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Desalination of Seawater using Geothermal Energy for Food and Water Security: GCC and Sub-Sahara countries

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ABSTRACT

Number of waters stressed countries are growing due to changes in global weather pattern and variation pattern in the rains. The most affected countries are Gulf Cooperation Council Countries (GCC) and Sub-Saharan countries like Ethiopia, Egypt, Djibouti and Eritrea. Currently nearly 70 million tonnes of food is imported to these countries and imports are expected to cross 100 million tonnes in few years. VWT (virtual water trade) is not a solution for food-energy-water security to these countries. Fortunately, these countries have huge geothermal resources, like Kenya, lying untapped. Financial institution should support the development of easily available energy sources rather than giving interim relief there by increasing the financial burden of these countries. Desalinated water using geothermal energy sources will cost << than US$ 1.6/L. This is far lower than the cost of fossil fuels based desalinated water that is being sold in these countries. Geothermal energy can liberate these countries from VWT and poverty within a short period of time.

1. INTRODUCTION

Food security is a great concern for all the GCC and Sub-Saharan countries. Water becoming a scarce commodity, these countries heavily depend on food imports to sustain life. The present volume of food imports by these countries stands at 70 million tonnes (Figure 1). Greater than 884 million people have no access to water (Papapetrou et al., 2010). In the present paper, food security issues and mitigation strategies using available geothermal energy in Saudi Arabia, Egypt, Ethiopia, Eritrea and Djibouti are discussed.

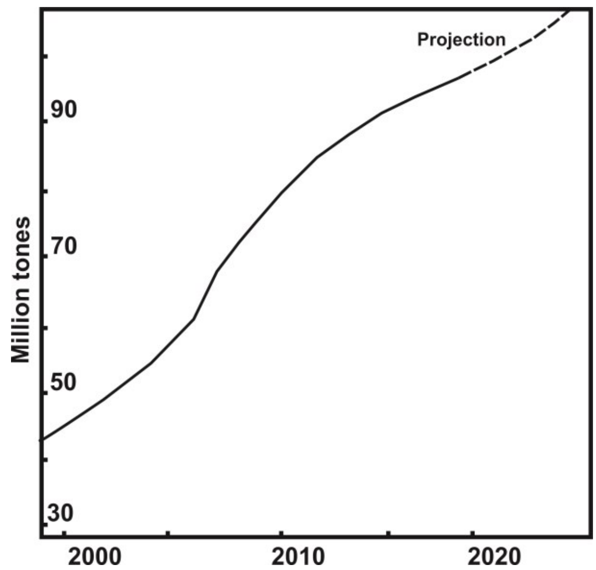

Figure 1: Food imports by GCC and Sub-Sahara countries (adapted from Nigatu, and Motamed, 2015, UNDP, 2016).

Greater than 85% of the landmass in these countries is desert. Due to poor rainfall, high evaporation, the fresh water supply to these countries is poor. If this situation continues, food secured countries will become very powerful in future and those which lack food security will collapse, even though they may have sufficiently rich oil resources. Water is essential not only for food production but also to sustain other developmental activities. Only 15% of water is available for energy production (IEA, 2012). Some of the countries, like Saudi Arabia, are using formation water stored in the old geological strata associated with oil rich formations. For example, Saq Ram sandstone aquifer belongs to the Cambrian while Umme-Raduma limestone aquifer belongs to the Ecocene. These aquifers are transboundary in nature and hence any one country have no control over the water available in these aquifers (Chandrasekharam et al., 2015). The per-capita water supply has decreased from 3500 cubic meters to 500 cubic meters and is expected to fall below 500 by 2025 (Chandrasekharam et al., 2018).

Currently these countries are managing water related issues through desalination of seawater using fossil fuels. Utilizing fossil fuels for desalination process is not economical-cost wise and is not environmentally friendly as this process generates large quantities of

CO_2. Both the issues can be solved if low carbon emitting free energy source is utilized for desalination process. In this paper we discuss the use of geothermal energy source as the best option to be food and energy secured by the countries under discussion.

