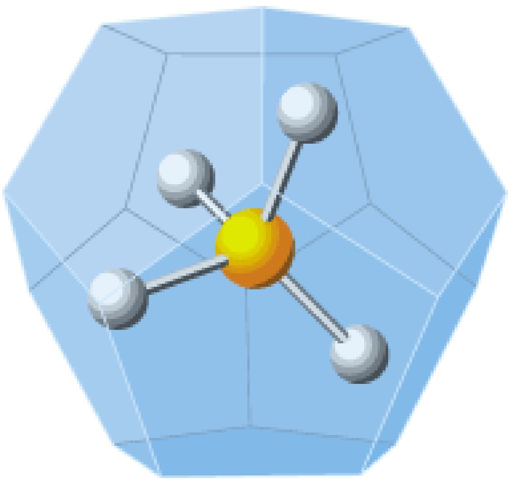

**Figure 20 A methane (CH4) molecule in a "cage" of water (H2O)molecules**

In 2008, Mouchel and Water Science won a Global Water Award for their work on developing this process. The technology is still under development but if it can be made to work on a larger scale, it could offer a cheap alternative to the traditional thermal and membrane desalination processes in future.

## 3.14 Membrane Desalination

**Electro dialysis (ED/EDR)**

The salts in seawater are formed with positive ions (cations) and negative ions (anions). For example, common salt (sodium chloride, NaCl) produces positively charged sodium ions and negatively charged chloride ions when dissolved in water.

$$NaCl = Na^{+} + Cl^{-}$$

Electro dialysis makes use of a stack of ion exchange membranes, which can discriminate positive and negative ions. Due to direct electrical current (DC) the positive sodium ions move across a cation membrane and the negative chloride ions go through an anion membrane as shown in Figure 19. The arriving saline water is therefore directed into two streams, one of concentrated salt water and one of desalinated water. Industrial electro dialysis plants consist of stacks of hundreds of membranes. Uncleanness of the ion exchange membranes can take place and this can be overcome to some extent by reversing the direction of the DC current. This method is called as electro dialysis reversal (EDR).

ED was the first membrane desalination procedure to accomplish commercial success. One of the first commercial units in the world was installed in Tobruk in Libya in 1959 and the British Company William Boby Ltd. conducted it. The plant had an output of 55m$^3$ per day and was successful in both technically and economically. Even though ED is still used today, it has been surpassed by reverse osmosis (RO) as the preferred membrane desalination process.

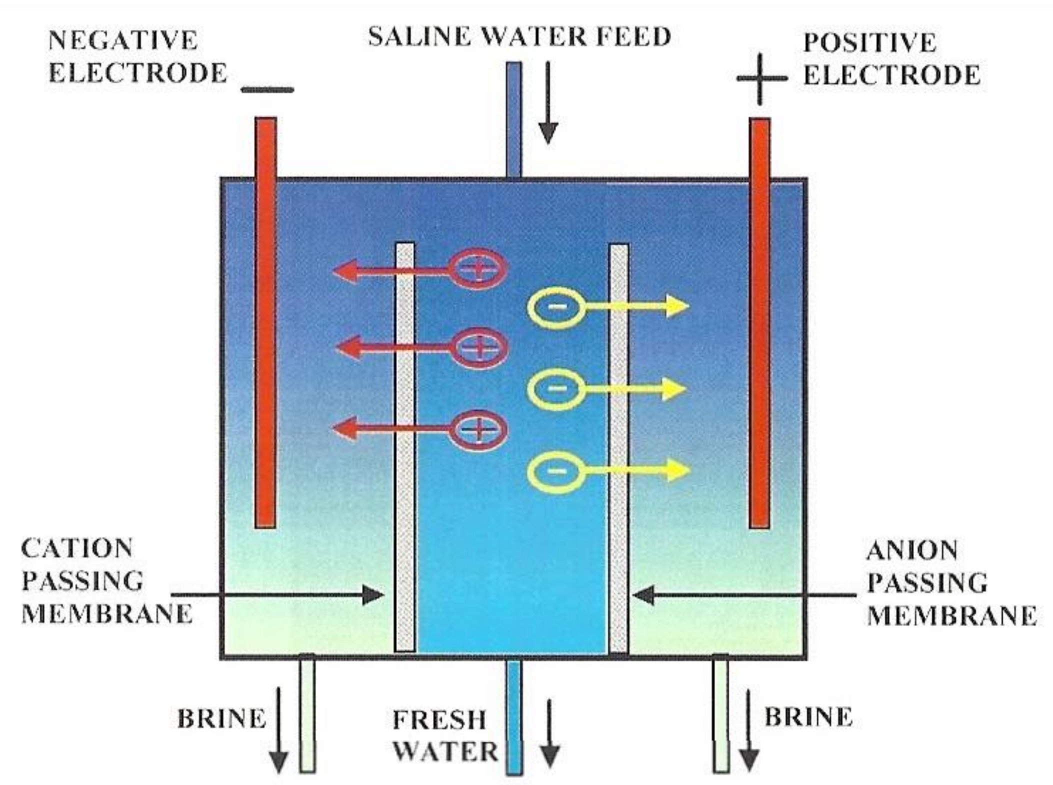


Figure 21 Diagram of an electro dialysis cell

**Reverse osmosis (RO)**

In Osmosis, water passes through a semi permeable membrane from a low-concentration solution into a high concentration solution. This process is normally occurred in plant and animal tissue including the human body (e.g. The secretion and absorption of water in the small intestine). If a pressure is applied to the high concentration part, the reverse process occurs where water diffuses through the semi permeable membrane from the high concentration solution into the low concentration solution. This is called reverse osmosis and shown in the diagram in Figure 20 below.

