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Geothermal sourced desalination to mitigate food and water security in GCC and MENA countries

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ABSTRACT

With exponential increase in population and decreasing fresh water supply for drinking and irrigation, the future concern of all the countries is food security. Nearly 884 million people in the world have no access to drinking and many countries are either importing large quantities of food or supporting agricultural outside the country. This is especially so in the Arabian Gulf countries For an example, the freshwater demand for domestic and agricultural sectors in Saudi Arabia will exceed 20000 MCM/day by 2030. Groundwater levels in the Paleozoic-Mesozoic-Cenozoic transboundary aquifers will decline drastically in a decade putting heavy stress on the country. These countries have to depend on freshwater generated from the sea through desalination. Desalination through conventional methods (MSF, MDF, RO) using fossil fuels is not economical due to large CO_2 emissions and cost of the product. The energy needed to generate 1 m^3 of desalinated water is about 12 billion kWh. Conventional energy based economy should be replaced by renewable energy based economy for sustaining food and water security and GDP growth. Geothermal based desalination process is very economical in terms of cost and CO_2 savings. The cost of production of 1000 lof fresh water generated using geothermal sourced desalination process is about 1.6 US$ while it is 9 US$ if Solar pvis used.

1 INTRODUCTION

The annual population growth rate across the world is exponentially rising while availability of fresh water is waning. This is notably true for GCC (Gulf Cooperation Council) and MENA (Middle East and North Africa) countries. The GCC countries include Saudi Arabia, Kuwait, Qatar, Oman, Bahrain and UAE, and MENA countries include Eritrea, Ethiopia, Djibouti, Kenya, Egypt).Fresh water shortage is a global problem that would lead to short supply of food especially in the MENA countries. These countries are likely to be water stressed because of sharp increase in the population, obsolete economic activities, out-dated irrigation practice and poor rainfall (Zhang et al. 2014). By 2050 world population will reach approximately 9.2 billion (Chapagain and Tickner2012).Water demand will rise from its present volume of 6400 to 9060 Gm^3/year by 2050 at a consumption rate of about 7%/year to support food and fodder production (Mekonnen and Hoekstra 2011). These countries have to depend or promote Virtual Water Trade to meet such demands due to poor rainfall and absence of major surface water bodies (Hoekstra and Chapagain, 2008). 'Virtual Water' a concept was introduced by Allan (1998) to tackle the pressure on world water resources. Countries with surplus water also encourage VWT in order to save the country's resources (Hoekstra and Chapagain, 2008). The only alternate solution for GCC and MENA countries is to depend on seawater to protect water and food security. But the conventional energy source currently being used for desalination purpose is adversely affecting the climate and preventing the very purpose of solving freshwater problem. This can be mitigated if low carbon emitting and cost effective energy source is deployed for desalination of seawater. The GCC and MENA countries have huge untapped hydrothermal and hot dry rock resources that can be developed to overcome the food and water security issues. This paper discusses the current water and food security issues, and geothermal resources available in the GCS and MENA countries that can be utilized for generating freshwater from the Red Sea.

2. WATER RESOURCES OF GCC AND MENACOUNTRIRS.

Saudi Arabia (GCC), Ethiopia and Egypt (MENA) are included in this study because of their considerable geothermal resources. Kenya and Ethiopia are already utilizing this energy for electricity generation. Kenya is already developing these resources under the fast track programme.

2.1 Saudi Arabia

Saudi Arabia's economy depends entirely on oil export earnings and depends heavily on food imports to meet the demand of food and water security for its growing population. Its population is expected to cross 40 million by the year 2030 from the current 30 million (Abderrehman, 2006). In order to reduce this stress from agricultural sector (Fig. 1), Saudi Arabia is planning to bring down the demand by increasing food imports and increase the water supply to domestic sector.

