Environmental Engineering and Management Journal November/December 2008, Vol.7, No.6, 667-685
http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

AN INTEGRATED ASSESSMENT OF THE SUITABILITY OF DOMESTIC SOLAR STILL AS A VIABLE SAFE WATER TECHNOLOGY FOR INDIA

Santosh M. Avvannavar[1*], Monto Mani[1], Nanda Kumar [2]

[1]*Center for Sustainable Technologies, Indian Institute of Science, Bangalore-560012, Karnataka, India*
[2]*Public Health Consultant, Dept. of Community Medicine, M. S. Ramaiah Medical College, Bangalore-560054, Karnataka, India*

Abstract

Improving access to safe drinking water can result in multi-dimensional impacts on people's livelihood. This has been aptly reflected in the Millennium Development Goals (MDG) as one of the major objectives. Despite the availability of diverse and complex set of technologies for water purification, pragmatic and cost-effective use of the same is impeding the use of available sources of water. Hence, in country like India simple low-energy technologies such as solar still are likely to succeed. Solar stills would suffice the basic minimum drinking water requirements of man. Solar stills use sunlight, to kill or inactivate many, if not all, of the pathogens found in water. This paper provides an integrated assessment of the suitability of domestic solar still as a viable safe water technology for India. Also an attempt has been made to critically assess the operational feasibility and costs incurred for using this technology in rural India.

Keywords: Solar stills, integrated assessment, technologies, impacts

1. Introduction

Water is fundamental for life, health and productive livelihood. According to the World Resources Institute report 1992-1993, many developing countries, where 80% of the population lives in the rural areas, their fresh water supplies can be far lower (< 55 L) per capita than in urban centers (Government of Karnataka, 2001; World Resources Institute, 1993). In India, 40 liters per capita is considered as an adequate supply per capita per day was the target to be achieved in rural areas as compared to 150-200 liters per capita is considered for urban domestic purposes (Park, 2007). Improving access to safe drinking water can result in multi-dimensional impacts on people's livelihood. Such as improvements in health and hygiene, rural and urban livelihoods, children's attendance at school, psychological well being and social interaction. An estimated 1.3 billion people globally lack access to clean potable water. Depending upon the season, children in the villages often had to stay dirty (Lamphe, 2007). A minimum of 3-4 L per person per day drinking water is required by an individual depending upon the geographical variations (Ponnuraj, 2006). Possibly water should be accessible within 500 meters (Mann and Williamson, 1979).

Currently, one in 15 people live in areas with inadequate fresh water supplies. Using United Nations' minimum population projections and data on renewable fresh water supplies, it is estimated that one in three people world-wide will be living under these conditions by the year 2025 (Ayoub and Alward, 1996). India ranks 133rd among 180 in water availability and 120th among 122 in water quality (The Hindu, 2003).

With increase in population and pollution there came centralized treatment units to treat the source water to each household, which lead to the municipal facilities in towns and cities. Assuming it would suffice the physiological needs of man by providing treated water pertaining to the local region. Experience shows that current system cannot always afford the operating and maintenance costs. For example, the capacity of the sewage water treatment plants in Bangalore, Karnataka is 718 million liters per day, but the treatment plants at 12 locations are treating only 350 million liters per day of sewage generated in the core area daily. Centralized treatment

* Author to whom all correspondence should be addressed: e-mail: santosh.avvannavar@gmail.com

may be a one of good option in cities but may not be suitable in villages because of sparsely populated area, where decentralized technologies are more likely to succeed.

There are various technologies which cater to the different needs for users. The available decentralized technologies such as Reverse Osmosis (RO), Electrodialysis (ED), Ion-Exchange (IE), Mechanical Filters (MF) etc. are made easily available in the market, but they are energy intensive, require operational and maintenance (O&M), needs a skilled labour etc. Most of these technologies would tend to fail due to the lack of institutional support to sustain O&M. Hence, in country like India, simple low-energy technologies are likely to succeed. One of such technologies to treat water is solar still. Solar stills would suffice the basic minimum drinking water of man. Solar stills use sunlight, which can be used to kill or inactivate many, if not all, of the pathogens found in water. This paper provides an integrated assessment of the suitability of domestic solar still as a viable safe water technology for India.

2. Current water status in India

With the declared objectives of providing at least the basic amenities, there has been a tremendous development in India in the agriculture and industrial sector, with concomitant pressure on the fresh water resources.

The waste generated by anthropogenic activities has not only polluted the environment as a whole, but had a particular detrimental effect on the quality of aquatio-envison too. Leachates from compost pits, animal refuse of garbage dumping grounds nutrient enriched return irrigation flows seepage from septic tanks, seepage from sewage etc. has adversely affected the ground water quality in several parts of India. Thirteen states in India (Fawell et al., 2006) have been identified as endemic to fluorosis due to abundance in natural occurring fluoride bearing minerals (Fig. 1, Table 1). In some villages of Rajasthan and Gujarat, the fluoride level has been recorded up to 11.0 mg/L. It has been estimated that the total population consuming drinking-water containing elevated levels of fluoride is over 66 million in India alone (Fawell et al., 2006).

Though iron content in drinking water may affect the human system as a simple dietary overload, the long run prolonged accumulation of iron in the body may result in homochromatosis, where tissues are damaged.

Iron content (Yellow color) in some districts of Rajasthan, Uttar Pradesh (U.P) and Bihar has found to have above the permissible level of 1.0 mg/L (IS 10500, 1991). In some districts of Assam (Barpota, Darrang, Kamrup, Sonipni) and Orissa (Balasore, Cuttack, Puri) ground water have high iron content ranging from 1 to 10 mg/L (Red color) as shown in the Fig 2.

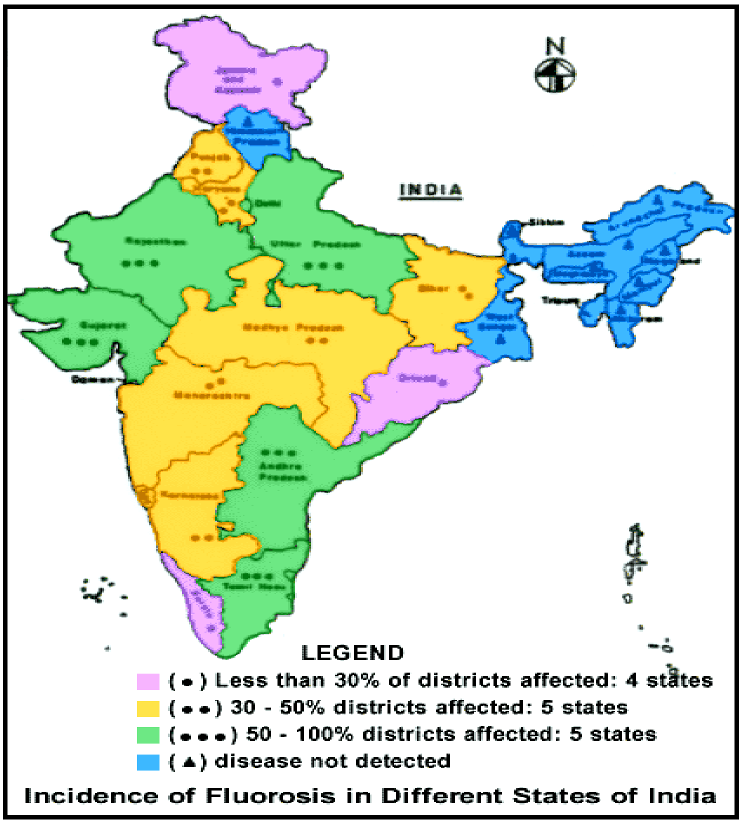


Fig 1. Map of India showing endemic states fluorosis (www.medvarsity.com)

Table 1. Fluoride concentrations reported in groundwaters of India (Fawell et al., 2006)

Regions/State	***Fluoride concentration (mg/L)***	***Maximum severity of fluorosis observed***
North-West India	0.4-19	Severe
Central India	0.2-10	Moderate
South India	0.2-20	Severe
Deccan Province	*0.4-8*	Moderate

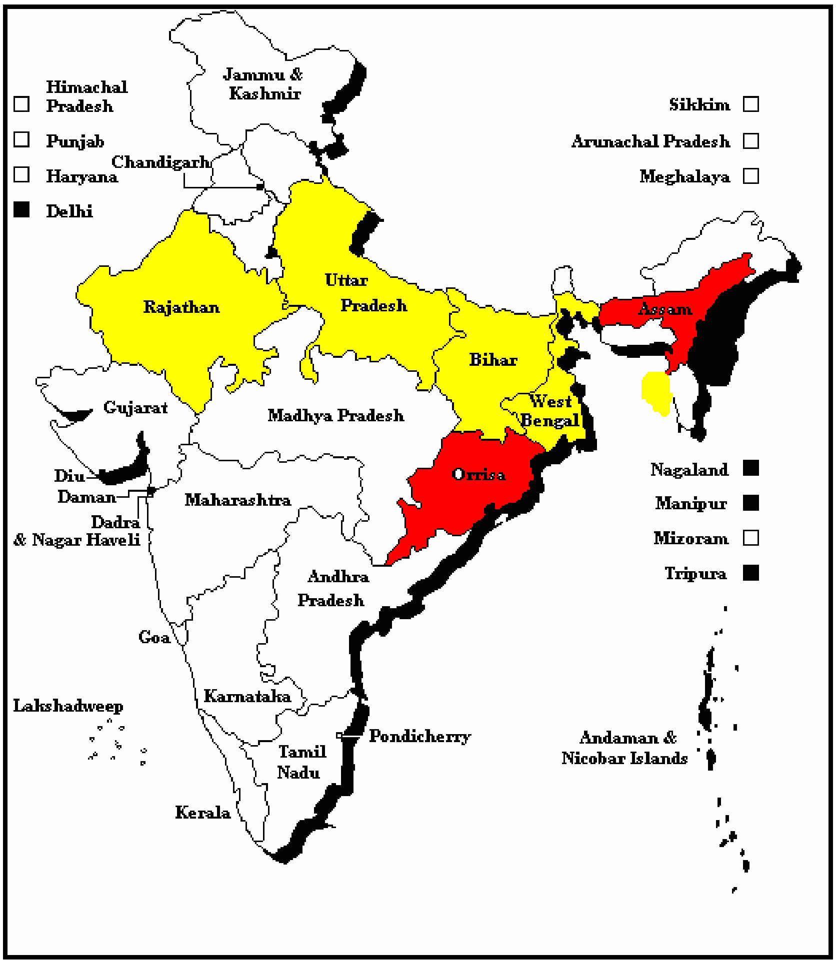


Fig. 2. Map of India showing endemic state of Iron content

Arsenic contamination of groundwater and sufferings of the people of West Bengal are well documented (Mandal et al., 1996). The present situation in West Bengal is that about 5 million people in 978 villages of 67 blocks from 9 districts including the southern part of Kolkota (Fig 3), are drinking contaminated water containing arsenic above the permissible limit of 0.05 mg/L and around 300 000 people are suspected to be suffering from arsenical skin lesions.

