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Geothermal Energy Resources of Saudi Arabia: Country Update

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ABSTRACT

Saudi Arabia consumes 240 terawatt hours of electricity to date from oil and gas and the projections are that the country's demand will reach 736 terawatt hours by 2020 (IEA, 2012, WB 2009). 80% of the electricity is being used for cooling purpose. The current per capita emission of CO_2 has increased to 0.016 Gg from 0.012 Gg in 2000. The country is now focusing on developing renewable resources that were not utilized due the availability of huge oil and gas resources. Large potential of unutilized geothermal resources are encountered in Saudi Arabia, mainly of three categories. Low enthalpy resources represented by deep-seated aquifers that can be accessed only by deep oil wells, medium enthalpy resources (hot springs) encountered along the western and southwestern coastal parts and high enthalpy resources (Harrats) that are represented mainly by lava fields of approximately 80,000 km², with fumarole activity (Harrat Khaybar). The issuing surface temperatures of the thermal springs in these provinces vary from 31 to 96°C with a flow rate of 5 to 20 l/m.

Preliminary assessment was made on the geothermal potential of the hot springs encountered at Al-Lith and Jizan sites (Ain Al Harrah, Al Khouba, Al-Ardah and Bani Malik) using integrated geological, geochemical and geophysical techniques. Wide ranges of reservoir temperatures (130-220ºC) and heat flows (120-210 µW/m2) are estimated from geothermometers. The geophysical investigations have indicated that geothermal feed zones are titled and controlled by a number of NW-SE, NE-SW and E-W oriented fault systems. Based on the reservoir characteristics, surface area of the volcanic flows, flow rates, heat flow and geothermal gradients of the geothermal provinces, it is estimated that the wet geothermal systems can generate about 23 x 10^9 kWh. Moreover, the western Saudi Arabian shield encloses a large number of pre and post orogenic high radioactive granites with very high generating capacity from 15 to 134 $\mu W/m^3$. It is estimated that this granite can generate about 160 x 10^{12} kWh of electricity.

1. INTRODUCTION

Electricity production is Saudi Arabia is based mainly on oil and gas resources, as of to date a figure of 240 terawatt hours of electricity is consumed. The country's demand will reach 736 terawatt hours by 2020 (IEA, 2012, WB 2009). 80% of the electricity is being used for cooling purpose. Further 17 million kWh is consumed by desalination plants to provide 235 l/day per capita of drinking water. The country's CO_2 emission from fuel combustion has increased from 252,000 Gg in 2000 to 446,000 Gg at present with contribution by oil is 175,000 Gg and by gas is 77,000 Gg (IEA, 2012). The current per capita emission of CO2 has increased to 0.016 Gg from 0.012 Gg in 2000. The country is now focusing on developing renewable resources that was not utilized due the availability of huge oil and gas resources.

The Kingdom of Saudi Arabia (KSA) is one of the world leaders in terms of established oil and gas reserves, which it attains with a very low actual production cost per barrel. Although there is no impending energy problem for the KSA in the near future, there has been a strategic tendency in the past few years to substitute hydrocarbon-related energy resources (oil and natural gas) with other renewable sources to free up additional crude oil for export. Renewable energy has several unique characteristics that should be considered when comparing these resources to oil-based alternatives (Ahmed 1994; Alnatheer, 2002). In the planning context of the KSA, these attributes are not currently fully understood. Thus, renewable energy is not properly valued, which has led to a situation in which the role of renewable energy technologies in meeting national energy demand is systemically underestimated. Renewable energy, particularly solar energy, is an abundant resource in this country, and it holds vast economic promise for the electric sector of the KSA (Alnatheer, 2007).

Geothermal resources are among those renewable energy sources that come from natural resources, such as sunlight, wind, rain, tides and biomass. Worldwide demand for the utilization and application of different aspects of energy has reached an unprecedented level. Rapid industrial development and the increase in lifestyle requirements as a function of population growth have created a gap between global demand and the actual supply of energy resources (Renewables, 2011). In Saudi Arabia there is a big gap of knowledge and information concerning the potential of geothermal resources. Despite the work executed by a team of researchers from King Saud University (Lashin et al. 2012, 2014; Hussein et al. 2013 and Lashin and Al Arifi, 2012, 2014) a more detailed and comprehensive work is needed to study and evaluate the country's economic reserves from these resources, for possible energy production and other direct/domestic applications, especially in the volcanic eruption regions.

2. GEOLOGIC BACKGROUND

Majority of the geothermal activity are encountered along the western and south-western coast of Saudi Arabia. It is represented mainly by hydrothermal resources and hot dry rocks (Harrats). Regarding the hydrothermal activity, two major provinces of prime interest (Jizan and Al-Lith) are indicated.

The geology of Jizan area is divided mainly into two features. The near shore deposits which include many valleys draining towards the sea and the crystalline basement and metamorphic rocks in the eastern portions of Jizan include a number of promising hot springs. In the absence of lithologic or structural units more favourable to the existence of reservoirs, all evidence indicates that these granite units act as a reservoir, and that the water rises to the surface either through fractures or lithologic and structural discontinuities (fracture separating the granite unit from its metamorphic or crystalline host rock). Regarding the geothermal potentiality of Jizan area, three promising geothermal locations are found. The first is located at Al-Ardah area, east of Abu Arish, more closely to and around the Dam Lake (7 hot springs). The second geothermal area is located at the south-eastern part of Jizan. One main hot spring of high surface temperature (76^{o}C) and fair to good flow rate is found (Al Khouba). The third geothermal target is located to the northeast of Jizan province in a very high and more complicated-topographic area. Bani Malik hot spring is originated from a low-temperature (45^{o}C) system of highly fractured basement and metamorphic rocks.

On the other hand, the geology of Al-Lith area is represented mainly by two sequences of the rocks. The first is represented mainly by a group of basement rocks, while the second is exhibited by recent Quaternary deposits and recent Wadi fills. Four main geothermal spots are found in Wadi Al-Lith area (Ain Al Harrah, Wadi Al Sader-Bani Hilal and Wadi Markoub areas).

Ain Al Harrah hot spring is located in Ghamika area, Wadi Al-Lith in deep-seated highly altered granitic rocks. Many alkaline dykes are found cutting through the whole area. Wadi Markub and Al Darakah hot springs are low-discharge hot springs which are located close to each other in highly altered granitic rocks.

Harrats are covering approximately 80,000 km^2 and composed of alkaline olivinitic basalts with a partially solid surface; they are exposed at both the surface and the subsurface, forming naturally roofed feeder channels of lava flows, known as "lava tubes." As a lava flow lengthens during the course of an eruption, the margins of the flow (with the exception of the advancing flow front) cease to flow, and a central channel (often with levees) forms in the older part of the flow to feed the advancing flow front (Roobel et al. 2002).

Three geothermal projects (academic scale) are now being run by King Saud University in the western parts of Saudi Arabia. Figure 1 shows location map of the different geothermal systems in Saudi Arabia. It shows areas of recent geothermal activity.