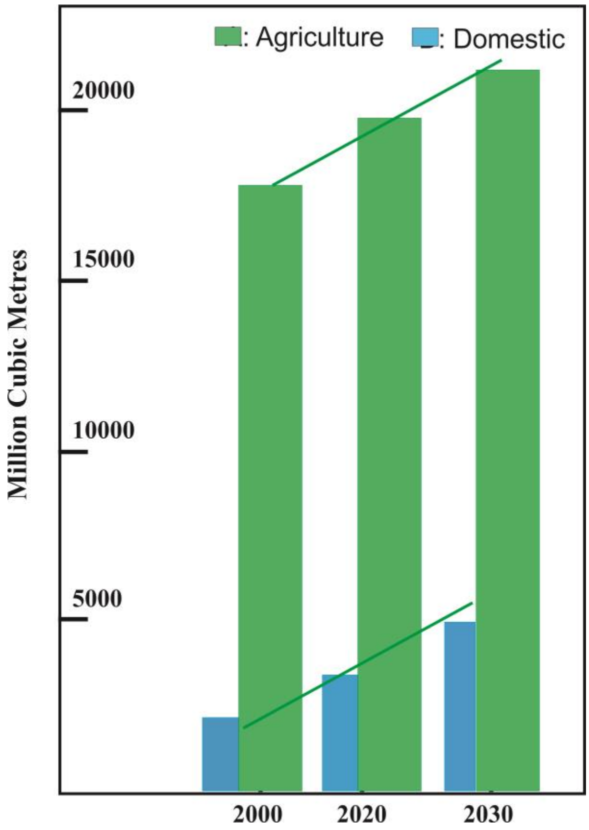

Figure 1: Current and future water demand of Saudi Arabia (adapted from Abderrehman, 2006 and Chandrasekharam et al., 2018).

Currently Saudi Arabia is targeting Paleozoic-Mesozoic and Cenozoic aquifers to obtainwater from depths of 1000 to 2000 m for irrigating large farms and utilizingconsiderable amount of energy (Grindle et al., 2015). The annual water demand by agricultural sector by 2030 is going to be > 4 times that needed by the domestic sector (Fig. 1). This increase is inevitable because the country lacks rivers and depends on canal irrigation supported by water drawn from deep non-renewable aquifers. The major aquifers supporting agricultural sector is the Saq sandstone aquifer with a capacity of 259 000 MCM, the Wajid sandstone aquifer with a capacity of 238000 MCM and the Tawilaaquifer with a capacity of 110 000. MCM. All are transboundary aquifers being shared by Jordan and Yemen and hence these aquifers cannot support the entire agricultural demand of Saudi Arabia (Chandrasekharam et al., 2018). There is, apparently no option for the country but to depend on desalination plants to generate freshwater to meet both domestic and agricultural demand. The current desalination technology in use is energy intensive (MSF and MED) consuming about, for example, 5.7 MWh/ton of energy for cultivating 5.6 tonnes/ha of wheat (Grindle et al., 2015) emitting about 4600 kg of CO_2 (Chandrasekharam and Bundschuh, 2008). The average energy consumed and the CO_2 emitted by energy intensive desalination technologies are presented in Table 1. At present, Saudi Arabia is consuming 134 x 10^6 kWh of electricity generated from fossil fuels to generate 275 l/ day per-capita desalinated water (Chandrasekharam et al., 2014 a,b).

Table 1. Energy consumption and CO_2 emission by energy intensive desalination technology adopted by Saudi Arabia (adapted from Chandrasekharam et al., 2018).

	MSF	**MED**
Average capacity (m^3/d)	**25000**	**10000**
Electrical energy (kWh/m^3)	**4**	**2**
Cost of plant ($\$m^3$/d)	**1300**	**1200**
Prodcution cost ($\$m^3$)	**1.1**	**0.8**
kg CO_2/m^3 (oil)*	**4.1**	**2.1**

The two desalination technologies are expensive compared to the reverse osmosis desalination technology. For example to generate, 1 m^3 of desalinated water, 12 x 10^6 MWh of energy is required (Ghaffour et al., 2014). The CO_2 emitted during this process is about 12 Mt (Chandrasekharam et al., 2015c). The country is already experiencing the effect of these emissions with increase in ambient temperature (Almazroui et al. 2012). Vacuum membrane desalination technology is relatively cheaper compared to MED and MSF. For example, the cost to generate 20000 m^3 / day of desalinated water using vacuum membrane technology is about US\$ 0.53/m^3 while the cost to generate similar volume of desalinated water using fossil fuels based technology is around US\$ 1.22/m^3 (Sarbatly and Chiam2013). The cost and CO_2 emissions issues can be mitigated if renewable energy sourced desalination technology are adopted. Among the renewable energy sources, geothermal energy is cost effective compared to solar pv (Fig. 2).