India has about 53 000 habitants with salinity greater than 1500 mg/L, most being remote and arid areas with saline water.

Statistics emphasis atleast 40% of the world's population lives without drinking water and roughly 80 000 habitations across the planet have no source of safe water. Of the 575 000 Indian villages, about 162 000 face problems of brackish or contaminated water and scarcity of fresh water. Fig 4 shows the places suffering from salinity lie in high radiation zones from 5.4 to 6.4 kWh/m^2 (annual average).

Even the annual average temperature of the country is sufficient to operate the solar stills (Fig. 5). This makes the use of solar desalination systems in these areas even more practical and sustainable.

There are about 575,000 villages in the country, about 227,000 have been classified as problem villages because either there is no water source available at less than 1.6 km distance, at less than 15m depth and 100 m elevation difference or the water is chemically and or biologically contaminated. The population of Indian villages ranges between 100 and 10,000.

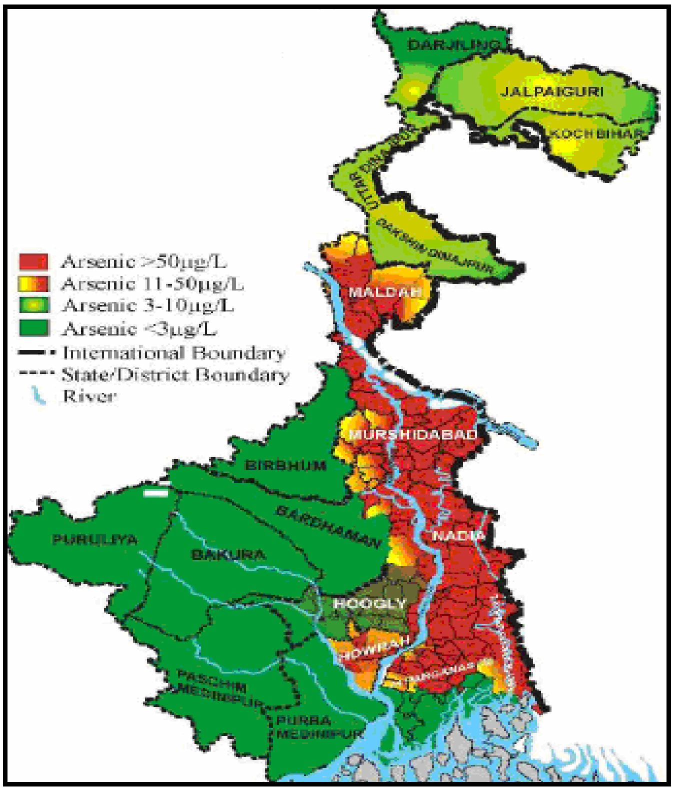


Fig. 3. Arsenic ground water Arsenic contamination status in West Bengal –India upto 2005

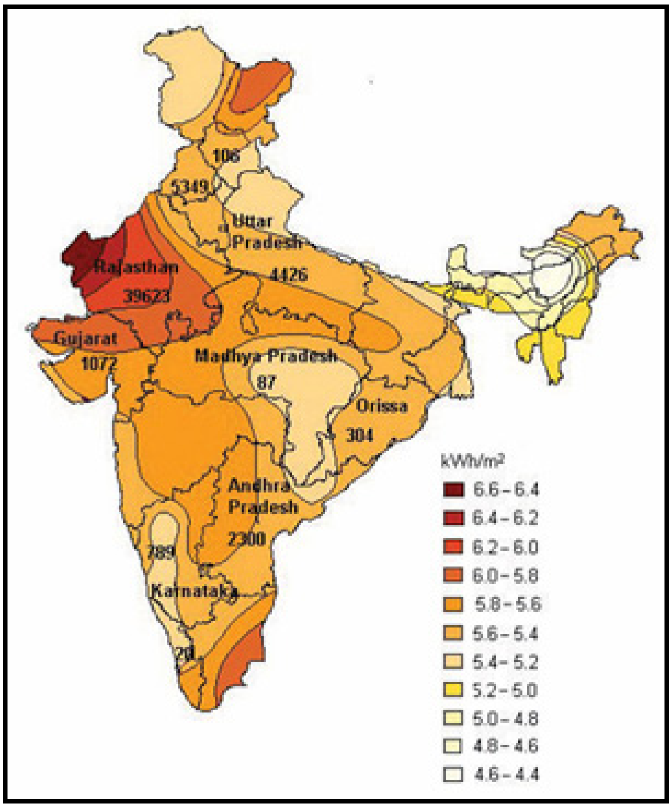


Fig. 4. Number of Habitants in India with salinity more than 1500 mg/L
Maps of India 2007, (http://www.infobase.co.in)

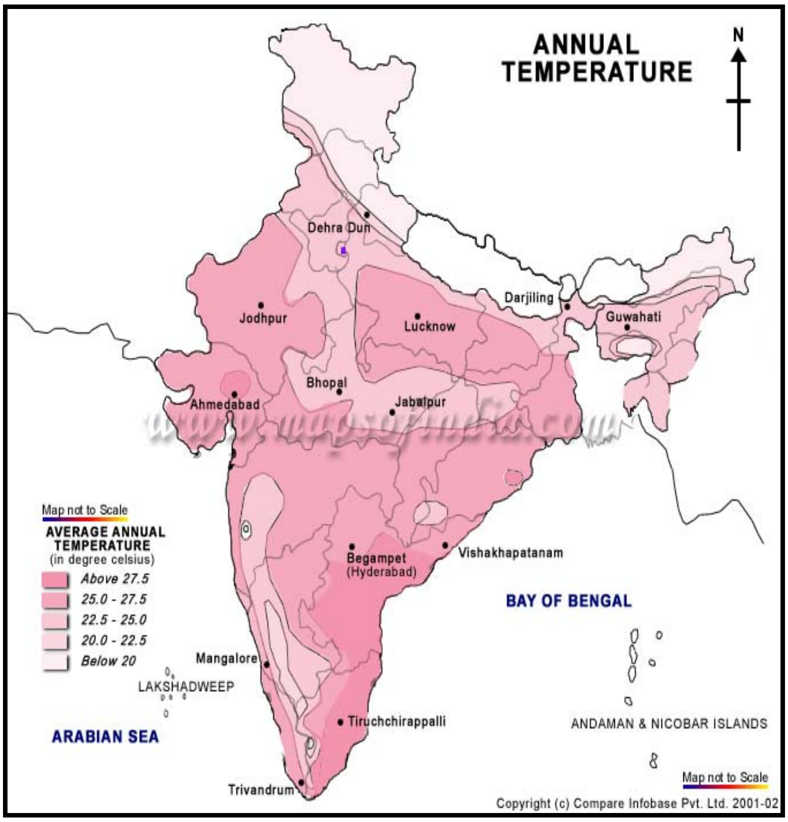


Fig. 5. Average Annual Temperature of India
Maps of India 2007 (http://www.infobase.co.in)

In many areas, the water table falls during the summer, and at times the wells and tanks run dry. Agriculture being the majority activity in Indian villages, there is great water requirement during summer. About 325,000 km^2 of the country (9.73% of the total area) is arid, characterized by dry climate, isolation, low population, and lack of fresh water; there may be abundance of brackish water or sea water (coastal areas) (Gomkale, 1988).

Globally, industrial water use is approximately 200 km^3/year or twice the actual domestic consumption. An additional 225 km^3/year is used by power stations as cooling water, and 40 km^3/year is taken up for livestock. Annual internal renewable water resources in India is about 1850 km^3 (18%) and about 380 km^3 annual withdrawals (Water Resources Institute, 1992-93).

The high water availability figure, however, includes some poor quality water caused by heavy industrial contamination and atmospheric acid rain pollution (Ayoub and Alward, 1996). The annual population growth rate of Indian population is around 1.44% (2004 estimate) (Sahu, 2007). The current population of India is 1,095 billion (July 2006 estimate) and 1,147 billion project population for 1 March 2008 (Census, 2001, Sawaal, 2008) and population density of India is about 324 person per sq km.

Fig 6 depicts the population of India (2001) at different scale. With increase in population and diminishing forests, inflation in standard of living has led to inventions of new technology to cope with the present standard of living. As environmental issues continue to gain world-wide attention, the world is becoming increasingly aware of shortage of fresh water. It is projected that the Indian population may be around 1.6 billion by 2050. As a result, gross per capita water availability will decline from approximately 1820 m^3/ year in 2001 to as low as 1600 m^3/year and ~1140 m^3/ year in 2017 and 2050 (Thacker, 2008).