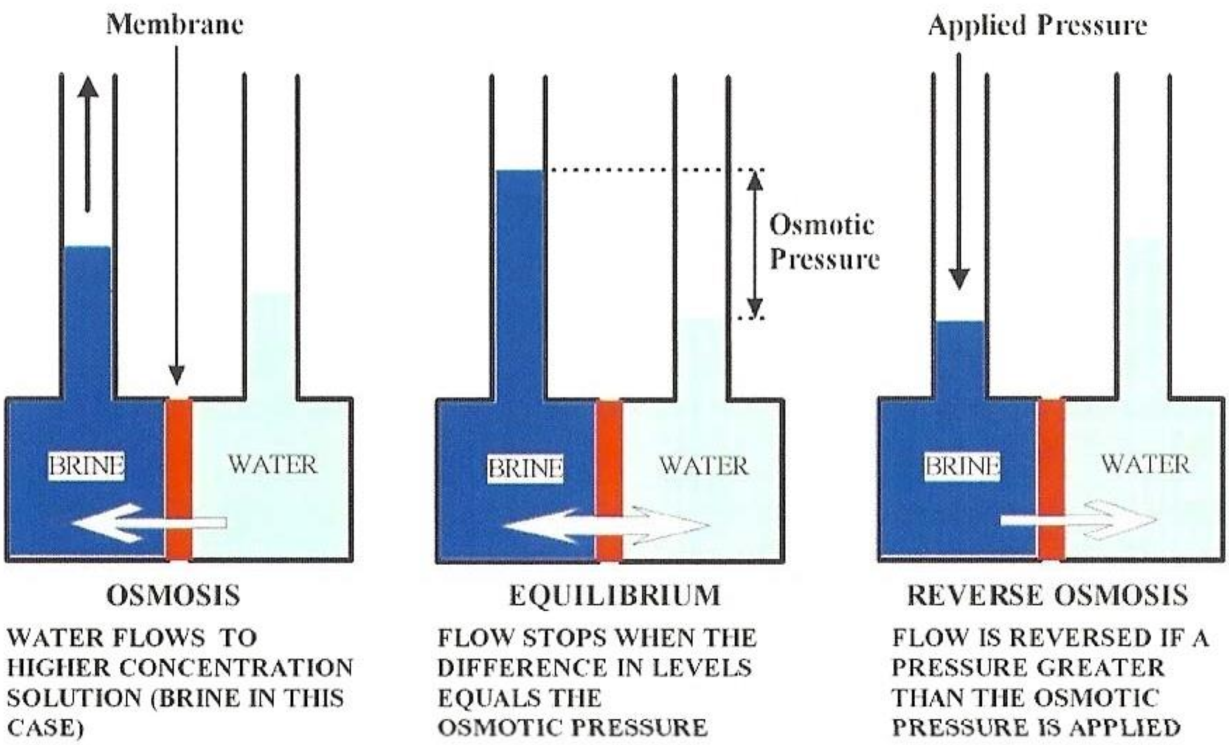


**Figure 22 Osmosis and Reverse Osmosis**

When seawater is pumped under pressure across the surface of the membrane, water molecules disperse through the membrane leaving its brine content behind which cause to produce a concentrated brine solution on the feed side of the membrane and fresh water on the low pressure side. The brine solution is discarded as wastewater and is considered to be in the region of 10% - 50% of the feed water depending on the salinity and pressure of the feed water. Membranes for RO process are manufactured from modern plastic materials in either sheets or hollow fibres. In a modern RO plant the membranes are grouped together in units which are linked together according to the size of plant required. RO plants use four different configurations of membrane, that is to say tubular, flat plate, spiral wound, and hollow fiber.

Reverse osmosis is becoming the most extensively used method for the desalination of brine and seawaters. The graph in Figure 21 below shows the increasing growth in capacity of desalination plant for membrane and thermal processes (most of which are now RO systems).

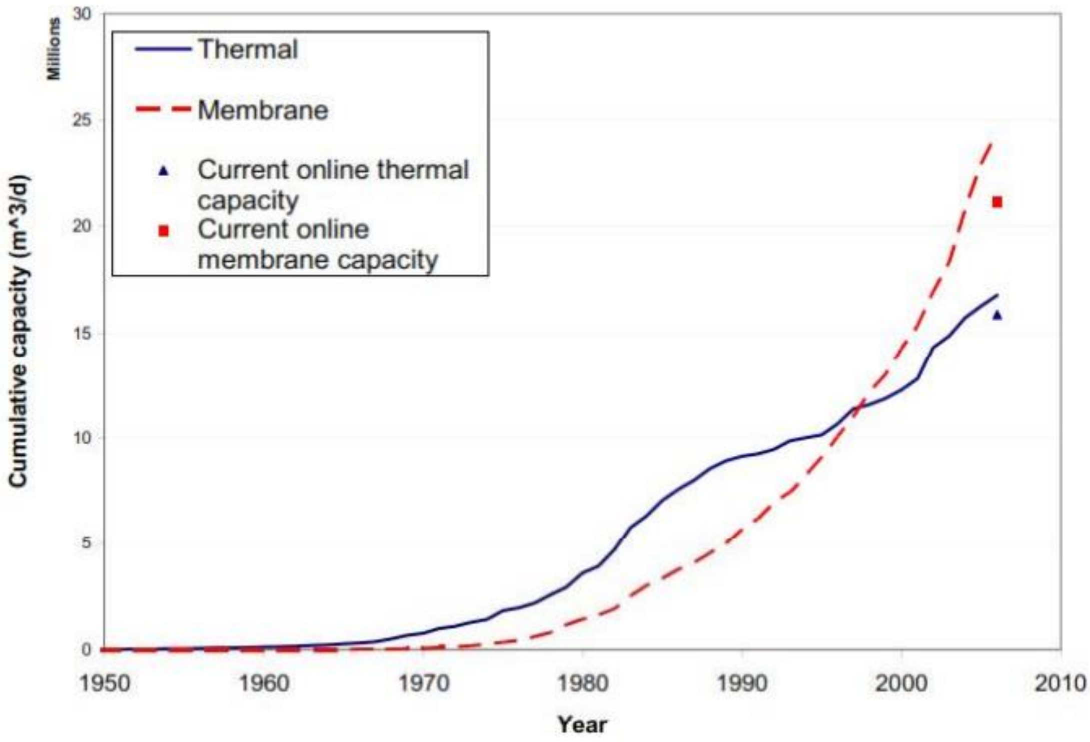


**Figure 23 Graph showing the cumulative growth of thermal and Membrane desalination capacity (National**

RO plants vary from small domestic components for use either in the home or on small ships to large industrial and municipal units for supplying a filtered water for communities. The world's largest RO desalination plant has been installed in Hadera in Israel. The plant, which came on line in May 2010, has a capacity of 127 million m³ of desalinated water per year (348,000m³ per day) and is one of large scale RO seawater desalination plants along the Mediterranean coast of Israel. RO is naturally an energy intensive process requiring in the region of 5-25 kWh/m³ for the desalination of seawater (Ravilious, 2010, Schäfer et al, 2004).