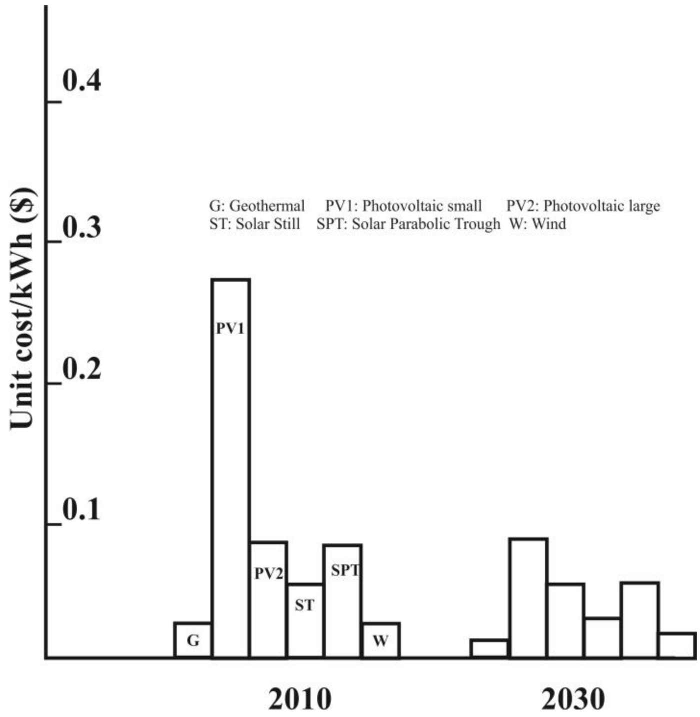

Figure 2: Unit cost of electricity generated from renewable energy sources (Chandrasekharam et al., 2018).

Therefore, desalination technology supported by geothermal energy source is cost effective compared to other renewables (Fiorenza et al., 2003). Once the EGS technology matures, the unit cost of electricity will match with that generated from fossil fuels.

2.2 Ethiopia

Ethiopia has considerable surface and groundwater resources. The Awash River basin is the main loci of agricultural activity in Ethiopia supporting domestic and agricultural sectors (providing 2,285 million m^3 of water for agricultural sector) and generating electricity (generating > 86 % of electricity) to support a population of95 million (MWR, 2011, Tucho et al., 2014). The hydroelectric power plant constructed over the Awash River has an installed capacity of 2300 MWe while geothermal energy source has the potential to generate over 30,000 MWe (USAID, 2016). In addition to the Awash River, Ethiopia has 9 major aquifers with an estimated volume of 30 billion $cm^3$of water supporting the agricultural sector (FDRE, 2011, 2014).

The additional advantage Ethiopia has is the Blue Nile, originating in Ethiopian mountains, which is a major feeder to the White Nile. Ethiopia is exercising exclusive rights on the Blue Nile water to expand its agricultural activity by constructing the *Ethiopian Grand Renaissance dam* over the Blue Nile. This will be the largest dam in Ethiopia that will limit large flow of water into the White Nile (Degefu and Weijun, 2015). Although Ethiopia‘s agricultural production depends on the monsoon (FDRE, 2011), with the proposed construction of the Grand Renaissance Dam over the Blue Nile and the development of geothermal projects, the country will be in a comfortable position with respect to food and energy security and may be in a position to offset biomass energy that supplies nearly 334 TWh of electricity to rural population (Tucho et al., 2014).Ethiopia may face future food and water security in the form of virtual water trade (VWT). Countries like China, India, Turkey and Saudi Arabia are investing in Gambella region in Ethiopia to grow soya, rice, sugar cane and cereals. This may erode part of Ethiopia's water resources if sufficient water resources management practices are not implemented by (Yassin, 2014). Ethiopia is the only country in the MENA region that does not require desalination plants.