2. WATER RESOURCES OF GCC AND SUB-SAHARAN COUNTRIES

2.1 Saudi Arabia

Saudi Arabia withdraws 20 billion m^3 of groundwater in a year. The annual groundwater recharge is only 2.4 billion m^3. The remaining 17.6 billion m^3 of water is drawn from Mesozoic Saq-Ram sandstone aquifer (fossil water) for domestic and agricultural purpose. About 17300 km^2 of area is irrigated using this water mainly to support wheat, barley and dates cultivation. This aquifer has 103,360 MCM of fossil water which slightly saline (Chandrasekharam et al., 2016). This is a trans-boundary aquifer being shared by the neighboring countries that drain nearly 394 MCM /y of water from this aquifer. Due to heavy withdrawal, the water table in this aquifer is receding. Due to prevailing water stressed situation, the country has increased wheat imports and stopped growing wheat and barley. Saudi Arabia is not able to support 88 kg/y of per-capita wheat production to its 28 million population (Chandrasekharam, 2018). Saudi Arabia may be able to support domestic water demand but its agricultural water demand will rise to 20000 million m^3 by 2025. To supplement the fresh water demand, Saudi Arabia operates nearly 128 desalination plants. Many desalination plants use multistage flash desalination (MSF) method using conventional fuel as source of energy. Nearly 12 TWh of electricity is utilized to generate about 1-meter cube of fresh water (Ghaffour et al., 2014; Chandrasekharam, 2018). This process generates about 13 Mt of CO_2 (Chandrasekharam et al., 2016). This method of generating fresh water through desalination using fossil fuel is not economically unsustainable (Ahmad and Ramana, 2014). The desalinated water is being sold at US$ 0.03/m^3 with government subsidy while the actual cost is US$ 6/m^3. The severity of the issues has been realized now and serious concerns are being expressed (Amery, 2015) to find out viable and sustainable solution to solve future water issues and provide food security to the country.

The country has huge untapped hydrothermal and EGS sources locked in the western Arabian shield region (Chandrasekharam et al., 2016, 2015a, b). The most economical and sustainable method to obtain fresh water from the sea is to adopt desalination method supported by either solar pv or geothermal sources. Solar pv is not cost effective due to many inherent issues related to supporting facilities. Geothermal is best suited as it can provide baseload electricity and the system can work continuously irrespective of weather conditions and work at 90% efficiency (Chandrasekharam, 2018). Further, the unit cost of electricity generated by geothermal will be lower relative the electricity generated by solar pv (without subsidy) in another decade (Chandrasekharam et al 2017).