Pretreatment is a necessary part of a RO desalination plant because membranes are prone to be polluted from suspended particles and microorganisms in the feed water. The Transparent Exopolymer causes such problems.

**Forward osmosis (FO)**

Figure 22 illustrates how a high concentration solution will draw water across a semipermeable membrane. It is possible to draw water from brine through a membrane by placing a sugar solution on the other side of the membrane

then normal(forward) osmosis occurs thus diluting the sugar solution but leaving the salt behind on the other side of the membrane. The sugar
solution can then be used drinking purposes. This method is used by the army and in natural disasters when drinking water supply is a problem. In a commercial plant, a strong solution of ammonium carbonate is used instead of sugar solution and water is drawn from the salt solution into the ammonium carbonate solution. Then the ammonium carbonate solution is heated where the ammonium carbonate is eliminated as ammonia gas and carbon dioxide gas and pure water is left behind. The gases are recollected and recycled (McCutcheona et al, 2004). The principle of the forward osmosis process is shown in Figure 14.

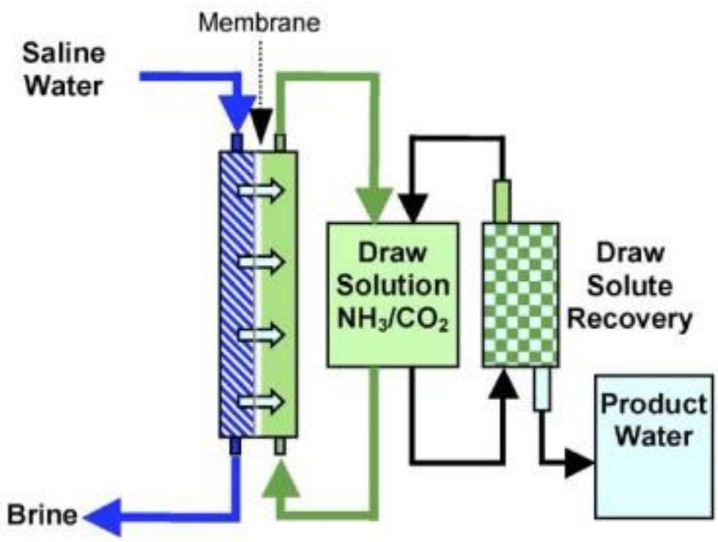


**Figure 24 Schematic diagram of the forward osmosis process**

(Semiat, 2008)

# 4.Available desalination technologies in Sri Lanka and the analysis of cost and technologies.

The practical application is only limited to RO plants in Sri Lanka other than the conventional Methods. The thermal desalination is not in practical use but small to medium scale RO plants available in throughout the country. The analysis of plant energy and  cost details are shown in below.

**Jaffna Delf island RO plant analysis**

The first sea water to fresh water plant had been successfully installed in Delft island in Jaffna peninsula. The project is funded by ADB. 4530 of residents are getting the benefit of the novel plant otherwise they would have  defended on the water which is transported by boats from Jaffna 30Km away.

Figure 25 RO Plant- Delf Island

### Table 9 Delf RO cost analysis

**SUPPLY & INSTALLATION OF 2 X 50 M3/DAY DAILY PRODUCTION CAPACITY (12 HRS OPERATION) SWRO PLANTS WITH ANCILLARY WORK FOR DELFT RWSS**

**Cost of Operation of 2 x 50 Cum/12Hrs. Operation RO Plants for 8 Years, CEB Mains Supply.**

**Name of Bidder:**

| No | Description | Unit | Quantity | Power kWh/cum. of Raw/ **Treated** Water | Chemical Consumption rate kg or lit / Cum. of **Treated Water** | Cost of Chemical/ Consumables/ Power **(Delivered at Site)** [LKR / kg or lit or kWhr] | Annual Production of Treated Water / (Cum.) | No. Hours of Operation Per Year | Cost for 1 Year (LKR) (Duty Paid & Delivered to Site) | Cost for 8 Year (LKR) (Duty Paid & Delivered to Site) |
|---|---|---|---|---|---|---|---|---|---|---|
| **A** | **B** | | | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
| **1.0** | **Replacement Cost (for SWRO Plant, other pumps and equipment from Intake to Treated Water Pump ) for 8 years** | | | | | | | | | |
| 1.1 | Membrane | Nos | 20 | | | | | | | 2,490,000.00 |
| 1.2 | Other Spares | Lump sum | 1 | | | | | | | 4,515,500.00 |
| 1.3 | Any other replacement-cartridge Filters | Nos | 672 | | | | | | | 600,000.00 |
| **2.0** | **Operator Maintenance (staff cost)** | **Nos** | **2** | | | | | | **480,000.00** | **3,840,000.00** |
| **3.0** | **Chemical Cost (for SWRO Plant, other pumps and equipment from Intake to Treated Water Pump)** | | | | | | | | | |
| 3.1 | Dosing Chemicals | | | | | | | | | |
| | Dosing Chemical # 1- SBS | **kg** | | | 0.012 | 286.00 | 36500 | | 125,268.00 | 1,002,144.00 |
| | Dosing Chemical # 2-Anti-scalant | **L** | | | 0.00646 | 1,080.00 | 36500 | | 254,653.20 | 2,037,225.60 |
| | Dosing Chemical # 3 -Ca(ClO)2 | **Kg** | | | 0.00279 | 680.00 | 36500 | | 69,247.80 | 553,982.40 |
| 3.2 | Chemical for Cleaning (Specify Name) | | | | | | | | | |
| | Cleaning Chemical # 1 - GE MCT 103 | **kg** | | | 0.00164 | 1,840.00 | 36500 | | 110,142.40 | 881,139.20 |
| | Cleaning Chemical # 2 -GE MCT 411 | **kg** | | | 0.00164 | 1,750.00 | 36500 | | 104,755.00 | 838,040.00 |
| **4.0** | **Power Cost (for SWRO Plant, other pumps and equipment from Intake to Treated Water Pump)** | | | | | | | | | |
| 4.1 | RO Plant, all pumps and equipment | | | 4.85 | | **12.50** | 36500 | 4380 | 2,212,812.50 | 17,702,500.00 |
| 4.2 | Yard lighting/ (kWhr/hr) | | | 0.04 | | **12.50** | 36500 | 4380 | 18,250.00 | 146,000.00 |
| | Add CEB Fixed charges | | | | | | | | | |
| | Avg. Energy Charge/ (LKR/ kWhr) | | | | | **12.50** | | | | |
| | Fixed Charges/ (LKR/ month) | | | | | **3,000.00** | | | 36,000.00 | 288,000.00 |
| | Max. Demand Charge/ (LKR/month) | | | | | **1,000.00** | | | 12,000.00 | 96,000.00 |
| | | | | | | | | Total | | 27,385,031.20 |
| | | | | | | | | Cost Per Year | | 3,423,128.90 |
| | | | | | | | | Cost Per Day | | 9,378.44 |
| | | | | | | | | **Cost/Cum** (without replacement cost) | | **93.78** |
| | | | | | | | | **Cost/Cum** (with replacement cost) | | **119.83** |