2.3 Egypt

Egypt's population is projected to grow to 106 million by the year 2030 from the current 87 million (WB, 2014, Pacini and Harper, 2016). Nearly 97% of its water demand is met by the Aswan Dam constructed over the Nile River and the rest from shallow aquifer. Aswan Dam supplies over 57 billion m^3 of water to Egypt. The per-capita water consumption is about 600 m^3 /year. In addition, Egypt draws water from the transboundary Nubian Sandstone aquifer (Mesozoic age) that is shared by Egypt and Libya. This aquifer is estimated to contain 200 trillion $m^3$of non-renewable water. Although the land area of Egypt is 1 million km^2, only 3% of it is cultivable and falls within the Nile River basin (ICARDA, 2011). The cultivable area is not able to support the population. To meet the irrigation demand, Egypt has commissioned several desalination plants to generate freshwater both for agricultural, domestic and to support livestock. However, due to current population growth trend, to meet the future demand, Egypt needs nearly 1200 such plants at a cost of 1.7 trillion US$ (Keith et al., 2013). The country has entered into virtual water trade with other countries to meet food security and save water. In the year 2000 Egypt saved 5.8 billion m^3 of water by importing 5.2 tonnes of maize (Renault, 2002).In future Egypt may have issues with the 57 billion m^3 of water being supplied by the Aswan Dam. The Nile riparian countries sharing NileRiver water (Table 2) are exercising their right to increase the use of Nile water putting an end to free usage of Nile River by Egypt and Sudan. With the proposed construction of Ethiopian *Grand Renaissance dam* over the Blue Nile, Egypt has no option but to enhance the number of desalination plants to meet future freshwater demand.

Table 2: Riparian countries sharing Nile River water (modified after Chandrasekharam et al., 2018).

Country	Area km2	Area within Nile basin km2
Burundi	27835	13260
DR Congo	2345410	22143
Egypt	1001450	326751
Eritrea	121320	24921
Ethiopia	1127127	365117
Kenya	826505	46229
Rwanda	26340	19876
Sudan	2505810	1978506
Tanzania	945090	84200
Uganda	236040	231366

3. Geothermal Resources of Saudi Arabia, Ethiopia and Egypt

Detail account on the tectonic and geochemical evolution of thermal springs around the Red Sea and in MENA countries can be found in several publications (Chandrasekharam et al., 2014 a, b, 2015 a,b,c,d, 2016 a,b,c, 2018). Only salient information related to these provinces is described here.

3.1 Saudi Arabia

Amongst the GCC countries, Saudi Arabia has considerable geothermal resources (both hydrothermal and EGS; Fig.3) that can be utilized for power generation and desalination. The hydrothermal systems are associated with "*Harrats"* with surface temperatures varying from 31 to 79 °C. The geothermal sites associated with the volcanic centers registered high geothermal gradient (>90 °C/km). The heat flow value recorded over the Western Arabian shield geothermal provinces is > 80 mW/m^2 (Gettings et al., 1982, 1986, Coleman et al., 1983, Chandrasekharam et al., 2016 a,b)