Total water requirement of the country has been assessed to 1450 km^3/ year. This is significantly more than the current estimate utilizable water resource potential (1122 km^3/ year) through conventional development strategies. Therefore, when compared to with the availability of ~500 km^3 year at present, the water availability around 2050 needs to be almost trebled (Gupta and Desphande, 2004).

This problem is exacerbated by population growth in many developing countries, such as India in this paper, with projections anticipating significant continued growth.

From the above all discussion it has become to have permanent technology which would provide clean water for various purposes.

Conversion of saline water to potable water has been the major response undertaken by water-poor countries to provide their populations with, at least, the essential daily basic requirements (Ayoub and Alward, 1996).

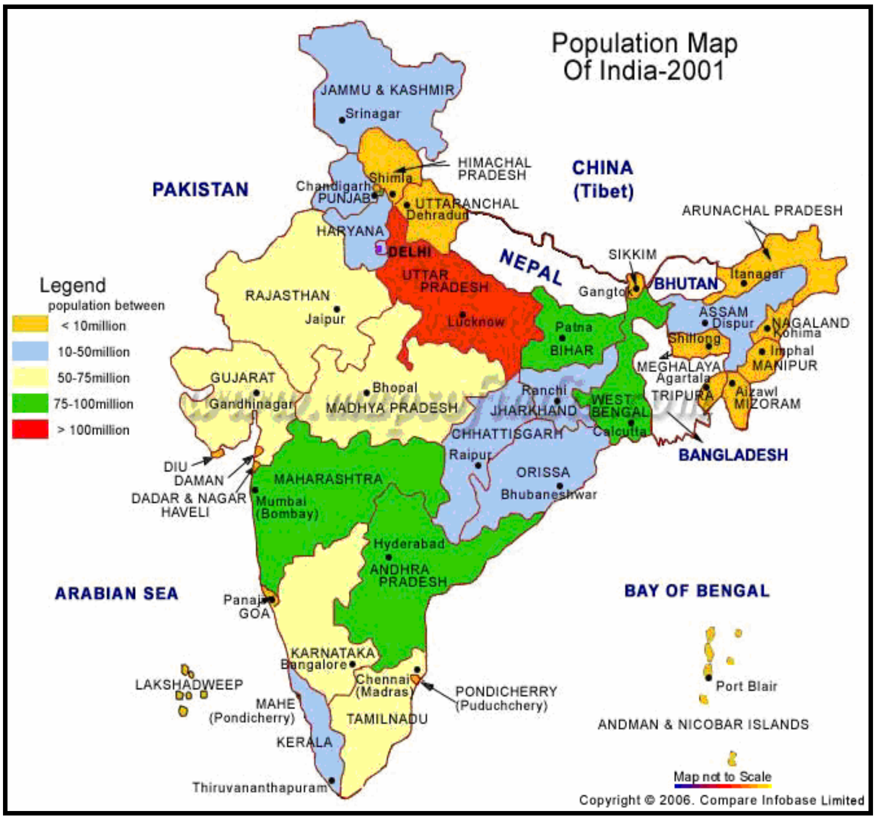


Fig. 6. Map of India showing the population of India -2001
Maps of India 2007 (http://www.infobase.co.in)

3. An overview of current decentralized/household technologies

There are various technologies available to treat brackish or sea water to produce fresh water as an alternative to water supplies. These can be classified into three main categories: membrane technologies, chemical methods, and distillation.

There are about 575,500 villages in India out of which 227,000 have been classified as problem villages because of no water source and/or contaminated water. Some of the factors needing careful examination are: the socio-economic circumstances of the community; the possibilities of adopting new technologies for treatment of contaminated or brackish water, cost of transporting the water to the village even if centralized system is implemented to serve the population of Indian villages ranges between 100 and 10,000 (Gomkale 1988). India has about 96,000 villages still to be electrified.

About 20,000 villages are isolated and situated in arid, semi-arid or coastal areas of the country, which cannot be electrified by conventional grid extension (Sastry, 2003).

In spite of their poor education they show a good capacity to learn the routine operation of new methods but they lack interest in good maintenance over long periods (Gomkale, 1988).

The above said technologies (Table 2) require power supply for treating and supplying water at large scale, medium and small level. This would be one of the major disadvantages of the advanced technologies in rural areas. The following passages discuss about the intangible impacts or cons of the alternative technologies.

The ***Reverse osmosis*** would reject constituents as small as 0.0001µm. There are different modules used in membrane field such as tubular, hollow fiber and spiral wound. These modules need periodic cleaning due to plugging using chemicals and generally expensive. Selection of membrane modules is important because polyamide and TFC membranes are sensitive to chemicals. Membrane fouling is an important consideration in the design and operation of membrane systems as it affects pretreatment needs, cleaning requirements, operating conditions, cost, and performance.

Regular chemical cleaning of the membrane elements (about once a month) is necessary to restore the membrane flux. In ***Electrodialysis*** process water has to be retained for about 10 to 20 days in a single stack or stage. Membranes are needed to be continuously washed. Problems associated with the electrodialysis process for wastewater renovation include chemical precipitation of salts with low solubility on the membrane surface and clogging of the membrane by the residual colloidal organic matter in wastewater.

Table 2. Pros and Cons of various technologies (* Younos and Tulou, 2005; ** Metcalf and Eddy, 2003)

Technologies	***Pros***	***Cons***
Membrane Technologies* • Reverse osmosis	1. Can remove dissolved constituents 2. Can disinfect treated water 3. Can remove organic compounds 4. Can remove natural organic matter and inorganic matter 5. Reduces labor requirements; can be automated easily 6. Smaller space requirements; membrane equipment requires 50 to 80 percent less space than conventional plants	1. Works best on ground water or low solids surface water or pretreated wastewater effluent 2. Lack of reliable low-cost method of monitoring performance 3. May require residuals handling and disposal of concentrate 4. Expensive compared to conventional treatment 5. Require replacement of membranes about every 3 to 5 years 6. Scale formation can be a serious problem. Scale-forming potential difficult to predict without field testing 7. Flux rate gradually declines over time. Recovery rate may be considerably less than 100 percent 8. Lack of a reliable low cost- method of monitoring performances 9. Rejects particles as small as 0.0001µm.
• Electrodialysis	1. Adaptable to various operation parameters 2. Require little labor and the maintenance cost is low	1. Treatment cost is directly related to TDS concentration in feed water 2. Best suited upto 4000 mg/L TDS 3. Short design life 4. Membrane cleaning (backwashing or chemical treatment), high membrane replacement cost, low resistance to chlorine, and lack of resistance to fouling.
Chemical methods* ** • Ion Exchange	1. Feasible for removal and recovery of metals	1. Extensive pre-treatment is required 2. Concerns about life of ion-exchange resins 3. Complex regeneration system required
Distillation * ** • Solar distillation	1. Low energy cost 2. Low material, maintenance and equipment cost 3. Ultra-pure water	1. Requires large amount of land and direct sunlight 2. Low productivities 3. Scaling and corrosion (medium and large scale and material used) 4. Disposal of concentrated waste

Since villagers are not educated, they take longer time to adapt to new developments. Disposal of the concentrated waste streams produced by the membrane represents the major problem that must be dealt with in their applications.

The concentrate will contain hardness, heavy metals, high-molecular-weight-organics, microorganisms, and often hydrogen sulfide gas.

Around 3643 g/m^3 concentration of the concentrated waste stream will remaining if 90 percent of recovery and rejection is considered to produce 4000 m^3/d of water for industrial cooling operation. This figure would depicts how large volume of the waste stream that must be treated (Metcalf and Eddy, 2003).

Ion exchange process uses resins; the stability of resins will be an important for the long-term performance. In turn these resins selectivity is based on operating and wastewater conditions such as pH, temperature, other ionic species, and chemical background. For example, higher concentration of influent total suspended solids (TSS) can plug the ion-exchange beds, causing high headlosses and inefficient operation. To date, ion-exchange has limited application because of the extensive pretreatment required, concerns about the life of the ion-exchange resins, and the complex regeneration system required (Metcalf and Eddy, 2003).

There are various house hold ***mechanical filters*** (spun cellulose) used in our day today life. There are various sizes used to connect the cold water lines (Tap) for treating small quantities of water. There are various problems associated with mechanical filters such as bacterial contaminations, rotten egg smell, bad taste, clogging of the filter etc., on prolong use. These do not remove nitrate, bacteria, or heavy metals. It requires regular maintenance such as cleaning and replacement.

Iron filters remove iron and manganese that cause staining of clothes and plumbing fixtures. Iron removal from the water supply can involve complex choices. Careful planning is needed when iron removal equipment is used in conjunction with other water treatment equipment. The type of iron removal equipment chosen depends on the type and quantity of iron in the water, the characteristics of the water supply, other water treatment equipment in use, and the user's requirements for cost, ease of use, and maintenance.

Neutralizers, passing the water through granular calcite (marble, calcium carbonate, or lime) are the most common method of home treatment. Neutralizers using soda or sodium compounds increase the sodium content of water which may be a health concern. Using calcite to neutralize water increases calcium, which increases water hardness. These factors must be considered in the treatment choice. All systems require routine maintenance to replenish the chemical used to neutralize the water. There are various models of Aquaguard available which uses little or no power input, but has its own limitations. It can treat specific kind of contamination. Some models need back flushing, in other terms little maintenance. However, it is important to keep in mind that no single water treatment device treats all problems, and that all devices have limitations. As many of villages do not have access to electricity, cost of device would be high and maintenance which would set back people using these kinds of models.

Thus if these non-electrified places have to be provided with drinking water by small-capacity desalination plants powered by renewable energy sources, solar energy will have to be adopted in most cases. The most of the technologies are expensive and uneconomical for small quantity of freshwater (Gomkale, 1988).