**Note:** If any of the chemical consumption is given **per m3 of Raw water basis,** then the annual cost has to be calculated by **multiplying the total quantity of Raw water pumped.**

**Daily KWh Consumtion assumed for unit cost calculation =** 485kWhr

Table 10 Cost summary

| Summary of cost | |
|---|---|
| Total cost for plant installation | 69Mn |
| Operation cost | 34.2Mn |
| Life time | 25 years |
| Total cost | 103.2Mn |
| Daily capacity | 100m3 |
| Cost per cubic meter in Rupees | Rs.109 |
| Cost per cubic meter in US $ | $0.72 |

Note: Project life time considered as 10 years

Average cost per liter is Rs. 0.10

TECHNICAL SUMMARY

Feed Flow: 125 m3/Day (12 hours operation)

Product Flow: 50 m3/Day (12 hours operation)

R0 Main Skid Size: (120W X 580L X 190Ht.)cm

Main Skid Weight (Gross): 2,500 kg

Power Supply: 400VX 3-Phase X 50Hz

**Solar Distillation**

A Prototype testing of solar still was carried out by Ecologic Pvt Limited and daily harvesting details as follows but they have only carried out out put measuring for given prototype still but not a deep research varying or measuring the other factors.

Figure 26 Solar Desalination prototype test :Wattala Sri Lanka

The covering surface is $2.5m^2$ and 2 collection slots at the both end of the Solar still direct the distilled water for collection.

Building Cost for Solar still is Rs.25000/=(172 US $)and this can be used for house hold potable water application without very low maintaining cost.

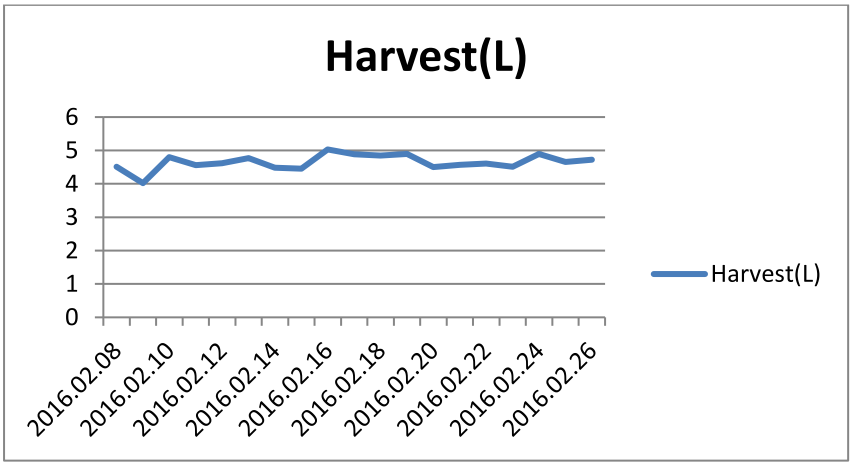


Figure 27 Harvest of Solar Distillation

Approximation method of yielding formula is

$$Q = \frac{E \times G \times A}{2.3}$$

Where Q is daily out put (Liters/Day)

A is area of Solar still

G is solar irradiation($MJ/m^2$)

E is overall Efficiency

E is around 0.3 for simple basin and G for Sri Lanka 4.5 $kWh/m^2/day$ , which is equal to 16 $MJ/m^2$

Average approximate harvest per day =0.3x16x2.5/2.3

=5.21L/Day

However the practical average quantity per day as the data mentioned in the graph is 4.64L/Day .If life time of equipment is 5 years. The cost for producing one liter of potable water is Rs.2.95/Liter which is 0.02 $ .

## 5.Desalination and renewable energy

For a sustainable desalination, It should be based on renewable energy. the cost will also be reduced because the cost for renewable energy decrease continuously and fossil fuel goes high day by day. Applying locally available renewable energy will increases affordability of desalination.

The right combination of a renewable energy resources with suitable desalination technology can be the key to manage both power and water demand.

Below table shows the applicability of various renewable technologies with the desalination methods.

Table 11 Applicability desalination with Renewable Energy

| Technologies | MSF | MED | VC | RO | ED |
|---|---|---|---|---|---|
| Solar thermal | x | x | x | x | x |
| Solar PV | | | x | x | x |
| Wind | x | x | x | x | x |
| Geothermal | x | x | x | x | x |
| Renewable Technologies | x | x | x | x | x |

Source:Al-karghouli,2011

Solar thermal desalination

There is a great potential for sea water desalination via MSF and MED using solar heat input. Generally, this kind of desalination plant consist of two parts. One is heat collector and other one is distiller. If both process are in same desalination plant, it is called direct process. If heat comes from separate process, it is called as indirect desalination.

Concentrating Solar Power(CSP) plants can be used a heat source in both direct and indirect methods In Sri Lanka Northern area can be utilized due to high solar due to geographical location and also they have suffering lacking of pure potable water.

Renewable desalination methods which can be utilized with RO

## Photovoltaic RO Desalination

Photovoltaic technology can be combined with RO desalination .The electricity generated by photovoltaic use as input power to run the RO plant. Although photovoltaic technology is good alternative for sustainable water generation but country like a Sri Lanka cannot afford it due to high owning and operating cost due to panel cost and electricity storage cost (batteries) are high in price.

## Wind Power RO Desalination

Either electrical power power generated or direct mechanical power can be used to combine with RO.

Costal and near costal area of Northern province has good potential to develop wind powered desalination. Currently in Puttalam district there are several wind power plants to generate around 10MW power. Puttalam district is one of the district which is having very low annual rainfall.

There are 10 wind power plants all over the country producing nearly 100MW.

## Feasibility study for Application of renewable energy for existing RO plant in Jaffna delf

As per the above mentioned plant in the Jaffna currently run buy 100kW generator and by connecting national power grid CEB.Let we discuss the application of renewable energy for the delf plant so that we can suggest applicability of renewable energy to other proposed plants.