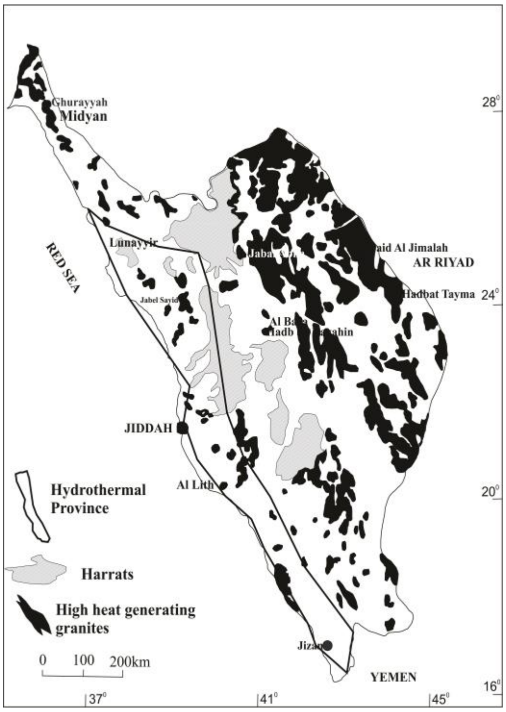

Figure 3. Geothermal sites in the western Arabian shield and the distribution of high heat generating granites (Chandrasekharam et al., 2015 d, 2016a).

The most prominent hydrothermal sites are located in Jizan and AlLith. These sites are estimated to generate 134 x 10^6 kWh and 120 x 10^6 TWh of electricity respectively (Chandrasekharam et al., 2014 a, b, Lashin et al., 2014). Besides the hydrothermal source, high heat generating granites constitute good sources for generating electricity. These radiogenic granites occupy an area of about 161467 km^2 (Stoeser, 1986) and contain high U (363 ppm), Th (625 ppm) and potassium (4%) concentration compared to normal granites. Thus the heat generated by these granites is of the order of 134 μW/m^3 and the surface heat flow value recorded over these granite masses is 1382 mW/m^2 (Stuckless et al., 1987, Harris and Marriner, 1980, Chandrasekharam et al., 2014a, Chandrasekharam et al 2015c). Further, geophysical investigations recorded the Moho at shallow depth (~ 18 km; Park et al., 2008). This gives a surface heat flow values of 250 mW/m^2 over the shelf region and 100 mW/m^2 over the region between the coast and the escarpment (Girdler, 1977). Similar value (175 mW/m^2) has been reported over the Suez Gulf region (Morgan and Swanberg, 1978, Zaher et al., 2011). Somerville et al (1994) estimated that 1 m^3 of such granites can generate about 79 x 10^6 kWh of electricity. Following the procedure adopted by EGS project of Cooper Basin, Australia, 2 % recovery of heat from granites with 134 μW/m^3 heat generating capacity e.g. Midyan granites (Fig. 3), can generate 160 x 10^{12} kWh of electricity (Somerville et al., 1994).

3.2Egypt

The main hydrothermal sites are located on the banks of the Suez Gulf, with surface temperature of the thermal springs varying from 51 to 70 °C (Swanberg et al., 1983). These sites have recorded high heat flow values (>95 mW/m^2) and bottom hole temperatures, measured in certain oil wells, vary between 120 and 260 °C (Morgan et al., 1976, Zaher et al., 2011, 2012).