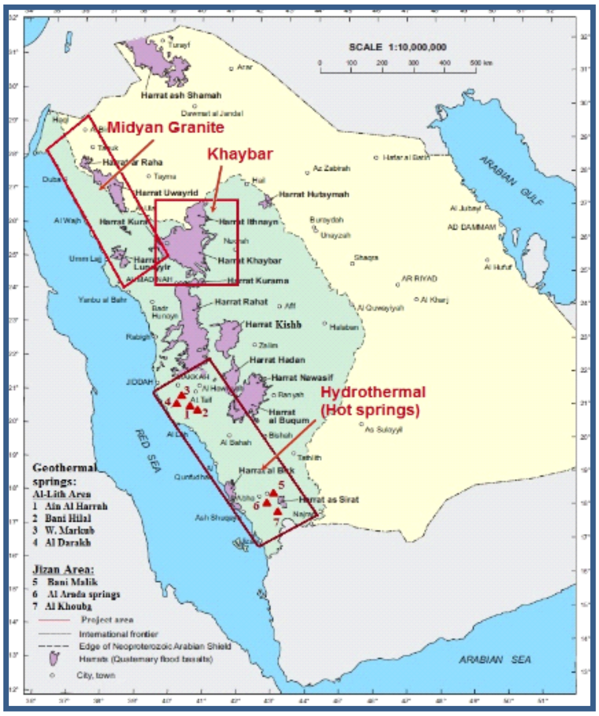

Figure 1. Location map of the different geothermal systems in Saudi Arabia.

3. GEOTHERMAL RESOURCES AND POTENTIAL & PAST/RECENT ACTIVITY

Geothermal power potential has many general characteristics compared with other oil or other renewable sources of energy. In the last few years, despite a significant amount of work and effort, which was accelerated by the Saudi Electricity Corporation (SEC) and the Ministry of Energy, to optimize the use of available renewable energy resources, geothermal resources are still almost untouched and is regarded as an unused target that is far away from economic use. Numerous exploration methods and technologies are now available to access these targets, and many of these methods are currently in use and have already been utilized extensively in other research areas (Comps and Muffler, 1973).

3.1 Geothermal resources of KSA

The geothermal resources of Saudi Arabia can be classified as four categorizes represented by the wet, and hot dry geothermal systems as well as the high production granite, as follow;

1. Low, medium and high enthalpy resources. The low-enthalpy resources that are represented mainly by deep-seated aquifers encountered in thick sedimentary basins in the eastern part of the KSA. These resources are confined, and their geothermal potential is represented by the normal geothermal gradient (sedimentary aquifers). They can only be accessed through deep oil wells.

2. Medium-enthalpy resources that are mainly encountered along the western and southwest coast (especially those located at Al-Lith and Jizan areas) and represented by shallow hot springs of hot surface water (hydrothermal). These resources are unconfined targets with direct access to hot subsurface anomalies through an open network of active faults and fractures (structure control).

3. Finally, the high-enthalpy resources that are represented by volcanic eruptions, largely basaltic in composition, forming a huge lava fields "known as Harrats" and extend along the coastal part of the Red Sea in Western Saudi Arabia.

4. High production granite that is enriched with high uranium, thorium and potassium concentrations. This radioactive granite are mainly located in the north and north-western part of Saudi Arabia (Midyan and Haal areas).

3.1.1 Hydrothermal (hot springs)

The promised hydrothermal geothermal resources are concentrated along the western and southwest coast of the KSA due to the tectonic (or volcanic) heating associated with the opening of the Red Sea/Gulf of the Suez Rift in this area (Boulos, 1990; Lashin, 2007, 2013). The thermal waters reach the surface through a complex grid of structural elements, which follow the main tectonic elements and activities that influence the entire Red Sea region (Gulf of Suez of Egypt, the eastern coasts of the East African Rift countries and the southwest coast of the KSA). Majority of the hot springs that attain surface geothermal activity are located at Al-Lith and Jizan areas (Table A1, Appendix A).

3.1.2 Harrats

The west coast of the KSA comprises a 1,400-km-long, 200-km-wide belt of coastal plains, stretched Precambrian crust, escarpment faulting and a passive inland plate boundary under the volcanic Harrats. The Harrats are young Cenozoic basaltic eruptions that cover approximately 80,000 km2, mostly along the west coast of the KSA. These basaltic lava fields include 10 major Harrats, i.e., Raha, Lunayir, Ithnayan, Khyabar, Kuraama, Rahat, Al Buqum, Shama and Al Birk. The preferred locations for high-enthalpy power production are the Harrats of Ithnayn, Khaybar and Rahat. The harrats of Khaybar and Rahat are believed to have the highest heat flow and enthalpy (Al Dayel, 1988 & Roobel, 1995).

3.1.3 High production granite

The western Saudi Arabian shield encloses a large number of pre and post orogenic granites with very high radioactive element contents. The heat generating capacity of the granites estimated based on U, Th and K content varies from 15 to 134 µW/m3, the highest value is recorded by the Midyan granites located towards NW of the shield and occupying 375 km^2 area. It is estimated that this granite can generate about 160 x 10^{12} kWh of electricity.

Thus by utilizing both wet geothermal resources as well as EGS resources; the country can reduce dependence on fossil fuel sources for electricity generation and reduce CO_2 emissions. Detailed exploration investigations have been initiated to install a pilot power plant at certain locations along the west coast of Saudi Arabia (Chandra et al. 2014).

3.2 Past/Recent Geothermal Activity

Before 2010, only a few studies have reported the characteristics and potential of geothermal resources and their utility, and only a few locations along the west coast of the Red Sea of the KSA have been investigated.

3.2.1 Past Activity

The first geothermal work conducted in the KSA was that of El Dayel (1988), which focused mainly on the hydro-chemical characteristics of the hot springs in the Jizan and Al-Lith regions by analyzing water samples from the hot springs. Other work regarding the petrography, petrochemical composition and mineralogy of the Harrats was conducted by Roobol et al. and Pint et al. from 1992 to 2007 (Roobol and Camp, 1991a,b & Roobol et al., 1995 & 2002, Pint 2006 and Pint et al. 2004). Roobel at al. 2002, while studying the mineralogical composition and lava tubes of Harrats, suggested three high-enthalpy locations (Harrat Ithnayn, Khaybar and Rahat) that would be suitable for geothermal power production. Some steam fumaroles were observed in these Harrats (Fig. 2).

More recently, Lashin and Al Arifi (2012) performed a preliminary investigation of the geothermal resources encountered in the south-western regions of the KSA (the Jizan region) based on Landsat images and chemical analyses. Through his participation in WGC 2005 and 2010, Rehman had reported and compiled all the geothermal information and activity in Saudi Arabia due these dates (Rehman & Shash 2005 and Rehman 2010).

3.2.2 Recent KSU geothermal activity

However, over the past four years, a promising geothermal activity is conducted by a team of researchers from King Saud University (KSU). Two big geothermal projects are funded through the National Plan of Science and Technology (NSTIP strategic technologies programs), King Saud University from the end of 2010 till now. A fund of about 1.10 Million US$ is offered for the team to carry out academic geothermal research regarding the hydrothermal activity along the western and south-western parts of the kingdom, as well as the investigation of the potentiality of the volcanic eruptions of Harrat Khyabar. In this respect, a consortium from the Colleges of Engineering and Science-King Saud University, Trieste University-Italy, Bombay Institute-India and the Energy Research Institute-King Abdulaziz City of Science and Technology (KACST), are now initiating this research program. Another 2-year project (2015-2017) with a fund of 0.53 Million US$ is now under evaluation. It aims to apply an EGS for investigating the potentiality of the high productive granite of the Midyan area (see Fig. 1).