Delf island total 435 kWh daily requirement for the $100m^3$/Day Plant capacity: Energy requirement is 40KW (Refer cost Plant calculation table No.8 ).For the calculation purposes we assume that, The plant is running solely in existing generator and plant Energy requirement is 45Kw and working only 12 hours from 6am to 6pm which consist lighting load of 10Kw throughout the day.

Since the generator is existing already it is capital cost assumed as $ 2000 which will incur for connection cost.

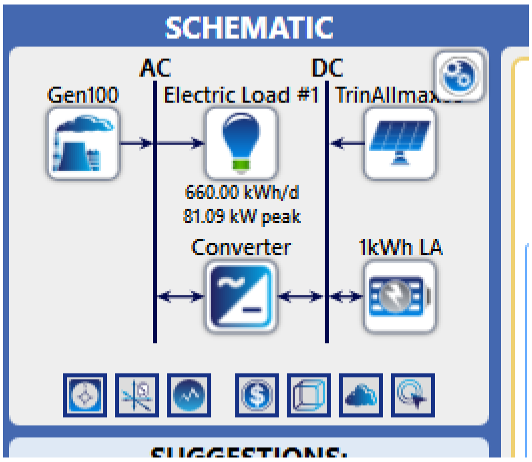


Figure 28 Basic design for simulation

By using Homer software the feasibility study done for the below configuration

01,Diesel Genset is readily available

Plant has diesel Genset 100 kW capacity ,it has included in initial project therefore the initial capital investment for hybrid system is very less only connection cost is included.

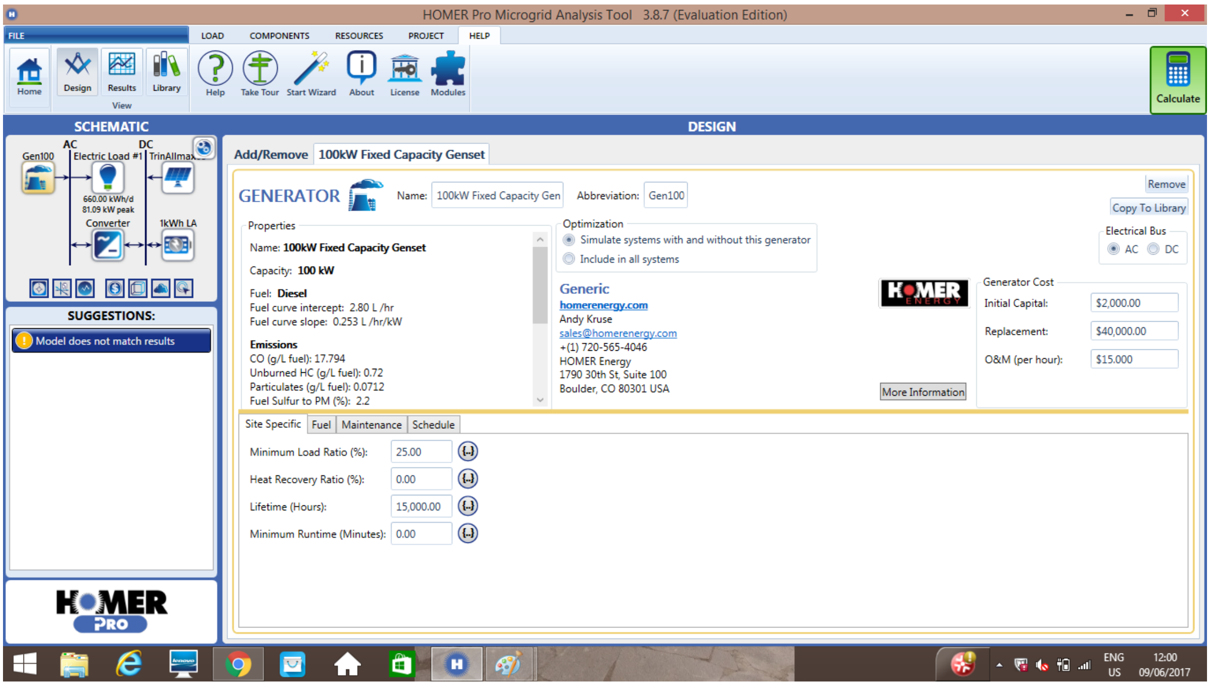


Figure 29 Generator data

02. Solar PV

Meteorological stations in the northern region do not record solar radiation data. Data sourced from www.eosweb.larc.nasa.gov web site indicate that solar radiation levels are fairly uniform over this region and vary from 4.4 kWh/m2/day to 6 kWh/m2/day.

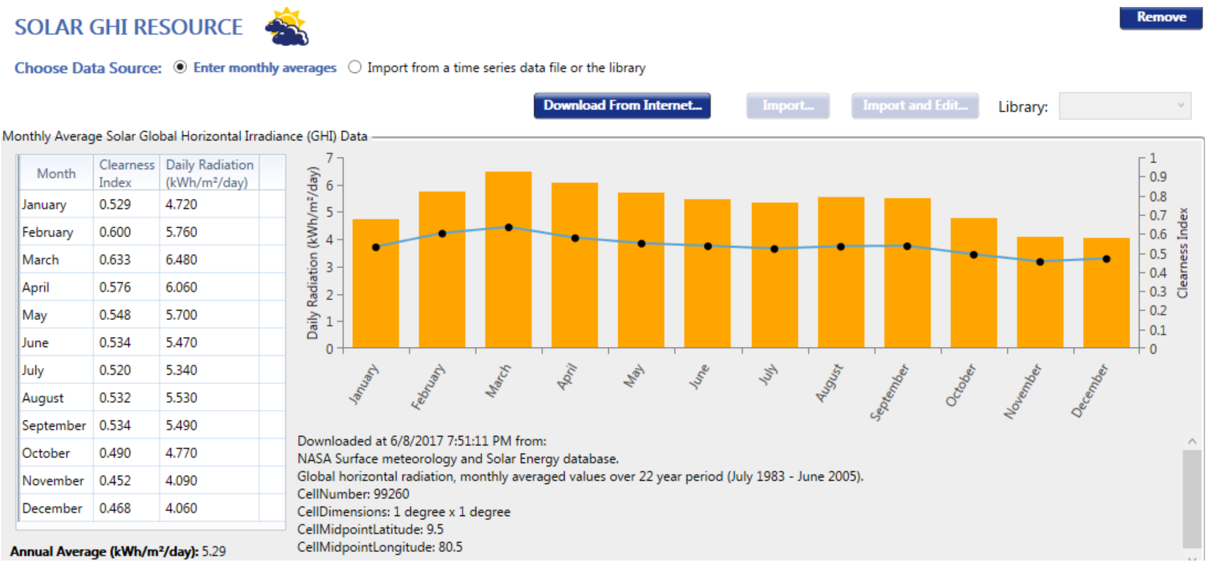


**Figure 30 Solar Radiation**

In here we are selecting Trina flat plate solar module for the calculation up to 45Kw.