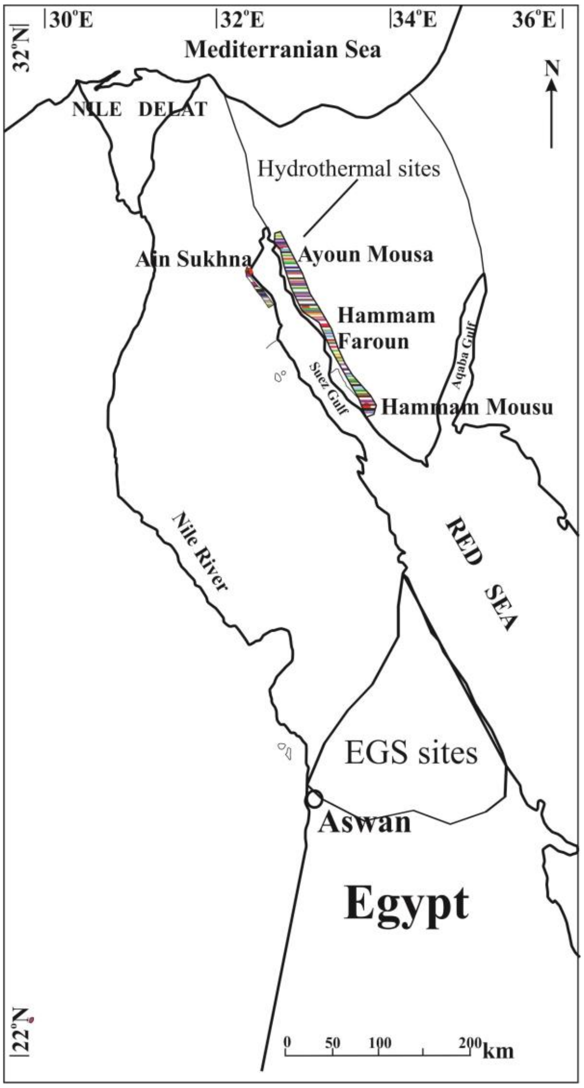

Fig. 4. Hydrothermal and EGS sites in Egypt. The heat flow values over EGS sites (represents outcrop radiogenic granites) vary between 100-1136 mW/m^2 (adapted from Chandrasekharam et al., 2016 c).

It was reported that the hydrothermal sites can generate 221 x 10^6 kWh of electricity (Lashin 2012, Zaher et al., 2012). The EGS sites represented by high heat generating granites registered heat flow values of 1136 mW/m^2 (Chandrasekharam et al., 2016 b, c). The El Faliq granites located east of Aswan Dam, has a surface outcrop of 95 km^2, and is estimated to generate 7 x 10^9 kWh of electricity (Chandrasekharam et al., 2016 c).

3.3 Ethiopia

The East African Rift valley in Ethiopia hosts several high temperature geothermal sites shown in Figure 5. Currently AlutoLangano, located within the rift valley and Tendaho located within the Danakil depression are being developed for power generation. The estimated installed capacity of these two sites is 100 MWe(MWE, 2012). Since Ethiopia is developing large hydro-electric projects on the Awash River and over the Blue Nile, geothermal development is given less priority at present. The existing and the future irrigation projects will keep the country food and energy secured. However, the East African Rift valley geothermal provinces (Olkaria, Menengai, Eburu, Silali, Suswa) in Kenya are well developed these provinces may become the energy provider to the entire East African countries in the next decade.

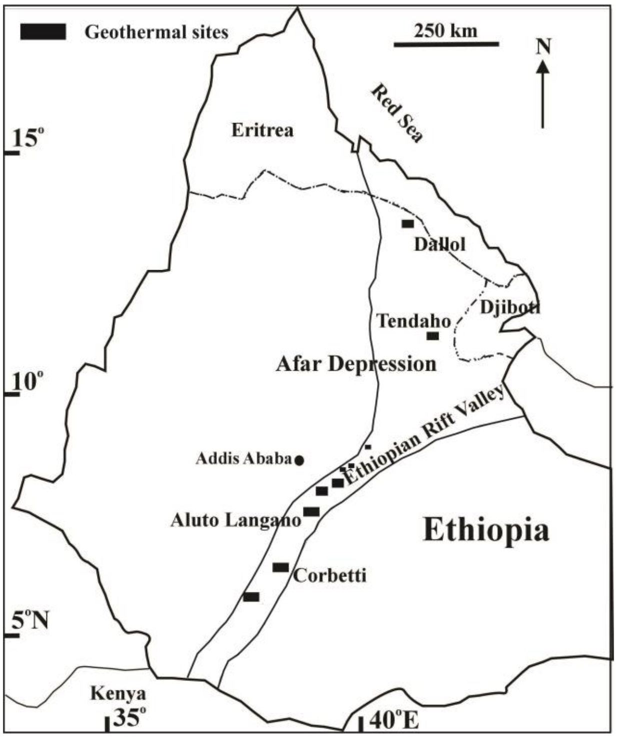

Figure 5. Geothermal sites in the Ethiopian Rift Valley.

4. Discussions

The levelized cost of electricity generated from geothermal energy source is much lower compared to other conventional and non-conventional energy sources (Table 3).