Figure 2. Three steam fumaroles escaping from geothermal rocks at Harrat Khyabar (Roobel et al. 1995).

Extensive geological, geochemical, and geophysical investigations are carried out through the course of these projects, including geothermal reserve estimation and cost analysis studies.

3.2.3. Landsat Analyses

A detailed Landsat analyses are carried over the Al-Lith and Jizan areas to determine the topographic nature and the structural elements/lineaments that may control the geothermal system. Briefly speaking, the extraction of structural elements/lineaments is enhanced through analyzing the available Landsat RGB images with 30 m resolutions. Figure 3 (A,B) includes adigital elevation model map (DEM) of the Jizan area illustrating highlands in the eastern and northeastern portions, and topographic map indicating the complicated ridges in the eastern part as compared with the simple coastal plains in the West. Meanwhile, Figure 3 (C,D) exhibits the drainage pattern map that illustrates the upstream (northeast)-downstream (southwest) prevailing dendritic pattern of the valleys, as well as the different basins of the Jizan area (Lashin and Al-Arifi, 2014).

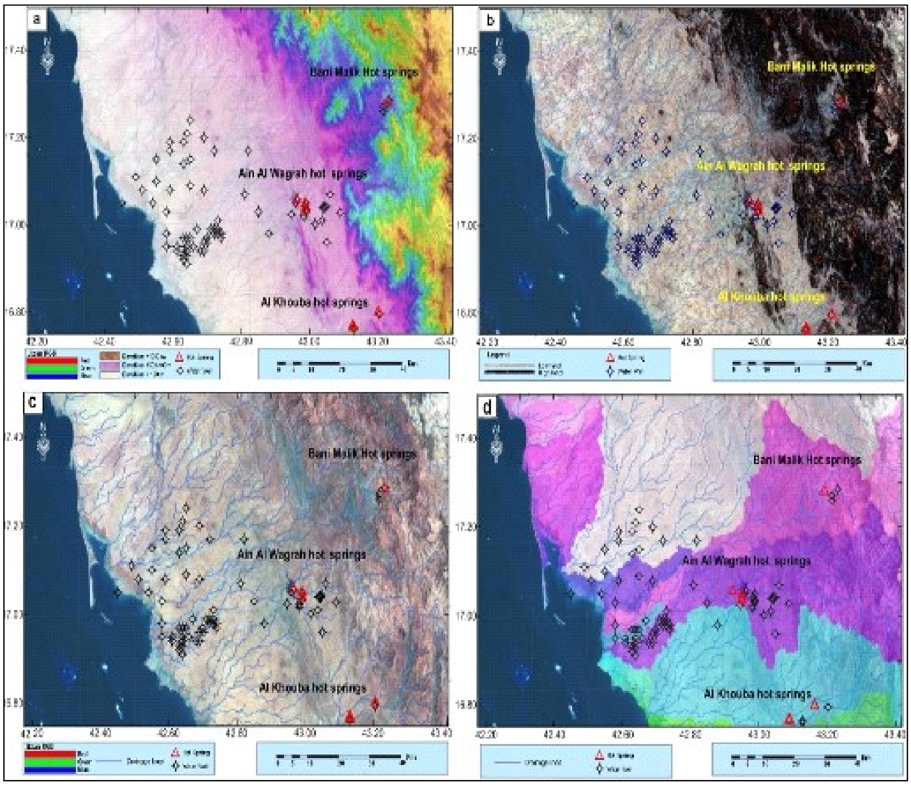

Figure 3. A) Digital elevation model map (DEM) of the Jizan area illustrating highlands in the eastern and northeastern portions, B) Topographic map indicating complicated ridges in the eastern part as compared with the simple coastal plains in the West, C) Drainage pattern map illustrates the upstream (northeast)-downstream (southwest) prevailing dendritic pattern of the valleys, and D) Drainage pattern and basin map illustrating the presence of different basins.

Due to the importance of Ain Al Harrah hot spring at Al-Lith area, a detailed geological and satellite image analysis were carried out to identify the different rock types in the area and the surface structures and lineaments (Figure 4). An accumulation grid map for the intersection, length and frequency of the extracted lineaments of Wadi Al-Lith basin are constructed. The main structural trends that are concluded from this analysis are represented in Figure 4 B. Majority of the detected surface fractures and fault systems are oriented along NNE-SSW. NW-SE faults are not clearly indicated at the surface (Fig. 5) (Hussein et al. 2013).