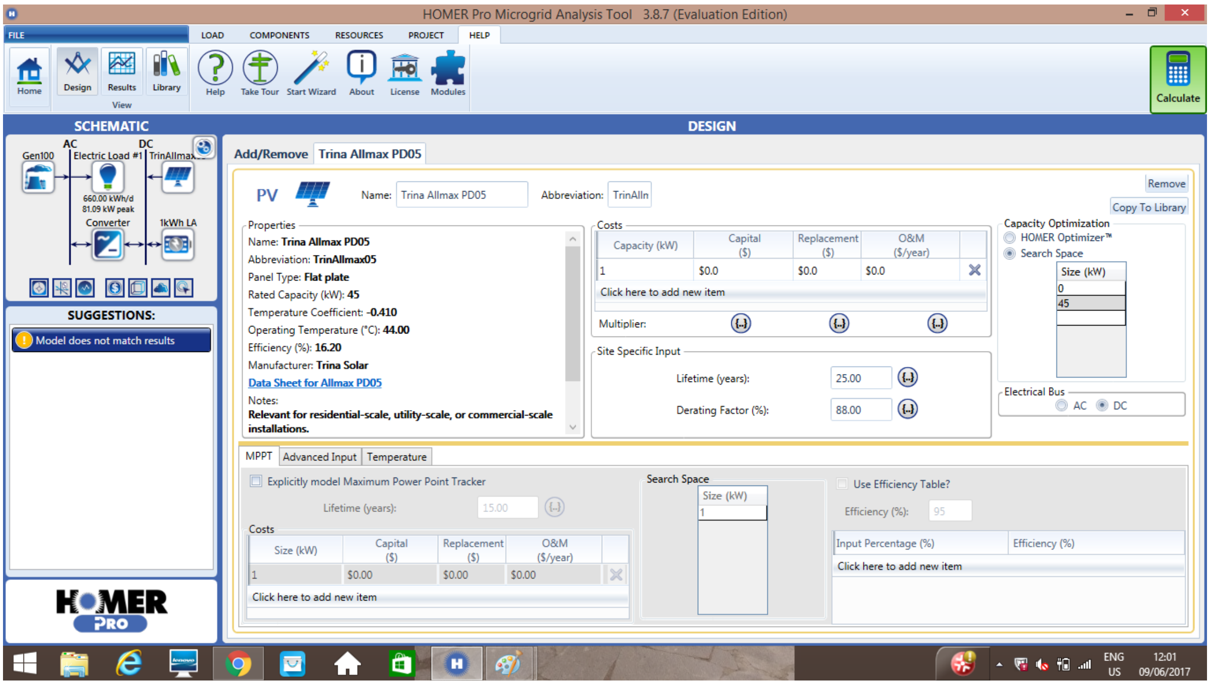


**Figure 31 Solar Panel data**

03.battery Bank

Battery bank has 45Kwh capacity to cater the plant demand.

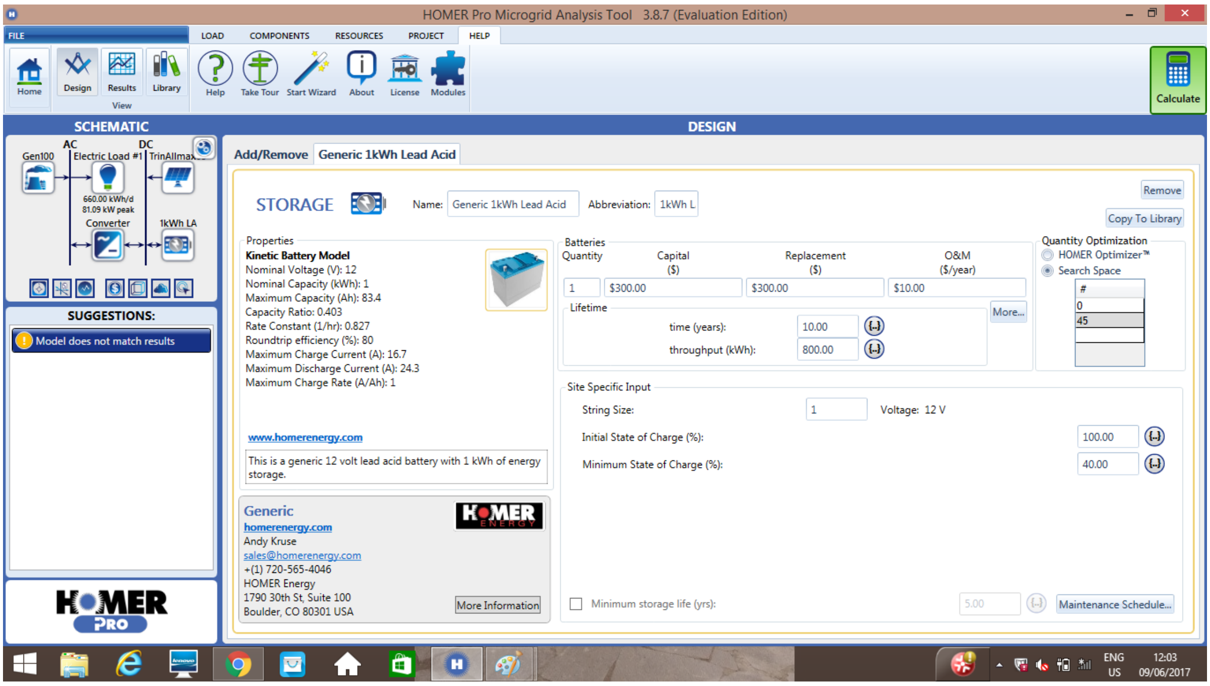

Figure 32 Battery data

## Simulation results

Most optimum design is run the Solar, and Generator set together with converter and battery bank.

The Results as follows.