Table 3. Levelized cost of electricity generated from various energy sources (adapted from Chandrasekharam et al., 2014a, 2018, Zarrouka and Moon, 2014; 1: Capacity Factor, 2; Levelized Capital Cost; 3. Fixed O & M; 4. Variable O & M; 5. Transmission investment; 6. Levelized cost US$cents/kWh; * 2011 US$ value).

	1	2	3	4	5	6
Conventional coal	85	66	4	29	1.2	10
Geothermal	93	76	12	0	1	9
Wind	34	70	13	0	3	9
Solar pv	25	130	10	0	4	14
Hydro	52	78	4	6	2	9

The capacity factor of geothermal power plants is much higher compared to other power plants using conventional and other renewable energy sources (Table 3). Unlike other power plants supported by conventional and non-conventional energy sources , the geothermal energy power plants can supply base load electricity and is online > 90% of the time. The land required for geothermal power plants is much smaller (1 to 2 acre/MWe plant) compared to solar pv (12 acre for MWe) and wind (65 acre/MWe) (Chandrasekharam et al., 2014a) based power plants. In addition to these advantages, the freshwater generated from geothermal energy sourced desalination plants is much cheaper relative to that generated using other energy sources (Table 4).

Table 4: Cost comparison of desalination plantssupported by conventional and non-conventional energy sources (adapted from Chandrasekharam et al., 2018).

Energy source	cost /m^3 (1000 L)
Fossil fuels	2.87
Wind	5.32
Solar pv	9.59
Solar collectors	8.5
Geothermal	1.61

Table 5. Renewable water availability in Saudi Arabia, Egypt and Ethiopia (adapted from Miller, 2003).

	Total (km^3/y)	Per Capita m^3/y	Per capita (m^3/y)
	Current	current	2030
Saudi Arabia	2	85	63
Egypt	69	636	789
Ethiopia	110	1680	1020

The per-capita water availability in the countries under discussion will drastically lower in future compared to the present level. Hence, these countries in future will be highly water stressed. Ethiopia has to manage its water resources by curtailing VWT with other countries and protect its food and water security. Other countries have to develop their geothermal resources so that the cost of desalinated water could be affordable to large population and in particular to the agricultural sector (Table 4). This will reduce food imports to large extent and provide food and water security for the millions. Emissions reduction will help the countries to manage issues related to climate and water resources. The advantage both Saudi Arabia and Egypt have is the presence of granites with high heat generating capacity, with temperatures > 180 °C at shallow depths (Chandrasekharam et al., 2015d). With advancement made in drilling technology (e.g. plasma drilling technology), the granites will be the future energy source to provide food and water security to water stressed countries (MIT, 2006).

5. Conclusions

Water and food security are the prime concerns of GCC and MENA countries due to their geographic location, arid climate and poor rainfall. They are water stressed countries. Taking into account the available geothermal energy sources, future water requirement and the present water availability, these countries are not in a helpless condition as for as food and water security are concern. Geothermal energy resources can bail out these countries from future water and food crisis. Compared to solar pv, geothermal is cost effective in supporting (US$ 1.6 /1000 l) fresh water supply to all the GCC and MENA countries. In addition to free energy source, these countries can save CO_2 and earn additional revenue through carbon trade. Although VWT is a good option (short term solution), with exponential growth in population, water rich countries will eventually exit from VWT due to local demand leaving the receiver countries in distress. The respective governments need to rethink and reframe their energy, trade, food, and water security policies. Countries will be energy independent once the EGS technology (plasma drilling) matures. It took nearly 160 years for the oil industry to attain the present status with industrial revolution acting as a catalyst for its augmented growth. Future water and food crisis will necessitate the countries to invest more in geothermal based desalination technology. Countries have to prioritize their developmental plans to generate fresh water from the sea to satisfy the growing millions using geothermal energy. Extraction of heat from earth and generation of electricity is a proven technology. With fine tuning of drilling and heat exchanger (hydro fracturing technology) technologies the cost of electricity will be affordable to the millions.

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