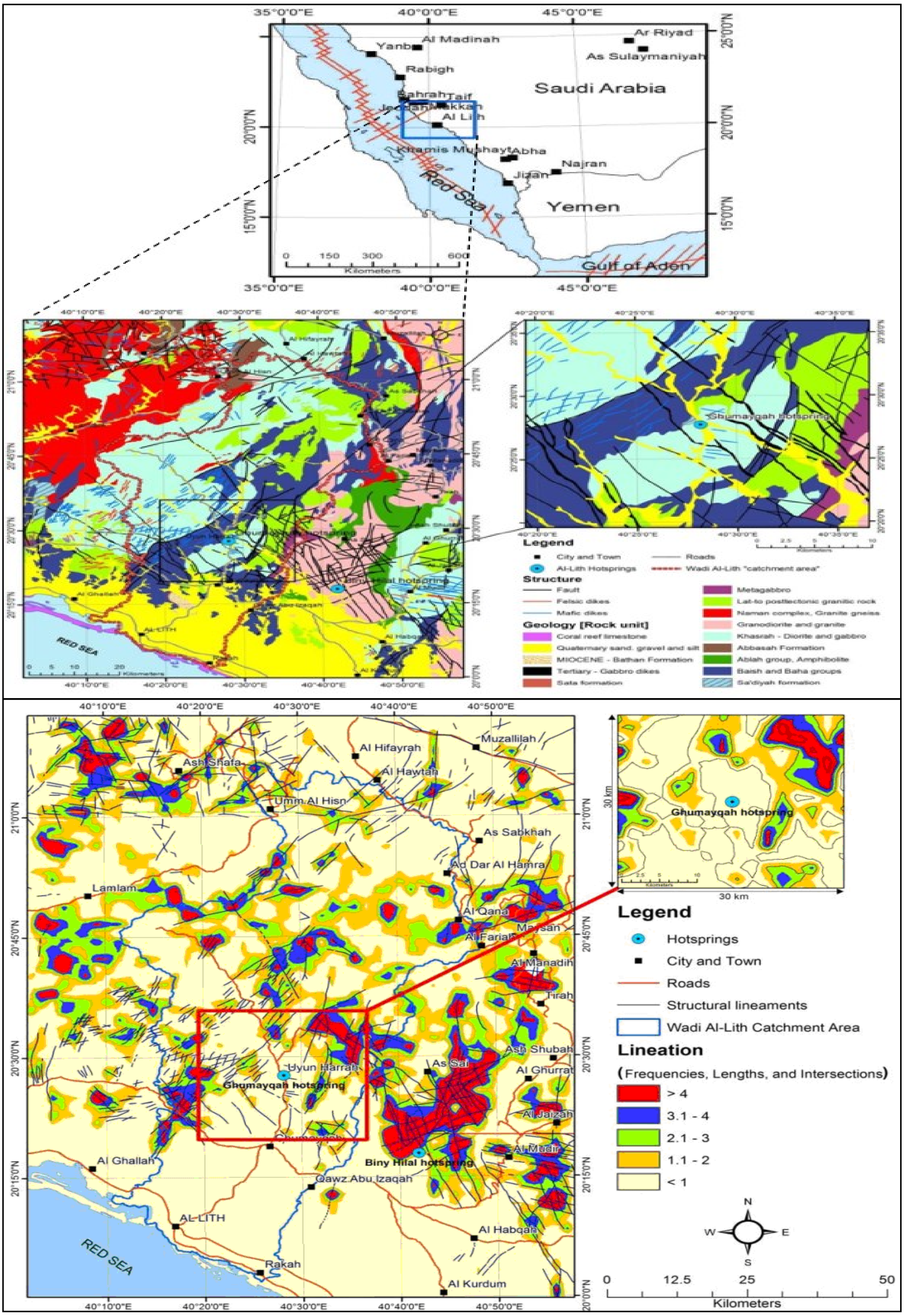

Figure 4. A) Geological map of Ain Al Harrah hot spring, and B) Accumulation grid map for the intersection, length and frequency of the extracted lineaments of Wadi Al-Lith basin (Hussein et al. 2013).

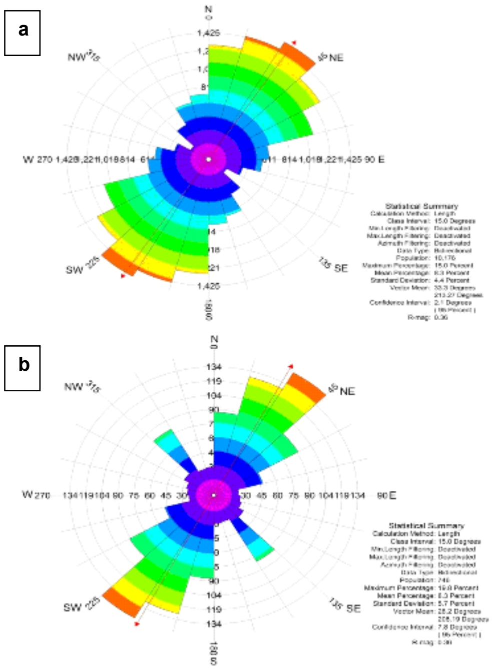

Figure 5. A) Rose diagram showing the surface structure lineaments of A) Wadi Al-Lith area, B) Ain Al Harrah hot spring area (Hussein et al. 2013).

3.2.4 Geochemical analyses

A large number of water samples were collected from the areas of hot springs at Jizan and Al-Lith areas. These water samples were analysed for the major, minor, and some trace elements and selected number of geo-thermometers are applied (Table A2, Appendix A).

Figure 6 shows the "Cl-SO4-HCO3" diagrams of the different hot springs encountered at Jizan area (Al Ardah, Al Khouba and Bani Malik) and Wadi Al-Lith area. The dominance of the chlorine and sulphate anions on the expanse of the bicarbonate group. The low "HCO3" associated with high sulphate indicates near surface process including oxidation such as incursion of shallow ground water (Fig. 6A). For Al Khouba and Bani Malik hot springs, the data points are located at the mature water area, while the clusters of other close water wells are located in the volcanic water area (Fig. 6 B,C). For the Al-Lith area, a majority of the hot springs occurred in the mature water area (Fig. 6 D). Al Darakah hot spring is lactated at the boundaries between the mature and volcanic water areas, suggesting mixed water type (Hussein et al. 2013).

Figure 7 represent the constructed Na, K, Mg Giggenbach diagrams for the hot springs at Jizan area. For the Al Khouba and Bani Malik areas, all data points are mainly located behind the 75° Mg-K temperature line and between the 200 and 220° Na-K temperature lines, while for the Al-Ardah area points are mainly located between the temperature lines of 200 and 250°C.

The hot springs at Al-Lith area are located in front of the 75°C Mg-K temperature line, and between temperature lines 200^o and 250^o along the Na-K geo-indicators (Fig. 7D). One point belonging to Ain Al Harrah hot spring is shifted upward and located along the 150o Mg-K thermal line and the 175^o and 225^o Na-K thermal lines. This hot spring seems to attain the highest geothermal condition among the other studied hot springs. Based on the geothermometers, fair to good subsurface temperature, discharge enthalpy and heat flow values are calculated for the hot springs of the Al-Lith area (105°C - 136°, 170 Kj/Kg - 219 Kj/Kg and 137 mW/m^2 - 183 mW/m^2) (Lashin and Al-Arifi, 2012 & 2014).

3.2.5 Geophysical Exploration

A number of 2D electric profiles were performed at the location of the hot springs in the Jizan and Wadi Al-Lith areas. The Syscal–R1, 72 multi-electrodes system and the Schlumberger-Wenner arrangement were used. Resistivity profiles were conducted to determine the shallow pathways of geothermal water, feed zones, and the possible facture system. For the Jizan area, a good geothermal reservoir volume with a thickness of 23 m (depths 9.20 m to 32 m) was found at the middle of the resistivity profile KH 1 (Fig. 8A). It represents a good geothermal reservoir that extends more than 80 m in the NE direction (between electrodes 40 and 56). A high-resistive uplift (216 ohm.m - 1866 ohm.m) was indicated at the middle of the section. It represents a massive body of the host granitic rocks.

Figure 8B, on the other hand, exhibits a NW-SE trending resistivity profile (line KH 4). It shows one of the major subsurface structural elements that controls the movement and ascending of geothermal water in the Al Khouba area. A good fault system (NE-SW direction) is indicated between electrodes 32 and 41, bounded by medium to high resistive beds in both sides (Lashin and Al-Arifi, 2012 & 2014). Figure 8C exhibits the interpreted 2D electric section (Line I) that is extended along an east-west direction at the Al-Lith area. It shows a tilted thermal feed zone at the middle of the section oriented along a very obvious fault zone. The strike of this fault is found to be along a northwest-southeast direction which is considered the main prevailing structure in the area (Red Sea Rift). This structure trends in opposite direction to another oriented northeast-southwest geothermal feed zone, detected at the western end of the profile H between electrodes 80-90 (Fig. 8D). A suggested fault system is recognized at the middle of the section. This may be interpreted as a result of the well-known northeast-southwest trending faults that influence the western coastal parts of the Red Sea area (Fig. 8E) (Hussein at al. 2013).