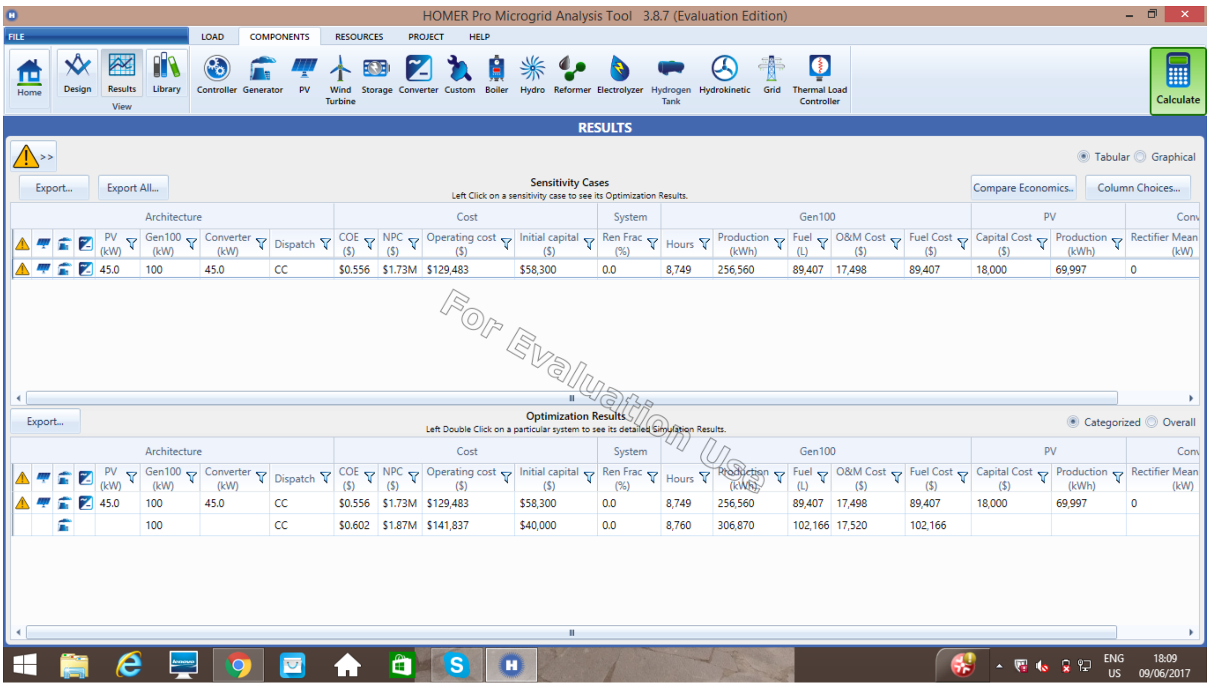

Figure 33 Optimized solutions

As per simulation it is clear that the most optimized design is combination of solar system with generator and Battery bank, the stand along gen set is option is not the optimized solution.

The initial capital investment for the project is shown in below.

**Table 12 Options- capital cost**

| Description | Option 01 | | Option 2 | |
|---|---|---|---|---|
| | Capacity | Cost | Capacity | Cost |
| DG set | 100kW | 2000(Existing set) | 100kW | 2000(Existing set) |
| converter | 45kW | 18000 | 45kW | 18000 |
| battery | 45kW | 10000 | 45kW | 10000 |
| Solar panel | 45kW | 18000 | | |
| fixed cost | | 10000 | | 8000 |
| | | | | |
| | | | | |
| Total | | 56000 | | 38000 |

As per the simulations the first option is the most viable.

# 6. Conclusion and recommendations

The most available technology in Sri Lanka is RO due to cost effectiveness in comparison with other available technologies since Sri Lanka is new to desalination.

Considering future water demand, Sri Lanka should initiate a desalination projects at least for dry zones, near coastal areas and highly chemical contaminated agriculture areas. Due to kidney failures and critical health issues, even the places where have plenty of water should be considered for desalination or chemical clean up processes since the water purity is debatable with agriculture chemicals.

As per the cost analysis in Delf RO plant, The cost is Rs.28 cents per liter and solar distillation. Although the price shows that the RO is better but due to high initial investment as a third world country it is very difficult to afford huge initial investment without government intervention.

The experimental solar thermal desalination units only produce nearly 5liters of potable water per day and directly impacted by availability of solar power. This can be introduced for drinking purpose only. Since the fabrication technology is easy, If government can provide, Interest free loans it will be useful, However this is not much viable comparing to the cost per liter since the cost per liter production is Rs.2.95 and limited production capacity.

The feasibility study simulation for renewable energy application for Delf RO plant is conducted through Homer software and the results shown that the running generator set along is not feasible comparing to Solar PV application.

There should be government intervention for building desalination plants, a policy should be initiated and should have plans to address severe health issues and future water demand which is estimated to be maximum in 2030.The renewable energy application for the existing facilities also need to be considered.

# 7. Bibliography


Almulla, A., Hamad, A.& Gadalla, M.(2005) Integrating hybrid systems with existing thermal desalination plants. Desalination, 174(2)**,** 171-192.

Awerbuch L, (2009) Future Directions in Integration of Desalination, Energy and the Environment. International Desalination Association Seminar, Boston, Feb. 23rd, 2009.

Berman, T. & Holenberg, M. (2005) Don't fall foul of biofilm through high TEP levels. Filtration & Separation, May. 30-32.

Blanco, J., Alarcón, D., Gernjak, W., Guillén, E., Farré, M.J. and Malato, S. (2008) Solar desalination - Recent research activities of Plataforma Solar de Almeria. In the conference Atelier Mediterraneen sur les nouvelles technologies de recyclage des eaux, 28 Apr - 1 May 2008, Agadir, Morocco.

Bolto, B.A. (1984) Development of Desalination in Australia. Desalination. **50**, p103-114, October-November. Burgen, S. (2010) Spain overtakes US with world's biggest solar power station.Guardian. 13 July 2010.

Cooley, H., Gleick P.H., Wolff G. (2006) Desalination with a grain of salt:

Ehrenman, G. (2004) From sea to sink: with supplies of water under stress, the prospect of rendering saltwater drinkable is growing more appealing and more affordable. Mechanical Engineering Magazine On-Line. Oct. 2004 issue. http://www.memagazine.org/backissues/membersonly/oct04/features/fromsea/from sea.html

European Environment Agency, (2010) The European environment – state and outlook 2010. Water resources: quantity and flows.
-pm5

Reference of the Information of design RO plant- Norachcholey Power plant phase 2

Fundamentals of Salt Water Desalination by H.T. El-Dessouky, H.M. Ettouney Pub. Elsevier, 2002. Hardbound, ISBN: 0-444-50810-4.