With any increase in population, economic development and global warming create an imbalance worldwide between supply and demand of fresh water. The task of providing adequate supplies of fresh water may indeed become the most serious problem facing the world on the onset of this new century (Naim and Abd El Kawi, 2002). The Bangalore city (India) lets 700 million litres of untreated sewage into three valleys everyday, contaminating groundwater and wells around these valleys of Bangalore, Karnataka, India (Pooja, 2007). The current systems cannot cope with the load. Even as the 50-year-old sewage network struggles with the growing load, it is no surprise that the 14 sewage treatment plants that together have the capacity to treat 718 million litres of sewage a day receive just about half that capacity is the present scenario of Bangalore, India. Many areas in the Bangalore city have no collection system at all (Hindu Newspaper, 2007).

With the reality of climate change very imminent relatively small climatic changes can cause large water resource problems, particularly in arid and semi-arid regions such as northwest of India. This will have impact on agriculture, drinking water and on generation of hydro-electric power. The various studies conducted by scientist at IIT Delhi have shown that the surface air temperatures in India are going up at the rate of 0.4°C per hundred years, particularly during the post-monsoon and winter season. They also warn that India will experience a decline in summer rainfall by the 2050s. Apart from monsoon rains, India uses perennial rivers, which originates and depend on glacial melt-water in the Hindukush and Himalayan ranges. Since the melting season coincides with the summer monsoon season, any intensification of the monsoon is likely to contribute to rising of snowline, reducing the capacity of these natural reservoirs, and increasing the risk of flash floods during the wet season. Deltas will be threatened by flooding, erosion and salt intrusion. Water-brone diseases like malaria may penetrate elevation above 1800m and 10% more states may become breeding ground for malaria vector. India has already started witnessing this by the last epidemics of chikungunya and dengue (Thacker, 2008). In India, water-brone diseases alone are said to claim 73 million work days every year. The world faces challenges if we are to deal effectively with the biggest challenge faced by humankind. Hence there is immediate demand to reduce carbon dioxide emissions drastically by moving to renewable technologies as soon as possible. The various sectors such as industrial, domestic etc. use fuel (oil, coal etc) for the production of energy and this would lead to global warming.

4. Solar stills overview

Solar energy can be used to evaporate water from the brine solution for household or community water supplies by constructing sealed units covered with glass known as solar stills. Solar distillation exhibits considerable economic advantage over other present technologies for treatment and recovery of water because of its use of free energy and its insignificant operating costs. Distillation with solar energy is a most favourable process for small compact water desalting at geographical locations where there is considerable solar radiation. Another advantage is its simplicity (no moving parts) as it requires low operation and maintenance. Solar stills are highly reliable, as they would be located in isolated communities without immediate access to technical assistance. Solar stills can easily provide us with the necessary daily amount of drinking water for the water scare and drought areas like Africa, Asian countries etc.

To date commercial development of simple, reliable, and inexpensive desalting units has been very limited due to high engineering and manufacturing costs (Ayoub and Alward, 1996). India has good climatic conditions and abundant solar energy is available, it is worthwhile developing and implementing solar stills. Solar distillation will provide with potable/distilled water virtually from any type of dirty input water such as sea, bore, effluent, urine, radioactive, arsenic contaminated, brackish etc. (Ward, 2003).

The technology for converting sea and brackish water to potable water is well established. The first written description of desalination is traced to the Old Testament (Bible) (Vetus, M.Dc. XXVIII), in Exodus (22-25) (about 1500 BC). So Moses brought the sons of Israel from the Red Sea and they went to the desert of Sour. And they marched three days in the wildness and they found no water to drink. And then they arrived to Merra and they could not drink from the water of Merra, because they were bitter, therefore he gave to the place the name Bitterness. And the people murmured against Moses. Saying: What shall we drink? and Moses cried onto the Lord. And the Lord showed him a wood and he put it into the water and the water became sweet. It is conceivable that the ‘‘wood’’ mentioned above had ion-exchange properties (Delyannis, 2003).

Aristotle (384-322) first described the production of drinking water by distillation of seawater undertaken by Greek sailors in the fourth century BC (Popkin, 1968; Ayoub and Alward, 1996). The water cycle is a huge solar energy open distillation plant in a perpetual operational cycle. For the seawater he writes salt water when it turns into vapor becomes sweet, and the vapor does not form salt water when it condenses again. This is known by experiment. Until medieval times no important ideas or applications of desalination by solar energy existed, but during this period, solar energy was used to fire alembics in order to concentrate dilute alcoholic solutions or herbal extracts for medical applications, and also to produce wine and various perfume oils.

The stills or alembics were discovered in Alexandria, Egypt, during the Hellenistic period (4 B.C-1 B.C). Cleopatra the Wise, a Greek alchemist, developed many distillers. The head of the pot was called ambix, which in Greek means the ‘‘head of the still’’, but this word was applied very often to the whole still (Delyannis, 2003).

In the first century A.D., the Romans are reported to have filtered sea water through a clay soil to obtain drinking water (Ayoub and Alward, 1996). The Arabs who overtook science and especially alchemy about the 7th century, named the distillers Al-Ambiq, from which came the name alembic (Delyannis, 2003). Della Porta (1589) used wide earthen pots, as shown in the Fig. 7, exposed to the intense heat of solar rays to evaporate water and collect the condensate into vases placed underneath (Nebbia and Mennozi, 1966; Tiwari et al., 2003). In 1589 he issued the second edition comprising 20 volumes. In the volume on distillation Della Porta mentions seven methods of desalination, but the most important reference is in the 19th volume where he describes a solar distillation apparatus that converted brackish water into fresh water. He also describes, in the second chapter of volume 20, a method to obtain fresh water from the air (nowadays called the humidification–dehumidification method) (Delyannis, 2003).

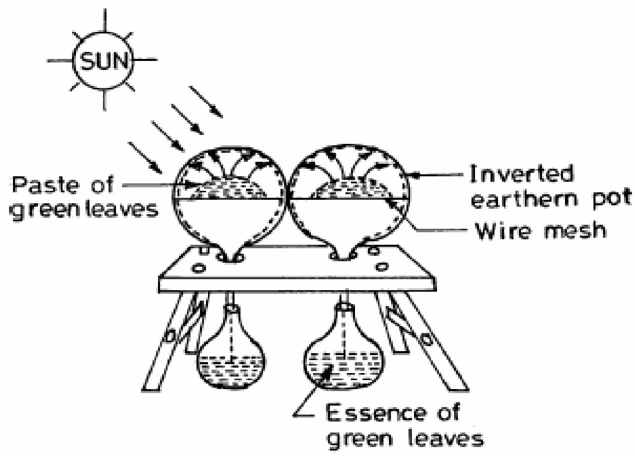


Fig. 7. The Della Porta solar distillation apparatus, as presented in his book ‘‘Magiae Naturalis’’ (Nebbia and Nebbia-Menozzi, 1966)

This basic process continued in use on shipboard well into the late 16 century (Popkin, 1968; Ayoub and Alward, 1996; Tiwari et al., 2003). Mouchot the well-known French scientist who experimented with solar energy during 1986’s, mentions in one of his numerous books that during medieval times Arab alchemists carried out experiments with polished Damascus concave mirrors to focus solar radiation onto glass vessels containing salt water in order to produce fresh water. He also reports on his own experimental work with solar energy to distill alcohol and about a metal mirror having a linear focus with a boiler located along the focal line.

5. Solar still modern application

The first known patent for a desalination process involving steam distillation was granted in England in 1869. In 1870 the first American patent on solar distillation was granted to Wheeler and Evans, 1870). The patent, based on experimental work, was very detailed. Almost everything known to us about the basic operation of the solar stills and the corresponding corrosion problems was described in that patent.

The report stated as follows: this invention is based upon well known physical laws. The inventors described the greenhouse effect, analyzed in detail the cover condensation and re-evaporation, discussed the dark surface absorption and the possibility of corrosion problems. High operating temperatures were claimed as well as means of rotating the still in order to follow the solar incident radiation (Wheeler and Evans, 1870). Two years later, in 1872, an engineer from Sweden, Carlos Wilson, designed and built the first large solar distillation plant, in Las

Salinas, Chile. The plant was constructed to provide fresh water to the workers and their families of a saltpeter mine and a nearby silver mine. They used the saltpeter mine effluents, of very high salinity (140 g/kg or 140,000 ppm), as feed water to the stills. The plant was constructed of wood and timber framework covered with one sheet of glass. It consisted of 64 bays having a total surface area of 4450 m^2 and a total land surface area of 7896 m^2. It produced 22.70 m^3 of fresh water per day (Fig. 8). The plant was in operation for about 40 years until the mines were exhausted (Delyannis, 2003).

Land-based desalination plants, in the other hand, came into use only in the early 1900s and were encouraged by the evolution of the petroleum industry, particularly in water-poor countries of the Arabian Gulf (Popkin, 1968; Ayoub and Alward, 1996). According to the technical brief report, UK, mass production occurred for the first time during the second word War (1939-1945) when 200,000 inflatable plastic stills were made to be kept in life crafts for the US Navy. However, it was not until the mid-1950s that the use of large land-based desalination plants, particularly those using multistage flash (MSF) distillations, began to appear economically feasible for non-industrial purposes. This spurred intensive research and development into a variety of desalination processes. By the mid-1960s, desalination was still some-what of a novelty for community water supply, and much of the work in this field remained experimental, improving on earlier designs of plants which failed to meet expectations (Ayoub and Alward, 1996).

Between the years 1965 and 1970 solar distillation plants were constructed on four Greek Islands to provide small communities with fresh water (Delyannis and Delyannis, 1983; Delyannis , 2003). The design of the stills was done at the Technical University of Athens (Fig 9). They used seawater as feed and were covered with single glass. Their capacity ranged from 2044 to 8640 m^3/day. The installation in the island of Patmos was the largest solar distillation plant ever built. These solar stills were of the asymmetric glass covered greenhouse-type with aluminum frames.