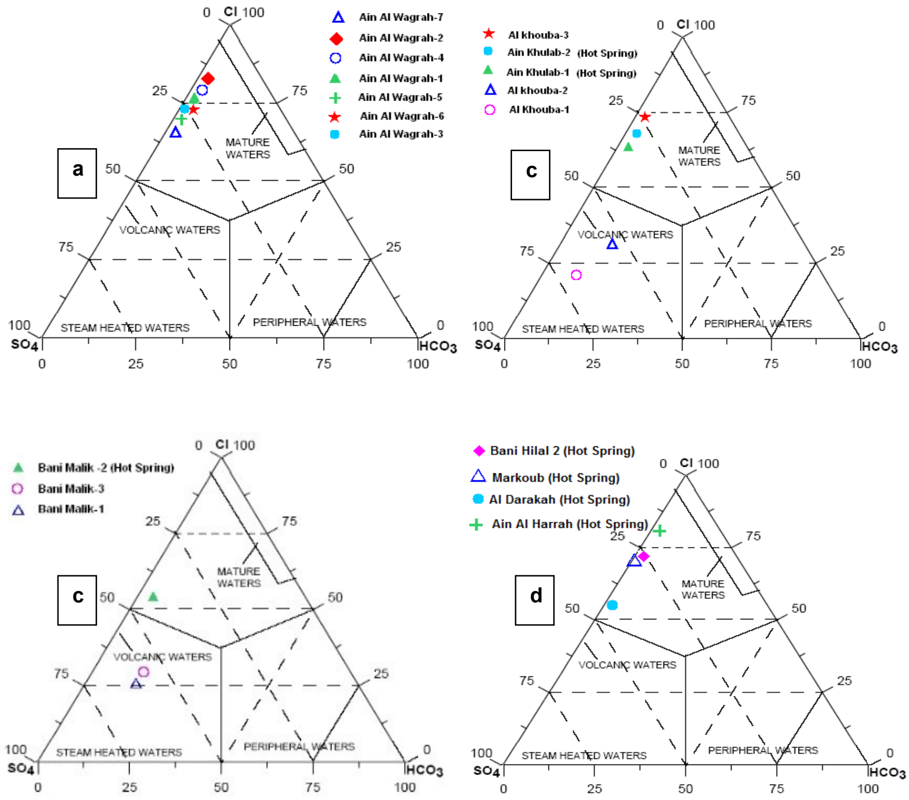

Figure 6. A) Ternary diagram "Cl-SO4-HCO3" for the thermal fluids of the hot springs at Al Ardah, B) Al Khouba area, C) Bani Malik area, and D) Wadi Al-Lith area.

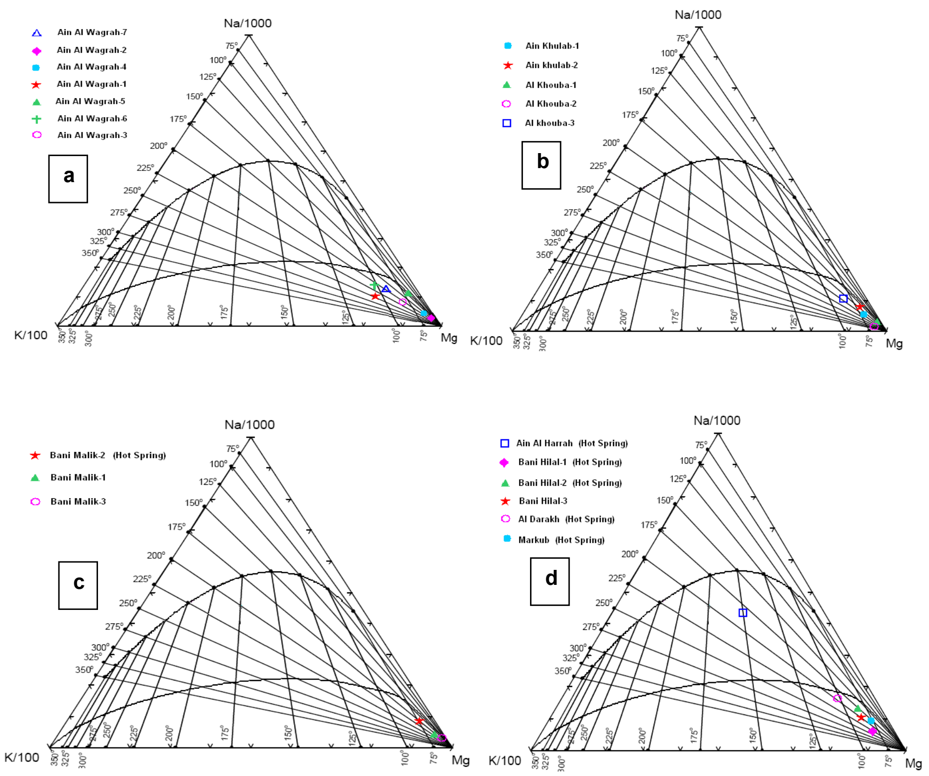

Figure 7. A) Giggenbach diagrams for the thermal fluids of the hot springs at A) Al Ardah area B) Al Khouba area, C) Bani Malik area, and D) Wadi Al-Lith area.