Water Desalination. United States Army, University Press of Pacific. Paperback Pub. March 18, 2005. ISBN 1-4102-2163-6.

Desalination and Water Purification Technology Roadmap - A Report of the Executive Committee(Roadmap). January 2003.
By The U.S.Bureau of Reclamation and Sandia National Laboratories. http://www.usbr.gov/pmts/water/media/pdfs/roadmapreport.pdf

Introduction to Desalination Technologies in Australia. Summary of a detailed report entitled "Introduction to desalination in Australia with particular reference to NAP priority regions." Available on the website at: http://www.environment.gov.au/water/publications/urban/desalination- summary.html

Desalination Markets 2005-2015: A Global Assessment & Forecast.
A Report by Global Water Intelligence, 1.4.2004.ISBN:0-9547705-0-1

Chapter 8: Desalination in Water: Sustainable management of a scarce resource. Ed. Mohamed El_Ashry, Najib Saab & Bashar Zeitoon. (2010). Pub. Arab Forum for Environment and Development (AFED).
See http://www.afedonline.org/Report2010/main.asp

The European Desalination Society, Science Park of Abruzzo Via Antica Arischia http://www.edsoc.com
The Desalination Directory, Science Park of Abruzzo Via Antica Arischia, 1 - L'Aquila 67100, Italy. http://www.desline.com/

International Desalination Association (IDA), POB 387, 7 Central Street, Topsfield, A 01983 USA. Tel. +1 978 887 0410 Fax. +1 978 887 0411 http://www.idadesal.org/

The Online Desalination Directory http://www.desline.com

Fells, I. (2005) Energy Solutions. Letter in The Times, 14th June 2005.
Garcia-Rodriguez, L. (2004) Desalination by Wind Power. Wind Engineering,**28(4)**,453-463.
HSBC Optimised Global Water Index, 2008. http://www.hsbcnet.com/treasury/attachments/structured-products/optimised-indices/water_brochure.pdf

Johnson, M.A. & Polyakov, I.V., (2001) The Laptev Sea as a source for recent Arctic Ocean salinity changes, Geophys. Res. Lett., **28**, 2017-2020. see website http://research.iarc.uaf.edu/~igor/research/nansen/index.php

McCutcheona, J.R., McGinnisb, R.L. & Elimelecha, M. (2005) A novel ammonia- carbon dioxide forward (direct) osmosis desalination process. Desalination **174**, pages 1–11.

McRae,W. (2000) Electroseparations, Electrodialysis, in Kirk-Othmer Encyclopedia of Chemical Technology, pub. John Wiley & Sons,Inc.

Media Analytics Ltd. (2004) Desalination Markets 2005-2015:Global Assessment & Forecast. A Report by Global Water Intelligence, 1.4.2004. ISBN: 0-9547705-0-1 Available from Research and Markets Ltd., Guinness Centre, Taylors Lane, Dublin 8, Ireland. Price: Euro 1,220.00.

Müller-Holst, H. (2007) Solar Thermal Desalination Using the Multiple Effect Humidification (MEH)-method, in Solar Desalination for the 21st Century, ed. L. Rizzuti et al., pp 215–225. Pub. Springer.

National Research Council, (2004) Review of the desalination and water purification road map. pub. National Academy of Sciences, ISBN 0-309-09157-8. See also the website at http://www.nap.edu/catalog/10912.html

National Research Council (2008) Desalination: A National Perspective. The Committee on Advancing Desalination Technology. ISBN-10: 0-309-11923-5. See also the web site at http://www.nap.edu/openbook.php?record_id=12184&page=72

OFWAT, (2002) International comparison of water and sewerage service; 2000-01 report. http://www.ofwat.gov.uk/legacy/aptrix/ofwat/publish.nsf/AttachmentsByTitle/publication_list_o ld.pdf/$FILE/publication_list_old.pdf

OFWAT,(2011) Cost of water in England. http://www.ofwat.gov.uk/consumerissues/chargesbills/householdcharges/metered/ water

Royal Academy of Engineering, (2010) Global Water Security - an engineering perspective. April 2010. ISBN 1-903496-55-1

Saltworks Technologies Inc., (2009) A fresh way to take the salt out of seawater: Cheaper desalination, The Economist, Oct 29th 2009 http://www.economist.com/node/14743791?story_id=14743791

Sawahel, W. (2004) Gulf's first wind power plant is opened; Wind power could be used to provide drinking water in coastal parts of the Middle East. SciDev. Net http://www.scidev.net/content/news/eng/gulfs-first-wind-power-plant-is-opened.cfm

Scher, E. (2010) Desalination to Dramatically Increase the Cost of Water. Op EdNews.com http://www.opednews.com/articles/Desalination-to-Dramatical-by-Eddie-Scher-100324-217.html

Semiat, R. & Hassan, D. (2008) Energy Issues in Desalination Processes. First UK-Israeli Workshop and Research Event on the Application of Membrane Technology in Water Treatment and Desalination, St Hilda's College, Oxford, June 2008.Sydney Water, 2009 "Desalination" Fact Sheet.

The Private Water Supplies Regulations 2009 SI 2009 No.310100.0

The Water Supply (Water Quality) Regulations 1989 SI 1989 No. 1147. The Water Supply (Water Quality) Regulations 2000 SI 2000 No. 3184.

The Water Supply (Water Quality) (Scotland) Regulations 2001 SI 2001 No. 207.

The Water Supply (Water Quality) Regulations 2000 (Amendment) Regulations 2007 SI2007 No. 2734

The Water Supply Regulations 2010 SI 2010 No.991

The Water Supply (Miscellaneous Amendments) (England and Wales) Regulations 2010 SI 2010 No. 996

URS Australia, (2002) Summary Report: Introduction to desalination in

Technologies in Australia. A report prepared for Agriculture, Fisheries & Forestry-Australia. http://www.environment.gov.au/water/publications/urban/pubs/desalination-summary.pdf

Yale Environment 360, (2010) Strain on Water Supplies Already Affecting Businesses

Globally.

http://e360.yale.edu/content/digest.msp?id=2685

Arsenic kills thousands while health ministry slumber http://www.thesundayleader.lk/2013/03/17