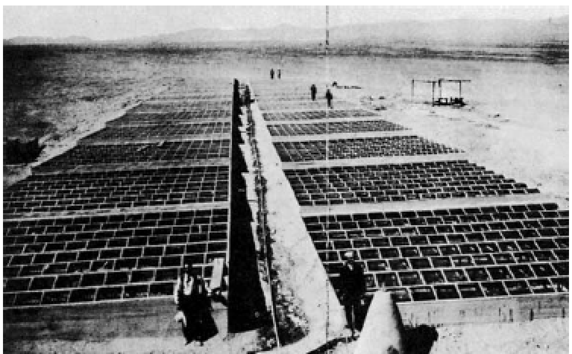


Fig. 8. The world-wide first large-scale solar distillation plant at Las Salinas, Chile

In three more Greek Islands the Church World Service of New York erected three solar distillation plants. These plastic covered stills (tedlar) with capacities of 2886, 388 and 377 m^3/day met the summer fresh water needs of the Young Men's Christian Association (YMCA).

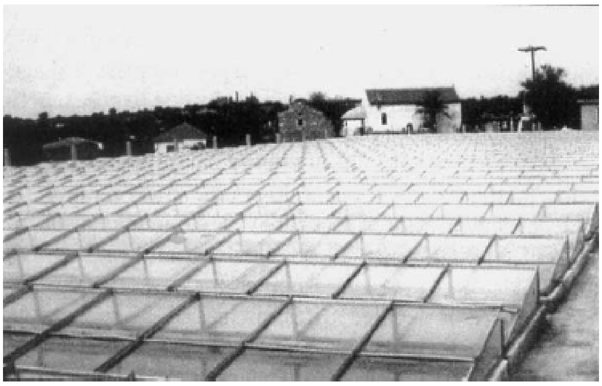


Fig. 9. The island of Symi (Greece) solar distillation plant

Edlin designed the stills which were tested by the OSW in Daytona Beach, FL. The first plant was an inflated, plastic cover design, while the other two were plastic V-shape configuration.

Solar distillation plants were also constructed on the Island of Porto Santo, Madeira, Portugal and in India for which no detailed information exists. Today most of these plants are not operational (Delyannis, 2003).

Renewable energy is the alternative solution to the decreasing reserves of fossil fuels. Total worldwide renewable energy desalination installations amount to capacities less than 1% of that of conventional fossil fuel desalination plants. This is due mainly to the high capital and maintenance costs required by renewable energy, making these desalination plants noncompetitive with conventional fuel desalination plants. Fig 10 shows the estimation by World Energy Council (WEC, 1994) of the increasing general use of renewable energies.

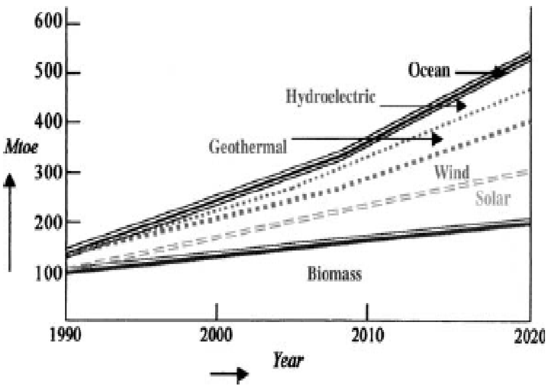


Fig. 10. The World Energy Council (WEC) estimation of renewable energies utilization increase up to year 2020.

The utilization of the sun's energy solar energy is the oldest energy source ever used. The Sun was adored, in many ancient civilizations, as powerful God (Delyannis, 2003).

6. Relevance of small-scale domestic solar still for India

Small desalting units in rural arid and semi-arid areas may provide individual households and communities with sources of clean drinking water otherwise unavailable. These units can be used as alternative where other water supply systems are not available. Solar distillation units are simple to operate, as there are no moving parts, high reliability, as they would be located in isolated communities without immediate access to technical assistance. Solar stills are economical because of cost-free energy and reduced operating costs. To date commercial development is of simple, reliable, and inexpensive solar stills has been very limited due to increased amortization cost, sometimes high engineering and manufacturing cost depend directly upon the location and local conditions. Nevertheless, there is continued interest in developing desalting equipment suitable in developing countries like India and Egypt where solar energy is abundantly found using renewable energy (Ayoub and Alward, 1996; Buros, 1991; Delyannis and Delyannis, 1983).

Several attempts have been made to develop high efficient solar stills. Which involve sophisticated designs, increased capital cost and operate more efficiently at relatively higher temperatures than the conventional solar still would do. These attempts were restricted to laboratory demonstration units and never reached a scale-up to commercial sizes (Delyannis and Delyannis, 1983).

Solar stills is a simple technology which will not only provide distilled water or drinking water for various end use, it even act as a good disinfectant for polluted water. It uses solar radiation to destroy pathogenic micro-organisms which cause water borne diseases. Sunlight is used for treating the contaminated water through two synergetic mechanisms: Radiation in the spectrum of UV-A (Wavelength 320-400 nm) and raises above 50°C, disinfection process is three times faster.

Indians are exposed to multitudes of natural and man-made calamities and their vulnerability to disasters has been exceedingly high due to high density of population. The number of people exposed to such disasters is increasing year after year for want of preparedness. The experience of Tsunami in the east coast, the earthquake at Kashmir and Gujarat taught us that micro level community based preparedness is very important in reducing the adverse impact. In many emergencies, only contaminated surface water (standing water, streams or rivers) is initial available. Water may contain pathogens, which are transmitted from faeces to mouth. The greatest risk associated with polluted water is the spread of diarrhea, dysentery, cholera, and infectious hepatitis (hepatitis A). Solar stills are useful in such places to provide clean and safe drinking water. As solar still is well-proven and familiar techniques, combined with efforts to improve protection against pollution, is often a sound solution. It acts through heating, the second through the effect of the natural UV radiation and the third through a mixture of both thermal and UV effects. Solar disinfection is included in the technologies reviewed by World Health Organization (WHO) for household water treatment and storage. Turbid water more than 30 NTU is not suitable for solar disinfection. The promoters of SODIS suggest the use of thin PET plastic bottles. The half of the bottle furthest from the sun should be painted with black paint to improve the heat gain from the absorption of thermal radiation, and the bottle can be laid on a dark roof to further increase the potential temperature rise in water. In order to make people aware of solar stills and usability during such emergencies various tools can be used such as social marketing one of them (Ponnuraj, 2006).

Solar energy is clean, pollution free and renewable source of energy. Development of this source of energy requires accurate detailed long term knowledge of the potential latitudes of 40°N and 40°S is generally known as the solar belt and this region is supposed to be with an abundant solar radiation. Karnataka (South India) being located between 11° 40' N and 18° 27'N has a geographic position that favors the harvesting and development of solar energy. Karnataka receives global solar radiation in the range of 3.8 – 6.4 kWh/ m^2. From the data it may be concluded that coastal parts of Karnataka with the higher global solar radiation and these regions are ideally suited for harvesting solar energy (Ramachandra and Shruthi, 2007).

The discussion of the paper may be extended to more precise way taking Karnataka state (India) as an example. The paper will further discuss the water pollution, need and necessities of solar energy technology in Karnataka. Karnataka is the eight largest states in India with 191,791 km^2, with 52 million population with mean population density of 275/ km^2 (Census, 2001) out of which 28 % population is in Urban, with summer: March to May (18^oC to 40^oC), winter: Oct to Dec (14^oC to 32^oC), South-West Monsoon: June to August and North-East Monsoon: October to December with minimum 500mm to 4000 mm rainfall ever year. There are many river basins such as Krishna River, Godavari River etc.

In Karnataka, 37% of habitations have found to have ground water contaminated. Habitations in Bagalkot, Bangalore Urban, Bijapur, Chamarajnagar, Chitradurga, Haveri, Mandya, Tumkur, Bellary, Davanagere, Kodagu, Kolar, Raichur and Koppal districts have serious groundwater quality problems, ranging from 50 to 79 per cent of habitations. More specifically, excess fluoride in groundwater is a major problem in 14 districts, ranging from 10 to 67 per cent of total habitations in each district.

Similarly, excess brackishness in 13 districts (10 to 27 per cent of habitations), excess nitrate in 8 districts (10 to 51 per cent of habitations) and excess iron in 12 districts (10 to 63 per cent of habitations) have adversely affected drinking water quality (Table 5). Nitrate levels in Banshankari premises (Bangalore) are as high as 300 mg/L (against the permissible limit is 45mg/L) in some places because of sewage contamination of groundwater (Hindu 24 February 2007).

Surface water contamination is yet another environmental problem in Karnataka as water has been polluted at certain pockets of some rivers and other water bodies. For instance, water in the river Bhadra is turbid and contaminated at the point of effluent discharge by the Mysore Paper Mills and Vishweshvaraiah Iron and Steel Limited.

Similarly, in Kabini and Cauvery rivers water is polluted around townships situated on the banks (Deccan Herald, 24 February 2001).