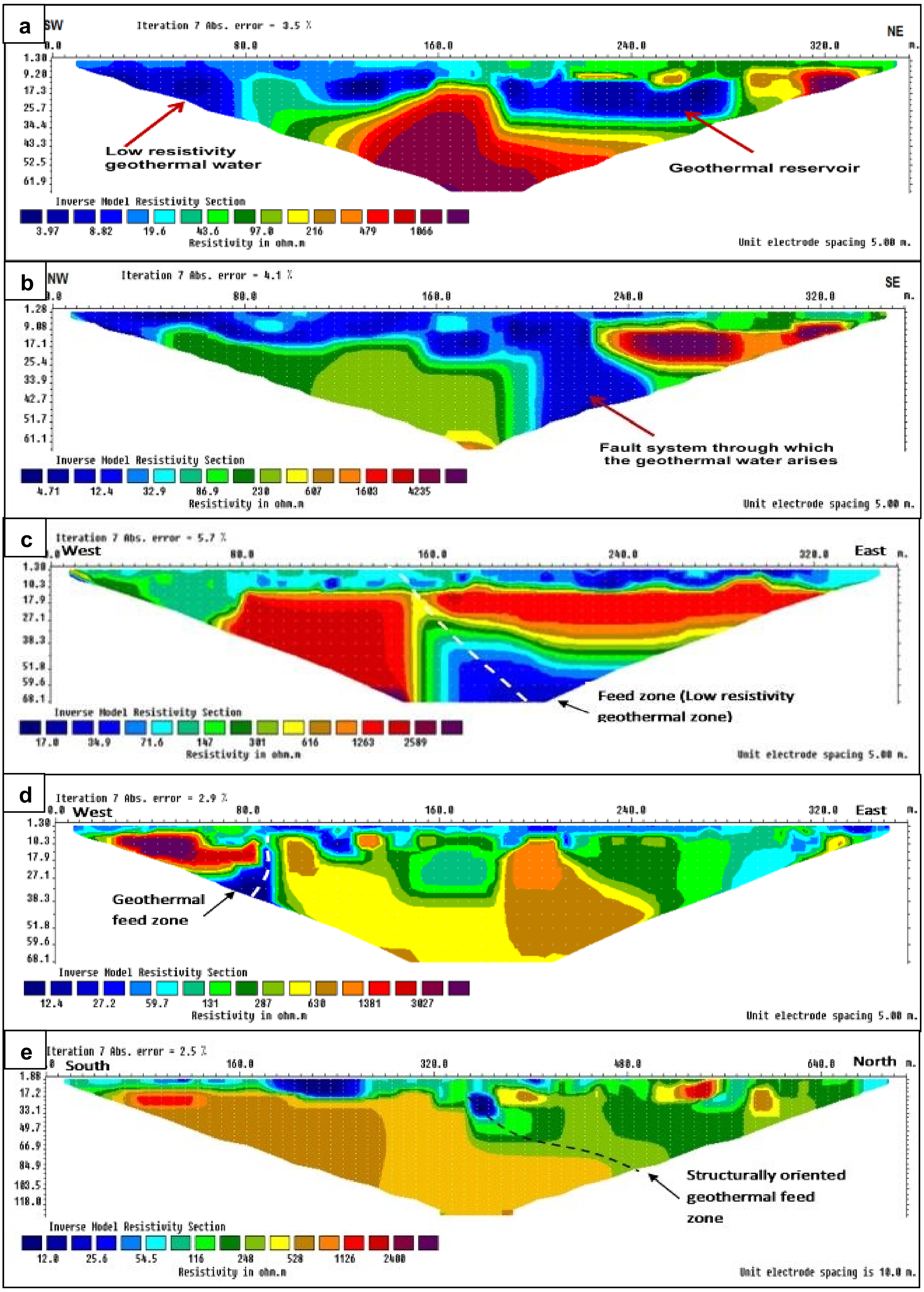

Figure 8. 2D interpreted resistivity profiles; A) SW-NE line KH 1, Al Khouba, B) NW-SE line KH 4, Al Khouba area, C) E-W line I, Wadi Al-Lith , D) E-W line H, Wadi Al-Lith and E) N-S line B, Wadi Al-Lith.

However, extensive seismic reflection and magneto-telluric surveys are also executed. Details of these surveys are discussed in another separate paper presented in the geophysical exploration session.

3.2.6. Reserve Estimation

There are a variety of methods for estimating the production capacity of a geothermal resource. Statistical methods such as "volumetric-heat-in-place" assessments are sometimes done at this stage when surface methods indicate that resource parameters suitable for a geothermal development are likely but no direct reservoir measurements are available from wells. A good geothermal potential of 17.847 MWt is estimated for the main hot spring at the Jizan area (Al Khouba hot spring) providing a reservoir area of

1.125 km^3. While for the Al-Lith area, an estimate of the geothermal reserve using the volumetric method, gave total stored heat energy of 1.713 x 10^{17} J (rock & fluid) and a geothermal reserve potential of 26.99 MWt (Hussein at al. 2013 and Lashin & Al Arifi, 2014).

4. GEOTHERMAL UTILIZATION

Till now there are no geothermal power plants (installation and generation) in Saudi Arabia. Some direct use applications are already installed in the five last years. But, due to the potential and the size of the high enthalpy eruptions of the Harrats, it is considered a sizeable opportunity for developing geothermal power. These geological formations may host geothermal systems between 150 and 300°C, the possibility of which is still uncertain due to the lack of deep drilling. Thus, both binary-type power generation and condensing steam turbines may be used to convert geothermal heat to power. According to previous geothermal studies in other geothermal areas (Jizan and Al Lith-KSA, Gulf of Suez- Egypt, Kalderholt geothermal field-Iceland), the available geothermal resources are sufficient for utilization on an economic industrial scale.

4.1 High-enthalpy power generation

In many of the locations in the KSA that have volcanic eruptions (regions of plate boundaries and rifting), including the study area, the vertical permeability and magma intrusions allow the convective flow of heat and mass and thus the depths are relatively accessible and the temperatures are favorable for power generation (150-300°C). There are also on-land escarpment faults of the Red Sea coast, which host geothermal potential in fractures and can also be viable for power development. Thus, the entire coast of the Red Sea in the KSA may have pockets of geothermal potential, with additional potential in a wider area extending inland towards the Harrats and beyond. Harrat Khaybar-Ithanyan is the most interesting due to its wide range of extension (large volume) and its proximity to a very densely populated area (Al Madinah Al Munwarah).

It is anticipated that the fractured, Precambrian formations are best suited for binary power applications due to their ±150°C temperature, as measured by geothermometers (Lashin 2005, 2006 & Lashin and Al Arifi 2010 & 2012). By using the global energy statistics for active volcanoes and by assuming that the fractured Precambrian crust is of similar geothermal quality to that of the state of Nevada, a 3- to 5-GW power-generating capacity is proposed for the west coast of the KSA. This figure should be put into perspective recent goal of King Abdullah City for Atomic and Renewable Energy (KACARE) of using 54 GW of renewable energy.

4.2 Low-grade direct applications

Some direct use low-grade geothermal applications are now in use is Saudi Arabia. Some refreshment and swimming pools are already constructed in the Bani Malik-Jizan area (Fig. 9B). However, a recent governmental geothermal activity at Al Khouba hot springs-Jizan area was enhanced by Saudi Ministry of Tourism and the municipality authority, through two small scale projects (6 months/ 0.53 Million US$). It aims to drill one shallow well that will hit the main fracture system of the hot spring, up to 75 m, to pump water and rise it through specific pipes to the close highly mountain area (south of the hot spring). A number of swimming pools, medical therapy, Spa and refreshment places are now under constructions (Fig. 9A).

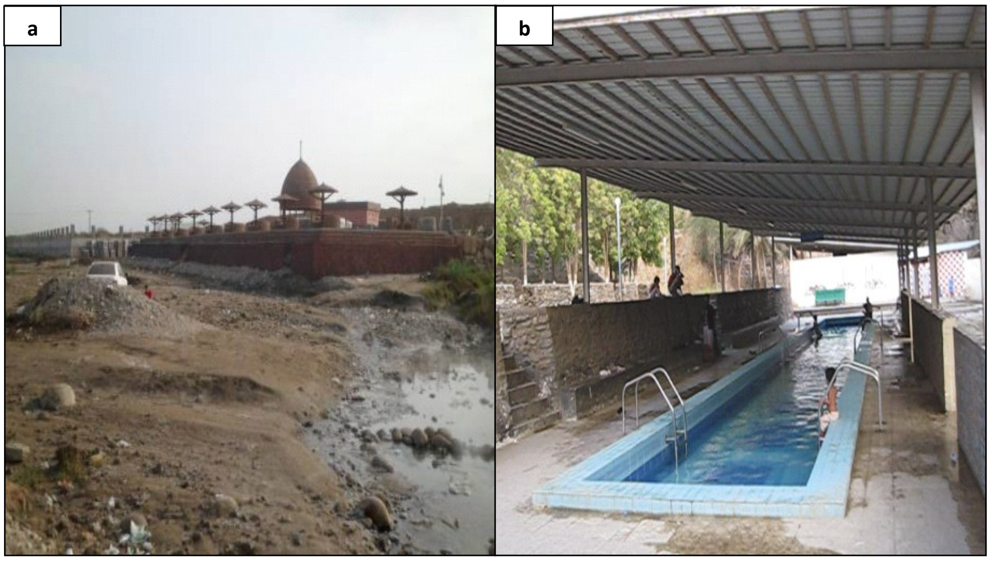

Figure 9. Recent geothermal activity at A) Jizan area by Saudi Ministry of Tourism and B) swimming pool at Bani Malik area.

Tables from 1 to 8 show statistical analysis of low/high and direct/indirect geothermal applications of geothermal resources in Saudi Arabia. Actually, the most common application of geothermal energy in Saudi Arabia is in the form of direct uses, mainly swimming pools and bathes. Till now no power generation power plants are now in use.