2.2 Egypt

The Nile River is the back bone of Egypt's development, providing 58 billion m^3 of water to meet domestic and agricultural demand and supporting a population of 97 million people. Besides this surface water source, the Nubian sandstone aquifer supplies non-renewable groundwater (fossil groundwater) both to Egypt and Libya. Like Saudi Arabia, Egypt's demand for water is huge and per-capita consumption, currently, is 985 m^3/y. With growing population and declining water sources, the per-capita water is going to fall drastically to 500 m^3/y by another decade (Attia and Mohammad, 1998; Abdin et al., 2009) when the population will cross 106 million (WB, 2014; Pacini and Harper, 2016; ICARDA, 2011; Degefu and Weijun, 2015). Once the proposed "The Ethiopian Grand Renaissance dam" over the Blue Nile is constructed, Egypt will be highly water stressed and have to increase food imports to sustain growing demand (Degefu and Weijun, 2015). Further, all the riparian countries of Nile River are claiming their right for water sharing. By 2025 water available to Egypt will drastically reduce. Egypt have to depend on virtual water trade (VWT) and keep the country's food security at risk. To avoid disputes with neighboring countries and to ensure food security, the country has to depend on desalination of seawater. Egypt has already commissioned several desalination plants along the Red and Mediterranean coast. Egypt has to spend about US$ 200 million to generate 20000 m^3/d of freshwater from the sea, using fossil fuel and MSF technology. Amongst MENA countries, Egypt was the first to have commissioned desalination plant 1912 (Fiorenza et al., 2003), generating about 75 m^3/d of freshwater from the seawater. The best option for Egypt is to develop its geothermal resources (hydrothermal and EGS) and utilize this energy for desalination process (Chandrasekharam et al., 2018). This will reduce its dependency on food imports and reduce CO^2 emissions. Egypt has the potential to generate about 890 x 10^6 kWh of electricity from its geothermal provinces located on either side of the Faraun is about 223 x 10^6 kWh (Lashin and Al Arifi, 2010; Zaher et al., 2011, 2012; Chandrasekharam et al., 2016 b, 2018). In addition to the above hydrothermal systems, Egypt has large volume (1100 km^2 of exposed surface area) of high heat generating granites along the Red Sea coast and around Aswan Dam. The heat generated by these granites varies between 82 and 136 µW/m^3 (Chandrasekharam et al., 2016a). It is estimated that the granites located east of Aswan Dam alone can generate over 632 x 10^9 kWh of electricity (Chandrasekharam et al., 2016 a, b).

2.3 Eritrea

Eritrea is a land of volcanoes built over the Precambrian basement. Groundwater occurs in fractured basalt flows and basement granites. The Barka Anseba basin receives large part of the rain (~ 200 -1000 mm) and holds large part of the surface water and supports large part of urban population and food production (Gurtner et al. 2006; Selamawit and Kohler, 2015). Besides surface water, several bore-well supply water for irrigation and domestic needs. While the available water is little above 500 x 10^6 m^3, the demand is about 2540 x 10^6 m^3 (Alemngus et al., 2017). There for a large part of cultivable land is not being utilized due to shortage of water. The country heavily depends on food imports and the in 2015 the food imports crossed US$ 160 million. If a sustainable solution to sustain agriculture activity is not found, the country will collapse due to huge debts and poverty (WAE, 2008; Chandrasekharam et al., 2018). Eritrea has several geothermal provinces associated with active and dormant volcanoes. The Alid geothermal province is one of the potential fields that can generate 10^9 kWh of electricity that can be utilized for desalination of Red Sea water. About 445 million m^3 of fresh water can be generated using tis energy from the geothermal source (Chandrasekharam et al., 29018). Harnessing similar amount of power from its other geothermal fields (in the active Danakil graben), the country could sustain agricultural activity and provide food security and energy to the population.

2.4 Djibouti

Djibouti, located within the Afar triangle, receives less than 200 mm of rain annually and a large part of it evaporates. There are no rivers in the country and agricultural activity has to depend on groundwater (JICA, 2014). Groundwater occurs in basalt flows and tuffs) and about 12 million m^3 of water per year is being withdrawn from these aquifers to support domestic and business activities especially in Djibouti town. The rural areas have no access to water (most of the land is desert). However, the country has large untapped hydrothermal resources located around Lake Asal, Lake Abhe and Hanle with a potential to generate 932 x 10^9 kWh from Lake Asal and several 9 x 10^6 kWh producing power plants around Lake Abhe and Hanle geothermal sites (Chandrasekharam et. al., 2019). This energy can be utilized to generate fresh water from the sea to support agricultural activity in rural Djibouti. Geothermal energy could provide sustainable development and free the country from agricultural imports.

3. COST OF ELECTRICITY AND DESALINATION

Figure 2 shows the cost of electricity generated from various energy sources. Considering the CO_2 emissions and environmental issues, level zed cost of electricity generated from geothermal energy is much lower (Breeze, 2010; Nusiaputra et al., 2014; Assad et al 2017; Chandrasekharam et al., 2018).