Table 3. Status of water quality by habitations in Karnataka state – 2002

	No. of Habitations affected by						
Districts	***Excess Fluoride***	***Brackishness***	***Excess Nitrate***	***Excess Iron***	***Total No. of Habitations affected***	***% of affected habitations***	***Total No. of Habitations***
Bagalkote	135	158	33	88	414	65.30	*624*
Bangalore (U)	262	224	0	318	804	62.57	*1285*
Bangalore (R)	406	148	411	189	1154	34	*3394*
Belgaum	134	159	1	419	713	47.34	*1506*
Bellary	499	91	38	26	644	55.14	*1168*
Bidar	37	56	123	1	217	26.72	*812*
Bijapur	200	241	19	113	573	61.75	*928*
C.R.Nagar	34	27	425	173	659	79.40	*830*
Chikkmagalore	51	77	136	524	788	23.41	*3366*
Chitradurga	519	345	126	87	1077	78.67	*1369*
D.Kannada	2	4	0	294	300	9.56	*3137*
Davangere	358	156	288	1	803	74.08	*1084*
Dharwad	49	115	1	74	239	48.38	*494*
Gadag	127	42	0	0	169	48.38	*494*
Hassan	159	181	39	323	702	18.00	*3900*
Haveri	77	113	130	198	518	82.22	*630*
Kodagu	3	0	6	306	315	54.97	*573*
Kolar	509	319	1005	109	1942	51.90	*3742*
Koppal	477	50	0	4	531	74.89	*709*
Mandya	158	518	51	684	1411	75.33	*1873*
Mysore	105	434	121	288	948	49.02	*1934*
Raichur	322	195	129	51	697	57.18	*1219*
Shimoga	89	87	2	362	540	12.21	*4424*
Tumkur	658	585	976	1490	3709	67.63	*5484*
Udupi	11	2	1	218	232	4.11	*5640*
Uttara Kannada	24	74	13	145	256	6.56	*3901*
Total	*5838*	*4460*	*4077*	*6633*	*21008*	*37.06*	*56683*

Source: Govt of Karnataka 2002, Rural Development and Engineering Department

Additionally, mining activities too affect surface water quality, for instance in intensive mining areas of Bellary district water has been reported to contain neutral pH, high turbidity and suspended solids . 72 villages in and around Bangalore water sources are contaminated with e-coliform bacteria (Times of India 17 February 2007). All these evidences indicate that the quality of surface water is deteriorating in the state. As observed from the above discussion environmental pressures are rising on drinking water sources, both ground and surface, and also in the distribution system. Problems of depletion and deterioration of quantity and quality respectively result either in sub-optimal or nonfunctioning of drinking water supply systems, ultimately crippling the process of providing adequate safe drinking water to people (Goverment of Karnataka 2002).

The adequate solar radiation and need for relatively small quantities of fresh drinking water in Karnataka, solar distillation may have excellent possibilities in such situation.

Remarkably, many regions of the world present this situation, including developing countries where in many cases energy cost are high, labor costs are low, and populations are not highly concentrated (Bloemer et al., 1965). In Karnataka more than 90 per cent of habitations especially rural out of 56682 rural areas, depend upon ground water and are facing major risks of depletion of the source.

Out of 56682 rural habitants (Government of Karnataka, 2001), over 35 per cent of the rural habitations are yet to be covered with adequate drinking water supply.

The problem of inadequate drinking water supply is more acute in drought, where more than 30 per cent rural habitations lack access to adequate water supply (Table 3).

The drought regions are the yellow shaded regions (expect Kolar) and few parts of light blue shaded regions (Dharwad, Bangalore Urban, Chitradurga) from the Fig. 11. From Fig. 12 it results that these regions have relatively higher density of populations compared to adequate water regions. For the drought regions the solar technologies would mean more viable, as adequate solar radiation may be available and needs less maintenance. This can be justified by the following discussion as follows:

A survey by the Directorate of Economics and Statistics (Government of Karnataka, 2002) evidenced that majority of habitants had below 55 liters per capita per day (lpcd) of water supply (Table 4), an indication of lacunae in engineering plan, capacity installation and satisfaction derived by people. The department of mines and geology (DMG) while studying fluctuations and depletion in ground water has concluded that the level of ground water has depleted up to 7m in several districts (Table 5).

Many rural habitations in Karnataka are facing health problems due to inadequate water use and fecal oral transmission. For instance, people in few villages of Jagalur taluk in Davanagere district reported skin diseases after they stopped bathing due to shortage of water. Gastroenteritis (GE) is the major diseases with nearly 24 thousands of incidences and about 200 deaths in 2001and 20,524 cases of GE in 2006. It should be noted that viral hepatitis is increasing rapidly in the state from 1714 cases in 1997 to 5438 in 2001. Apart from health effects, inadequate water supply increases hardship on women and children, compelling them to spend more time and energy in collecting water.

India received solar energy equivalent to more than 5000 trillion kWh/ year, which is far, pre than its total annual energy consumption. The daily average global radiation is around 5 kWh/m^2 day with the sunshine hours ranging between 2300 and 3200 per year.

Table 4. Status of rural water supply in Karnataka (Government of Karnataka, 2002)

District	*No. of Inabitants with lpcd < 55 lpcd*			
	No.	*% to total*	*55 lpcd and above*	*Total*
Bangalore (R)	956	30.09	2221	*3177*
Belgaum	995	64.44	549	*1544*
Bellary	590	57.28	440	*1030*
Bidar	211	23.29	695	*906*
Bijapur	524	52.04	483	*1007*
Bagalkot	333	46.77	379	*712*
Chikkamagalore	705	19.79	2857	*3526*
Chitradurga	504	33.14	1017	*1521*
Davangere	391	31.94	833	*1224*
Dakshina Kannada	1470	47.88	1600	*3070*
Udupi	1402	41.38	1986	*3388*
Dharward	245	54.69	203	*448*
Haveri	339	48.85	355	*694*
Gadag	128	34.04	248	*376*
Gulbarga	1208	62.59	722	*1930*
Hassan	1923	44.53	2395	*4318*
Kodagu	452	82.94	93	*545*
Kolar	705	18.29	3149	*3854*
Mandya	705	18.29	3149	*3854*
Mysore	540	26.77	1477	*2017*
Chamarajnagara	509	75.18	168	*677*
Raichur	529	37.7	874	*1403*
Koppal	265	33.42	528	*793*
Shimoga	1068	23.39	3498	*4566*
Tumkur	1918	37.33	3220	*5138*
Uttara Kannada	1298	22.74	4411	*5709*
Bangalore(U)	701	64.79	381	*1082*
Total	20495		36187	*56682*
% to total no of villages	*36.16*		*63.84*	*100*

Table 5. Actual level of drinking water supply in rural areas (Puttaswamaiah, 2005)

Bore-well with hand pumps	91.7% of 470 rural habitations had less than 55 lpcd
Mini water supply schemes	Out of 646 schemes surveyed 91.48% reported less than 55 lpcd
Piped water supply schemes	86.07% of 977 rural habitations had adequate water supply less than 55 lpcd

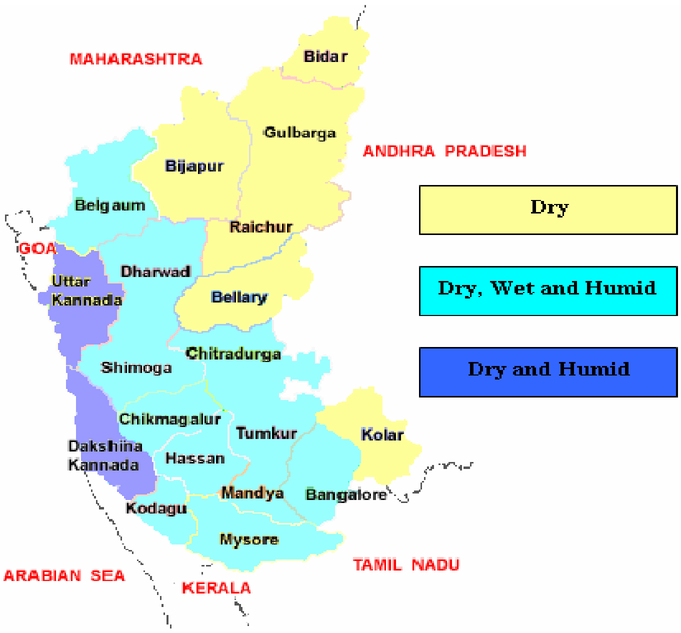


Fig. 11. Climatic variations in Karnataka (adapted: upon Government. of Karnataka, 2001)

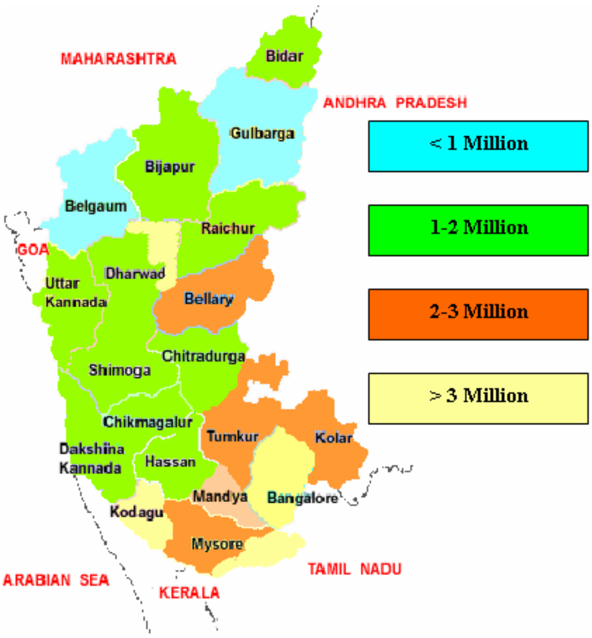


Fig. 12. Human settlement density in Karnataka (adapted: upon Government. of Karnataka, 2001)

Karnataka receives daily solar radiation in the range of 5.1–6.4kWh/m^2 during summer, 3.5–5.3kWh/m^2 during monsoon and 3.8–5.9kWh/m^2 during winter. The potential analysis reveals that maximum global solar radiation is in districts such as Uttara Kannada, Dakshina Kannada, etc. The study identifies that coastal parts of Karnataka with higher global solar radiation are ideally suited for harvesting solar energy.

Global solar radiation in Uttara Kannada during summer, monsoon and winter is 6.31, 4.16 and 5.48kWh/m^2, respectively. Similarly, Dakshina Kannada has 6.16, 3.89 and 5.21kWh/m^2 during summer, monsoon and winter, while Mandya district has minimum global solar radiation of 5.41, 3.45 and 3.73 kWh/m^2 during summer, monsoon and winter, respectively. The results were implemented in GIS to obtain maps showing district wise variation of global solar radiation. Fig. 13 shows the district-wise variation of global solar radiation during summer, Fig. 14 during monsoon and Fig. 15 during winter (Ramachandra and Shruthi, 2007). If one is keen in using solar stills, some of the few important parameters need to be considered such as area required per house, area availability, adequacy of insolation. Let us consider Bagalkot district (Northern Karnataka) which is located off the Raichur-Belgaum state highway as shown in the Fig.16.