5. DISCUSSION

At present, the KSA's energy is derived almost entirely from fossil fuels, with approximately two-thirds originating from oil and the remainder from gas. The KSA produces approximately 10 million barrels of oil daily. This significant amount of hydrocarbons is mainly utilized for electricity production in the KSA. The petroleum sector sells the oil to the Ministry of Electricity with a subsidy of up to 90% ($10/barrel). According to the United States Energy Information Administration, the energy use per person within the KSA is also high by world standards because energy prices are kept so low. Renewable and energy-efficient technologies could meet a substantial portion of the energy needs in the KSA. In the process of shifting new investment to these energy forms, numerous public benefits will be created, including enhanced environmental quality, increased energy security and local economic development benefits.

5.1 Economic Considerations

Saudi Arabia utilizes more than 25% of its daily oil production for domestic purposes (electricity production, direct use, etc). Assuming that 15% of these hydrocarbons support the electricity demands of the KSA and considering the fact that the tariff for selling oil "from sector to sector" inside the KSA is 10-12 US$ for one barrel of oil, then a total amount of 1.50 million barrels of oil is conserved internally with a cost of 16.5 billion US$ (1.50 million barrels * 11$/barrel) instead of being exported to the world at a cost of 165 million$ (1.5 million barrels *110$/barrel). Thus, an expected daily difference of 149 million US$ can be conserved or added to the country's economic income if a renewable energy resource can be used instead of fossil oil.

5.2 Environmental Considerations

The most important factor for using geothermal energy is the environmental benefits due to the high recorded rate of pollution from the enormous use of fossil energy, considering the fact that a majority of the geothermal activity is very close from the Holly places that are of crowded nature due to the large number of people who come to visit through the year. Upon successful installing of geothermal plants, the geothermal potential will help in providing Saudi Arabia, in general, and the Holly places, in particular, with a continuous source of energy that is not expensive, clean and sustainable.

5.3 Cost Analysis

Based on the results obtained from the extensive geothermal activity that have been conducted by King Saud researchers, a cost analysis and plausible design for possible geothermal power plants are made for some geothermal targets. Al-Khouba geothermal system is taken as an example. It has not been drilled, but exploration data indicate a viable resource that could feasibly support planned development for power production and direct use applications. Two exploration shallow temperatures wells and two confirmation wells are assumed to prove a resource up to 150 m. Plant construction per 1 MW is assumed to be 1 million US$. A reasonable average cost estimate for a new geothermal power development including exploration, drilling, facilities and power plant is about $1,553/kWe, assuming a total cost of about 2.95 million US$. For accessing a high temperature geothermal resource, much deeper wells should be drilled which means increasing of the average tariff for each producible kWe, than the estimated above (Lashin and Al-Arifi, 2014).

6. FUTURE DEVELOPMENT AND INSTALLATIONS

As the largest oil producer in the world, the KSA has plans to become completely powered by renewable and low-carbon forms of energy. Thus, in the past few years, it has become clear that the KSA is moving ahead with investments in renewable energy, nuclear power and other alternatives to fossil fuels so that it could use its vast oil reserves for other goods, such as plastics and polymers.

As Prince Turki Al Faisal Al Saud said, "Oil is more precious for us underground than as a fuel source. If we can get to the point where we can replace fossil fuels and use oil to produce other products that are useful, that would be very good for the world. I wish that may be in my lifetime, but I don't think it will be" (Guardian, 2012). This quotation reflects the goal of future energy planning for the KSA and the current policy shift from dependence on fossil fuels to using alternative renewable and sustainable energy resources. On April 17, 2010, King Abdullah City of Atomic and Renewable Energy (KACARE) was established by a Royal Order with a mandate to contribute to sustainable development in the KSA in industries related to renewable energy (wind, biomass, solar, tidal and geothermal) and to atomic energy for peaceful purposes. Among the different types of renewable resources, geothermal power has a unique role in terms of power energy owing to its high conversion coefficient (>95%) compared to other renewable resources.

The KACARE Charter establishes an all-encompassing approach to contributing to a sustainable energy mix that emphasizes education, research, global collaboration, local integration, commercialization and social benefit. KSA's renewable energy competitive procurement program is being designed to use the best practices from similar procurement programs worldwide and is uniquely adapted to meet the KSA's energy mix targets and economic development objectives. It has been developed with the objective of being ready for implementation when the need arises. Initially, the process was envisioned to consist of multiple procurement rounds preceded by an introductory round over a two- to three-year period.

The geothermal power plants are not yet installed in Saudi Arabia. The Saudi electric ministry has designed more advanced optimization and control technology system that could improve overall plant reliability and deliver operational and maintenance efficiency over the generating life of the facility. It is planned to add 30 gigawatts of generating capacity to the electricity grid and to accommodate all types of energy generations by the end of 2020, including the renewable ones (i.e. geothermal, solar, wind, etc.). However, nowadays in cooperation with the research team of KSU, two leading energy companies from the private sector are in the screening phase of the given geothermal data. Three geothermal wells are proposed to be drilled at Al-Lith area by the end of 2014. One MW geothermal binary power plant is planned to be installed by the mid-of 2015.

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STANDARD TABLES

Table 1. Present and planned production of electricity.

	Geothermal		Fossil Fuels		Hydro+Wind		Nuclear		Other Renewables (Solar + Solar CSP)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2014	Nil	Nil	55,000	-	650	-	Nil	Nil	1,900	-	57,550	-
Under construction in December 2014	Nil	Nil	5,000		-	-	Nil	Nil	1,100	-	6,100	-
Funds committed, but not yet under construction in December 2014	250	-	-	-	1,050	-	-	-	1,300	-	2,600	-
Estimated total projected use by 2020	1,000	-	120,000	-	6,000	-	14,000	-	20,000	-	161,000	-

Table 3: Utilization of geothermal energy for direct heat as of 31 December 2014 (other than heat pumps).

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)		(MWt)	Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet (Reservoir T)	Outlet (Surface T)	Inlet	Outlet (Discharge)		(kg/s)	(TJ/yr)	Factor[5)]
Ain Al Harrah (Al Lith area)	B	-	185	96	-	219	26.99	6.3	78.94	0.34
Bani Hilal (Al Lith area)	K	-	120	45	-	120	-	0.35	-	-
Wadi Markoub (Al Lith area)	K	-	120	56	-	120	-	0.4		-
Al Darakah (Al Lith area)	K	-	105	41	-	105	-	0.1	-	-
Ain Al Waghrah-1 (Jizan)	B	-	129	44	-	184	-	-	-	-
Ain Al Waghrah-2 (Jizan)	B	-	152	45	-	188	-	-	-	-
Ain Al Waghrah-3 (Jizan)	B	-	120	57	-	239	-	-	-	-
Ain Al Waghrah-4 (Jizan)	B	-	120	57	-	239	-	-	-	-
Ain Al Waghrah-5 (Jizan)	B	-	123	45	-	188	-	-	-	-
Ain Al Waghrah-6 (Jizan)	B	-	125	61	-	255	-	-	-	-
Ain Al Waghrah-7 (Jizan)	B	-	96	57	-	239	-	-	-	-
Al Khouba (Jizan)	B	-	133	76	-	318	17.84	6	73.95	0.27
Bani Malik (Jizan)	B	-	105	45	-	188	-	-	-	-
TOTAL										

Table 5. Summary table of geothermal direct heat uses as of 31 December 2014.