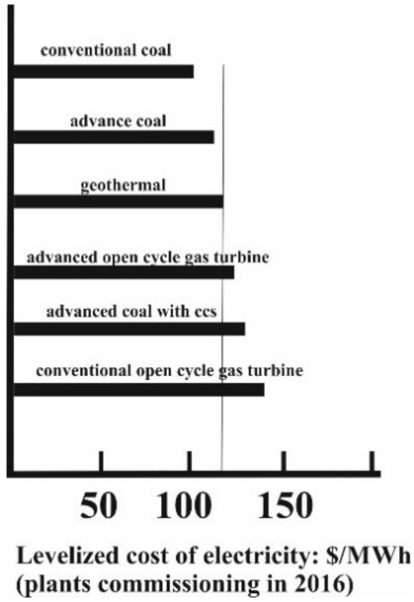

Figure 2: Levelized cost of electricity (adapted from (Breeze, 2010; Nusiaputra et al., 2014; Assad et al 2017).

The commonly followed desalination technologies are i) Multi Effect evaporation/Distillation (MED), ii) Multistage Flash Distillation (MSF), iii) Mechanical Vapour Compression (MVC), iv) Electro Dialysis (ED), and v) Reverse Osmosis (RO). All these desalination technologies are energy intensive and consumes large amount of electricity. All these plants are operated through fossil fuel sourced energy. Even the RO, which is low electricity consumer technology, needs 4 kWh/m^3 of freshwater generated through desalination of seawater. A good example is the RO plant being in operation in Sydney. This desalination plant here generates 25000 m^3/d of freshwater from the seawater and emits about 954 tonnes of CO_2 /day (Ghaffour et a., 2014). The fresh water generated hence is expensive and the cost is not sustainable over a period of time. The cost is about US$ 0.53/m^3 (when fossil fuels price was ~ 10 US$/ton). In the case of same volume of water generated using other desalination methods is about US$ 1.22/m^3 (Sarbatly and Chiam 2013). But this cost can be mitigated using geothermal energy as source for desalination. As shown in Table 1, out of the conventional and renewable energy sources, geothermal stands out in terms of cost of freshwater generated and CO_2 emissions.

Table 1 Cost of desalinated water and CO_2 emissions from desalination plants sourced by fossil fuel and renewable energy (modified after Chandrasekharam et al., 2019)

	Fossil fuel	Solar	Geothermal
Power input kWh/1000 L	6	6	6
Cost US$/1000L	21	15	1.6*
CO_2 emissions kg/1000 L	4	0	0.4**

The unit cost of desalinated water was around US$ 0.5/m^3 (when the cost of fossil fuels was ~10 US$/ton (Reddy and Ghaffour 2007). The energy required for generating 1000 m^3/d of (1 x 10^6 kg/y), freshwater from the sea is about 11 x 10^6 MWh. The CO_2 emitted by 1 MWe (~613 x 10^6 MWh) of fossil fuel supported power plant is about 817 kg (Chandrasekharam and Bundschuh, 2008; Kalogirou 2005; Gude 2015). Amongst the desalination technologies commonly adopted currently, MED gives most optimum results in terms of cost, energy consumption and CO_2 emissions and salinity concentration of the feed water. (Table 1). The GCC and Sub-Saharan countries discussed here have considerable geothermal resources that are lying untapped. These countries should exploit this energy resource to sustain long term food and water supply.

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4. CONCLUSIONS

The GCC and Sub-Saharan countries depend heavily on VWT and import large volumes of food items to meet growing demand. Thus, their food security lies outside the country. If this situation continues for a long time then these countries will have risk of lowering their sustainability. Although these countries, at least couple of them, have facilities to obtain freshwater through desalination even at higher cost, there other countries which are poor and need rapid economic development to float above the poverty line need to focus on developing their geothermal resources. Geothermal supported desalination method is cost effective and lift the countries from the poverty line by providing food and water security. Financial grants these countries receive from financial institutions should be utilized for developing their geothermal energy resources. These countries have unexploited geothermal energy resources that can be utilized for the above purpose.

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