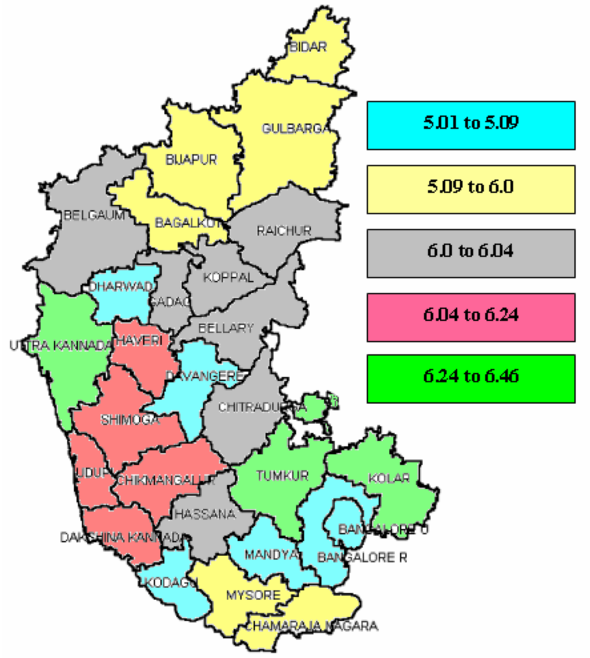


Fig. 13.Global solar radiations during summer

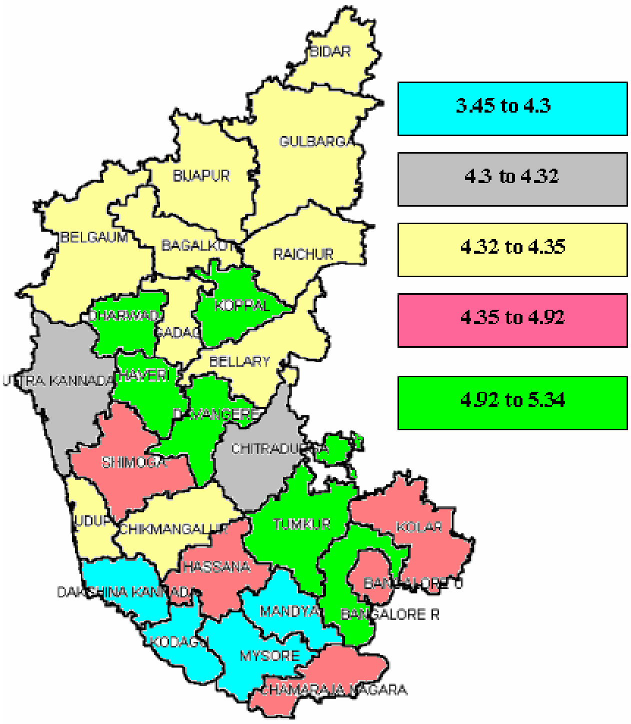


Fig. 14. Global solar radiations during monsoon

The Bagalkot district is spread over 6593 Sq. km. of an area, with 1.65 Million populations, 251 per Sq. km. of populations' density. It is positioned at 16°12′N, 75°45′E, the climate is warm and dry (41° C to 28° C) through out the year and rainfall (489 mm) is scarce (Census, 2001).

The following solar stills are considered for the analysis of selection of solar stills:

Single sloped solar still (left) consists of two units with and without perforated black plate (act as energy storage) were designed and constructed to maintain the comparison under the same weather conditions (Fig 17). The area of each solar still is 0.25 m^2 and 3.2 L/ m^2/ day and 2.8 L/m^2 /day were the respective productivity for 500 – 1400 W/m^2 (Nafey et al. 2001). The high output single unit solar still of 0.5 m^2 which would give 9 L/m^2/day at 35° C ambient temperature or approximately 1000 W/m^2 of insolation (Ward 2003).

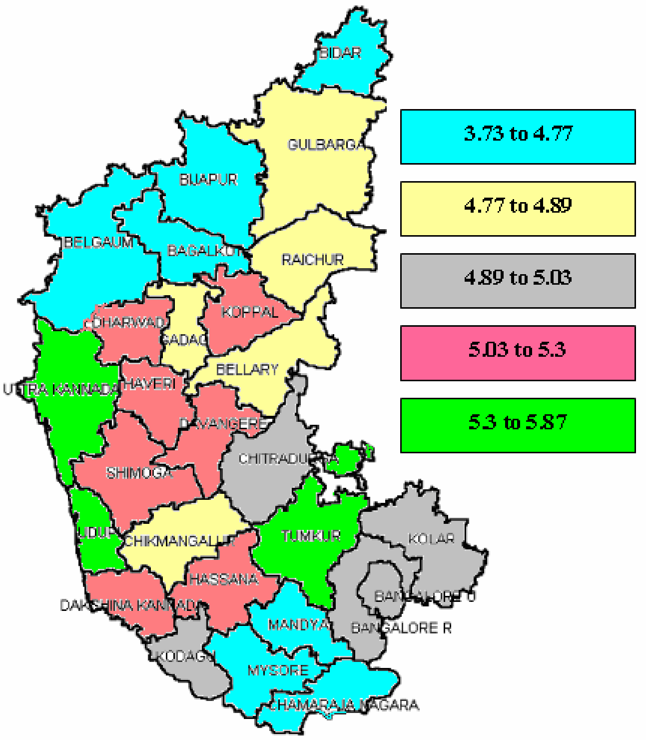


Fig. 15. Global Solar radiations during winter (Ramachandra and Shruthi, 2007) (Fig 13, 14 & 15)

7. An integrated assessment into suitability of various solar stills for India

Solar distillation (Bloemer et al., 1965), if a basin still is used, has a number of economic characteristics that are different from the other sea water conversion processes:

1. Unit construction cost is not affected appreciably by still size.
2. Power requirement are negligible.
3. The still is constructed on-site using unskilled or semi-skilled labor.
4. Operation and maintenance can be handled by people with little technical training.
5. Materials of construction are durable and readily available.
6. The still design is essentially modular; capacity of an existing still can be increased by any desired increment with practically no cost penalty.

Considering household size (per household) 6, the number solar still(s) required is/are:

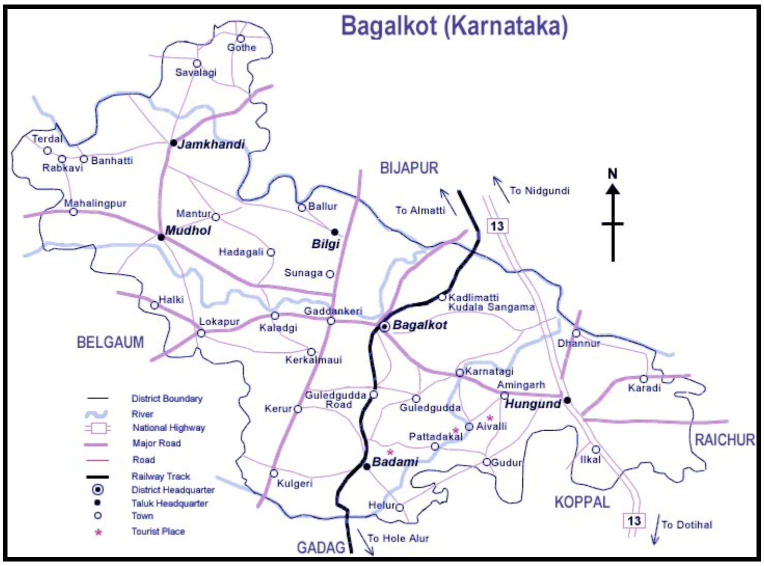
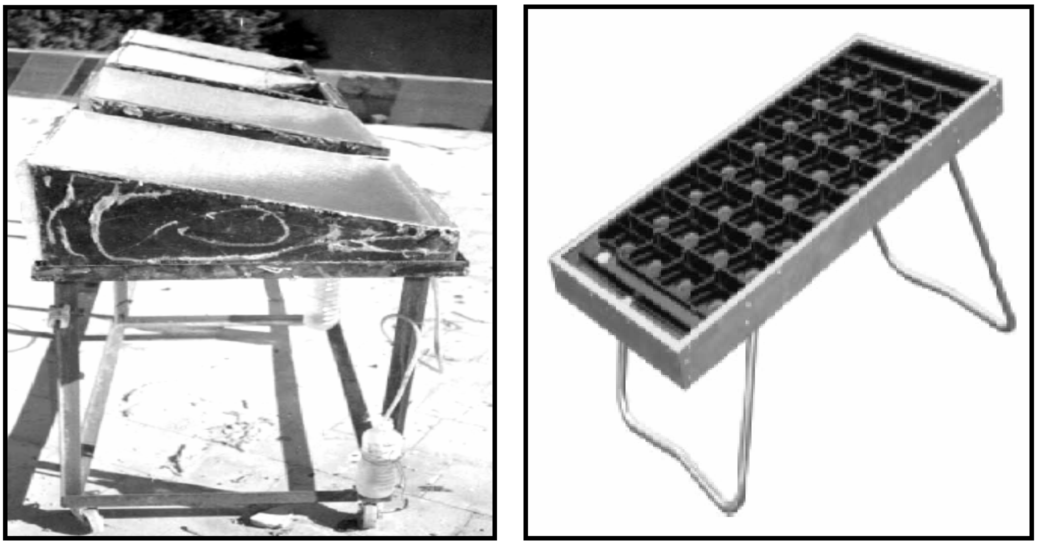


Fig. 16. Map of Bagalkot district (Northern Karnataka) (http://bagalkot.nic.in)



a) b)

Fig. 17. Single slope solar still (a) and High output single unit solar water purifier (b)

- Assuming the consumption of water per person is 3 L/day for drinking purposes. For a household size of 6, approximately 18 L/day for drinking purposes is needed. The selection of which type of solar still will depends upon the area available, for the singled slope solar still (left) of 0.25 m^2 whose productivity is 3.2 $L/m^2/day$. The number of solar stills required would be 6 stills. If one chooses the high output solar still unit (right) then two units would suffice. The above analysis can be used to extrapolate the study for any other regions also.
- The cost of the singled solar still would be 3000 (Indian Rupees) or 74 US $ (1 US Dollar = 40.00 Approx Indian Rupee (INR, Nov 2007)). The common configurations are V and L shapes. They are simple from the maintenance view and low construction cost. On the other hand, the advantages of having solar purifier are it is rugged, lightweight, portable and suitable for remote outback or Third World countries (Ward 2003). Other sophisticated solar still such as solar purifiers (Fig. 17) have been constructed, but the gain of increasing the productivity is canceled by the complexity of the unit (Nafey et al. 2001).