Use	Installed Capacity1) (MWt)	Annual Energy Use2) (TJ/yr = 10^{12} J/yr)	Capacity Factor3)
Individual Space Heating4)	Nil	Nil	Nil
District Heating 4)	-	-	-
Air Conditioning (Cooling)	-	-	-
Greenhouse Heating	-	-	-
Fish Farming	-	-	-
Animal Farming	-	-	-
Agricultural Drying5)	-	-	-
Industrial Process Heat6)	-	-	-
Snow Melting	-	-	-
Bathing and Swimming7)	40	138.89	0.31
Other Uses (specify)	4	14	-
Subtotal	-	-	-
Geothermal Heat Pumps	-	-	-
TOTAL	44.0	152.89	

Table 6. Wells drilled for electrical, direct and combined use of geothermal resources.

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration1)	(all)	-	1 (Jizan)	-	-	46 m
Production	>150° C	-	-	-	-	-
	150-100° C	-	-	-	-	-
	<100° C	-	1	-	-	46 m
Injection	(all)	-	-	-	-	-
Total		-	1	-	-	46 m

Table 7. Allocation of professional personnel to geothermal activities (Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	-1	-2	-3	-4	-5	-6
2010	-	-	King Saud University (4 persons)	-	-	-
2011	-	-	King Saud University (4 persons)	-	-	-
2012	-	-	King Saud University (6 persons)		-	Meahona/ ACWA (3 persons)
2013	KACare	-	King Saud University (6 persons)	-	-	Meahona/ ACWA (3 persons)
2014	KACare	-	King Saud University (8 persons)	-	-	Meahona/ ACWA (3 persons)
Total	2 Years	-	8perons /5 Years	-	-	3 persons /3 Years

(1) Government; (2) Public Utilities; (3) Universities; (4) Paid Foreign Consultants; (5) Contributed Through Foreign Aid Programs; (6) Private Industry

Table 8. Total investments in geothermal in (2014) US$.

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	Nil	Nil	Nil	Nil	Nil	Nil
2000-2004	-	-	-	-	-	-
2005-2009	-	-	-	-	-	-
2010-2015	1.25 M	0.20 M	0.36 M	-	-	100%

APPENDIX A

Table A1. Field measurements of hot springs at Jizan and Al-Lith areas.

Location	Hot Spring	Co-ordinates	Surface Temp.(°C)	Elev. (M)	PH	TDS (ppm)	EC (μScm^{-1})
Al Ardah (Jizan)	Ain Al Waghrah-1	17° 02.124′ 42° 59.374′	44	179.5	7.7	3592	5987
	Ain Al Waghrah-2	17° 02.130′ 42° 59.370′	45	180.7	7.5	8815	14692
	Ain Al Waghrah-3	17° 02.156′ 42° 59.360′	57	178.0	7.2	3072	5120
	Ain Al Waghrah-4	17° 02.160′ 42° 59.365′	57	178.0	7.2	3076	5127
	Ain Al Waghrah-5	17° 02.165′ 42° 59.370′	45	178.0	7.2	3135	5225
	Ain Al Waghrah-6	17° 02.960′ 42° 59.390′	61	178.8	7.0	3066	5110
	Ain Al Waghrah-7	17° 03.443′ 42° 57.830′	57	167.5	7.6	2088	3480
Al Khouba (Jizan)	Ain Khulab	16° 45.854′ 43° 07.769′	76	160.0	7.4	2510	4183
Bani Malik (Jizan)	Bani Malik	17° 16′11.2″ 43°13′ 08.6″	45	647.5	7.3	1290	2150
Al-Lith	Ain Al Harrah	20° 27′ 41″ 40° 28′ 36.1″	96	167.0	7.8	2180	3633
	Bani Hilal-1	20° 17.892′ 40° 42.088′	45	170.0	7.5	2426	4043
	Bani Hilal-2	20° 18.182′ 40° 42.328′	41	176.0	7.4	2349	391
	Wadi Markub	20° 31.684′ 40° 09.404′	56	136.0	6.85	2960	4933
	Al Darakah	20° 40.312′ 40° 02.386′	41	151.0	7.6	2900	4825

Table A2. Thermal properties of hot springs encountered at Jizan area (geo-thermometers).

Area	Hot Spring	Geo-thermometer		Quartz	Chalcedony	Na-K	Na-Ca	Na-K-Ca
Al Ardah	Ain Al Waghrah-1	Subsurf. Temp.	T1	129.37	101.85	237.72	79.85	146.02
			T2	129.24	101.01	-	-	-
			Used	129.31 °C				
		Discharge Enthalpy		184 Kj/Kg				
		Heat Flow		171.95 mW/M^2				
	Ain Al Waghrah-2	Subsurf. Temp.	T1	151.98	126.99	262.8	85.51	149.14
			T2	152.2	124.12	-	-	-
			Used	152.1 °C				
		Discharge Enthalpy		188 Kj/Kg				
		Heat Flow		205.92 mW/M^2				
	Ain Al Waghrah-3	Subsurf. Temp.	T1	119.63	91.17	219.81	77.51	141.38
			T2	119.85	91.12	-	-	
			Used	119.74 °C				
		Discharge Enthalpy		239 Kj/Kg				
		Heat Flow		158.24 mW/M^2				
	Ain Al Waghrah-4	Subsurf. Temp.	T1	119.91	91.48	229.4	78.38	144.32
			T2	120.13	91.41	-	-	-
			Used	119.97 °C				
		Discharge Enthalpy		239 Kj/Kg				
		Heat Flow		158.69 mW/M^2				
	Ain Al Waghrah-5	Subsurf. Temp.	T1	122.62	94.44	171.94	89.93	109.68
			T2	122.82	94.15	-	-	-
			Used	122.72 °C				
		Discharge Enthalpy		188 Kj/Kg				
		Heat Flow		162.86 mW/M^2				
	Ain Al Waghrah-6	Subsurf. Temp.	T1	124.57	96.57	168.05	70.75	125.31
			T2	124.76	96.13	-	-	-
			Used	124.67 °C				
		Discharge Enthalpy		255 Kj/Kg				
		Heat Flow		165.69 mW/M^2				
	Ain Al Waghrah-7	Subsurf. Temp.	T1	95.32	64.93	92.77	82.16	79.13
			T2	95.79	66.65	-	-	-
			Used	95.56 °C				
		Discharge Enthalpy		239 Kj/Kg				
		Heat Flow		121.73 mW/M^2				
Al Khouba	Al khouba	Subsurf. Temp.	T1	110.84	81.62	133.34	79.72	101.43
			T2	111.15	82.24	-	-	
			Used	133°C				
		Discharge Enthalpy		318 Kj/Kg				
		Heat Flow		144.23 mW/M^2				
Bani Malik	Bani Malik-2	Subsurf. Temp.	T1	104.64	74.92	144.11	78.03	107.98
			T2	105.01	76	-	-	-
			Used	104.83 °C				
		Discharge Enthalpy		188 Kj/Kg				
		Heat Flow		136.34 mW/M^2				