The above explanations can be justified as follows; when the purifier is operated in the static mode the dissolved solids in the water continuously flow through the purifier, then solids which were in solution are deposited on the surface on each tray and further exposure to the sun ultimately produces a colored hardened deposit that is undesirable. In order to remove these deposits dilute acids such as citric acid or oxalic acid need to be used, which be additional cost apart from labor cost. This means skilled labour is needed to maintain the solar purifier. Where has the singled sloped solar still would require minimum maintenance such as cleaning once in two days using simple brush.

- For common man time is equivalent to money. Having easy accessible to safe drinking water will reduce poverty. According to Asian Water Watch 2015 report (2006) safe water supplies immediately improves people's health and save them time, which they can use to study, or improve their livelihoods, so they can earn more, eat nutritiously, and enjoy more healthy lives (Paelmo, 2006). The above explanation can be justified with subsequent discussion.

Poverty Alleviation

Studies conducted by the Asian Development Bank (ADB, 2003) and Water Aid India (2005) on the impact of their projects on the communities in different parts of the Asia region found that multiple benefits were the norm, including many that had not been anticipated or invested in these benefits, which affected many aspects of life (UN-HABITAT 2006), included (Fig 18):

Time saved, along with reduced fatigue from not having to collect water from, on average, 6 kilometers away: this was often the benefit most valued by the community. The saving was usually directly translated into productive activities, especially women. For example, the education of women is severely affected as they have to devote much time in procuring water from long distances. The literacy rate for women in Rajasthan is the lowest in India 1.7 %, as compared to 87.8 % in Kerala (Census, 2001).

Health benefits, including lower medical expenditure and the reduction of the long-term debilitating effects of diseases such as endemic dysentery and worm infestations.

In India, water-borne diseases alone are said to claim 73 million work days every year. The cost in terms of medical treatment and lost production is around US$600 million per year.

Improved ***income opportunities*** from home-based livelihood activities that used the new water supplies, such as vegetable and live-stock production, brick and pot making, and operating food stalls.

Multiplier effects throughout the local economy from increased incomes and new enterprises based on improved water supplies.

Local organizations set up to build and run water supplies were often the basis for wider social mobilization, and led to the empowerment of women and greater social cohesion.

Savings and credit groups led to the development of wider access to credit among the communities and improved financial management skills. In urban areas, poor households also saved on the cost of water, as they had to pay informal providers high process.

The new skills, organizations and social cohesion, along with increased economic momentum, had impacts on the wider ***political and social system***, including at times influencing government policies and bringing about more balanced representation.

The above explanations can be justified by the following example, ease availability of water in Makueni district, Eastern Kenya has made life much easier as they used to travel for 3 hours carrying 20 litre of jerry can on their back in search of water along with group of people because of wild animals in their region.

Women in village worked out a timetable with their husband where they would go on alternate days to fetch water. They could now grow varieties of crops and vegetables. The diet has changed and they could save some money (Kshs* 300) after selling vegetables at the market (Lampe, 2007).

Fig. 18. Benefits of water for poverty alleviation

8. Conclusion

It can be concluded from the above the discussion that there is alarming need of solar distillation for community/ domestic levels to curb the existing problems to certain extent. Desalination may be advantageous for villages which are more than 20-25 km away from fresh water source from where a pipeline would have to be laid down. As seen above the situation in India is grim with its inherent problems of affordability and adaptation of cost intensive modern technologies. Thus the above technology has all the potential to be one of the cost-effective and pragmatic solutions to the water problems of rural areas in developing countries. Operationalzing this technology on a pilot basis to ascertain the affectiveness and receptive factors would enable it to be adopted on a large scale basis.

References

Ayoub J., Alward R., (1996), Water requirement and remote arid areas: the need for small-scale desalination, *Desalination*, **107,** 131-147.

Bloemer W.J. , Eibling A.J., Irwin R.J., George Lof G.O., (1965), *A Practical Basintype Solar Still*, Solar Energy Society Conference, Phoenix, Arizona, March 15-17, 197-200.

Buros O.K., (1991), *The world of desalting*. Paper presented at the second Brace Research Institute Conference, McGill University, Montreal.

Census, (2001), Number of literates and literacy rate, On line at: http://www.censusindia.gov.in/census_data_2001/India_at_glance/literates/.aspx, accessed on June 01 2008.

Delyannis A., Delyannis E., (1983), Recent solar distillant developments, *Desalination*, **45**, 361-369.

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

Fawell J., Bailey K., Chilton J., Dahi E., Fewtrell L., Magara Y., (2006), *Fluoride in Drinking-Water*, In *WHO Drinking-water Quality Series*, IWA Publishing, London.

Gomkale S.D., (1998), Solar desalination as a means to provide Indian villages with drinking water, *Desalination*, **69**,171-176.

Government of Karnataka, (2001), Study on rapid sector assessment in Karnataka, project planning monitoring unit, RDPRD, Bangalore.

Government of Karnataka, (2002), Study on rapid sector assessment in Karnataka, project planning monitoring unit, RDPRD, Bangalore.

Gupta S.K., Desphande R D., (2004), Water for India in 2050: First-order assessment of available option, *Current Science*, **86**, 1216-1224.

IS 10500, (1991), Bureau of Indian Standard, Drinking water specification. New Delhi, India.

Lampe J., (2007), The African Bulletin, Monthly News paper, July issue, The Netherlands.

Mandal B.K., Roy Chowdhury T., Samanta G., Basu G.K., Chowdhury P.P., Chanda C.R., Lodh D., Karan N.K., Dhar R.K., Tamili D.K., Das D., Saha K.C., Chakraborti D., (1996), Arsenic in groundwater in seven districts of West Bengal, India—The biggest aresenic calamity in the world, *Current Science*, **70**, 976-986.

Maps of India, (2007), On line at: http://www.infobase.co.in, accessed on July 2007.

Metcalf and Eddy, (2003), *Advanced wastewater treatment, waste water engineering treatment and reuse*, Tata McGraw Hill, Delhi, 4th Edition, 79, 101, 110, 1125-1205.

Naim M.M., Abd El Kawi M.A., (2002), Non-conventional solar stills Part.1 Non-conventional solar stills with charcoal particles as absorber medium, *Desalination*, **153**, 55-64.

Nebbia G., Mennozi G., (1996), *A short history of water desalination,* Acque Dolu Dal Mare, II Inchiesta Internazionaole, In: Proceedings of International Symposium, Milan,129.

Paelmo A., (2006), *Asian water watch 2015- Are countries in Asia on Track to Meet Target 10 of the Millennium Development Goals?* Asian Development Bank Publications, 1-16.

Park K., (2007), *Park's Textbook of Preventive and Social Medicine*, Banarsidas Bhanot publishers, Jabalpur, India, 19th Edn., 611-617.

Pooja V.K., (2007), Biosanitisers to make ground water potable. The Times of India, Bangalore, 3, Daily National Newspaper.

Ponnuraj S., (2006), *Manual on Water and Environmental Sanitation for Disaster Management*, WHO, India Country Office, New Delhi.

Popkin R., (1968), *Desalination: Water for the World's Future*, Praeger, New York.

Puttaswamaiah S., (2005), *Drinking water supply: Environmental problems, causes, impacts and remedies- Experiences from Karnataka*, Presented in the Drinking Water Session of the IWMI-TATA 4th annual partners meet, 24-26 Feb 2005, Anand, Gujarat, India.

Ramachandra T.V., Shruthi B.V.,(2007), Spatial mapping of renewable energy potential, *Renewable and Sustainable Energy Reviews*, **11**, 1460-1480.

Sawaal, (2008), What is the current population of India?, http://sawaal.ibibo.com/search/population. Accessed on 2 June 2008.

Sastry E.V.R., (2003), Village electrification programme in India, 3rd world conference on photovoltaic energy conversion, May 11-18, 2003, Japan, 2125-2128.

Thacker T., (2008), By 2017 India will be water-stressed, Indian Express, India's National Newspaper, April 08.

The Hindu, (2003), Quality of water in India among the worst, India's National Newspaper. March 6.

Pooja., (2007), City's ground water unsafe, The Hindu, India's National Newspaper, 15 Feb.

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

UN-HABITAT, (2006), *Social Marketing of Sanitation*. UN-HABITAT, Kenya and SIAES, India publication, 28, 29.

Ward J., (2003), A plastic solar water purifier with high output, *Solar Energy*, **75**, 433- 437.

Water Aid India, (2005), *Drinking water and saniation coverage, financing and emerging concerns*, Water Aid publisher, New Delhi.

Wheeler N.W., Evans W.W., (1870), Evaporating and distilling with solar heat. US Patent No. *102.633*.

World Resources Institute, (1993), World resources 1992-03: Toward sustainable development, Oxford University Press, New York.

Younos T., Tulou E. K., (2005), Overview of desalination techniques, *Journal of contemporary*, *Water Research and Education,* **132**, 3-10.