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Geothermal resources of Egypt: Country Update

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ABSTRACT

Egypt's present energy strategy aims at increasing the share of renewable energy to 20 percent of Egypt's energy mix by 2020. Egypt's demand for electricity is growing rapidly (an annual rate of increase from 1,500 to 2,000 MWe) and with time alternative sources of power supply become more urgent. Some aspects of utilization of renewable energy is already made from wind and solar resources. Despite scares direct utilization, the geothermal potential "till now" is not included in the renewable energy map of Egypt.

Majority of the geothermal resources of Egypt are mainly located along the Gulf of Suez and Red Sea with a surface temperature range of 40 - 76^{o}C. Some other spots are found in the Western Desert of Egypt, close to the Oasis (Baharia and Dakhla). Regarding the Gulf of Suez, the previous studies and analyses of temperature profiles, logging data from deep oil wells and geo-thermometric parameters referred to spots of good geothermal potentials, i.e. good geothermal gradient (45^{o}C /Km) and heat flow (120 mW/m^{2}). The fracture and faulting systems associated with the tectonic activity of the Red Sea and Gulf of Suez provide a continuous supply of heat energy to the deep circulated fluids. Geothermal assessment and reserve estimation studies assigned good figures of geothermal power energy that can be used for installing binary power plants. Hammam Faraun geothermal spring is the best location for such an investment where an estimate of geothermal reserve of 12.4 MWt is already made. Away from the Gulf of Suez, some other thermal springs (up to 35^{o}C) enriched with sulphur are located 25 km south of Cairo close to Helwan city. In the Western Desert of Egypt, hot water is produced from some deep artesian wells. The temperature range is in the range from 35-45^{o}C. These resources can be used for low and direct geothermal applications (district heating "especially in winter", swimming pools, medical therapy, green houses, etc.

A detailed field mapping, geochemical and geophysical exploratory work is needed in the future to better define the potentiality of the geothermal resources in Egypt.

1. INTRODUCTION

Egypt's demand for electricity is growing rapidly and the need to develop alternative power resources is becoming ever more urgent. It is estimated that the demand is increasing at a rate of 1,500 to 2,000 MWe a year, as a result of rapid urbanization and economic growth. Egypt has been suffering severe power shortages and rolling blackouts over the past years, necessitating the requirement to look to alternative energy options to help meet increasing demand (Perston and Croker, 2013).

Egypt has traditionally been a net exporter of energy. Until the late 1990s, these exports were of oil; oil production has declined from its peak in the early 1990s and is now roughly matched to Egyptian consumption. The discovery and exploitation of large reserves of natural gas means Egypt is now a significant exporter of gas, both by pipeline and as liquefied natural gas (LNG).

Egyptian energy policy has been driven by considerations of how oil and gas should be exploited and how they should be used domestically and for export. Electricity generation has been a major source of demand for fossil fuels. Previously, Egyptian power generation was dominated by oil but now natural gas dominates, representing three-quarters of the power generated. The remainder comes from the Aswan Dam hydro-electricity complex and from heavy fuel oil "mazut" (Al Sobky et al., 2009). The development of geothermal power must be seen within the main frame of the development of fossil fuels in Egypt. This section gives a brief on the different "in use" renewable energy resources in Egypt that are utilized for electricity generation; their historical development and future prospects.

1.1 Hydro

Hydro-electricity has played a role in electricity generation in Egypt for decades. The hydropower energy constitutes approximately 11.2% of Egypt's power. The first of which (Aswan Dam) was built in 1960 to control the Nile water discharge for irrigation. It produces about 15,300 GWh a year and provides from 5 to 10% of Egypt's annual energy needs. In 1967, the 2.10 GW High Dam hydropower plant was commissioned, followed by the construction of the Aswan-2 power plant in 1985, the Isna hydro power plant in 1993 and that of Naga-Hamadi in 2008 (EERA, 2009).

1.2 Solar

Egypt has substantial potential for solar energy, as two-thirds of the country's geographic area has a solar energy intensity of more than 6.4 kWh/m^{2}/day. Due to its location, topography and climate, Egypt has an average level of solar radiation of between 2,000 to 3,200 kWh per square metre a year, giving it significant potential for utilizing this form of renewable energy. In 2010, Egypt's only major solar power project was commissioned in Kuraymat. The capacity of the plant is a 140 MWe solar thermal combined cycle power plant of which 20 MWe is from solar energy. It is one of 3 similar projects that are being implemented in Africa (Morocco,

Algeria, Egypt), which mainly depend on integrating a solar field with a combined gas cycle. However, the investment cost of solar power plants is currently very high in comparison with fossil hydrocarbon based power plants.

1.3 Wind

Egypt is recognized as having some of the world's best wind resources, especially in the Gulf of Suez and Red Sea areas where wind speed approaches 10 m/s. A significant additional potential is well recognized along the east and west banks of the Nile. According to the Egypt Wind Energy Association 700 square kilometres have been set aside for new wind projects in the Gebel el-Zayt area which has wind speeds of 11 m/s.

So far, the Zafarana district is considered the best Egyptian region for wind development (wind speeds of 9 m/s). In 2011, NREA begin constructing a series of linked wind farms at Zafarana area. From 2010 - now, NREA is operating a big wind farm project with a total installed capacity of 550 MWe, making it one of the largest onshore wind farms in the world. Another 200 MWe wind project is being installed in the Al-Zayt area which is expected to become operational by the end of 2014.

2. GEOLOGIC BACKGROUND

According to the nature of geothermal systems in Egypt, the geological setting of the geothermal resources is mainly of two systems:

1. The first is structurally controlled and mainly controlled by the geology and tectonics of the Gulf of Suez where a number of hot springs are located. Geothermal activity around the Gulf of Suez can be recognized through a number of hot springs, which can be observed at the surface. Some of these hot springs are detected at the eastern coast of the Gulf of Suez and others are located at the western coast. These springs owe their existence to the tectonics and the structural elements that control the whole Gulf area.

2. The second is controlled by the depositional system of the different stratagraphic units in the Western Desert of Egypt, where many flowing hot springs are encountered.

Figure 1 shows a geological map of Egypt illustrating the main two areas, where the geothermal activity does occur. However, a more detailed map illustrating the distribution of the geothermal hot springs is provided in Figure 3.

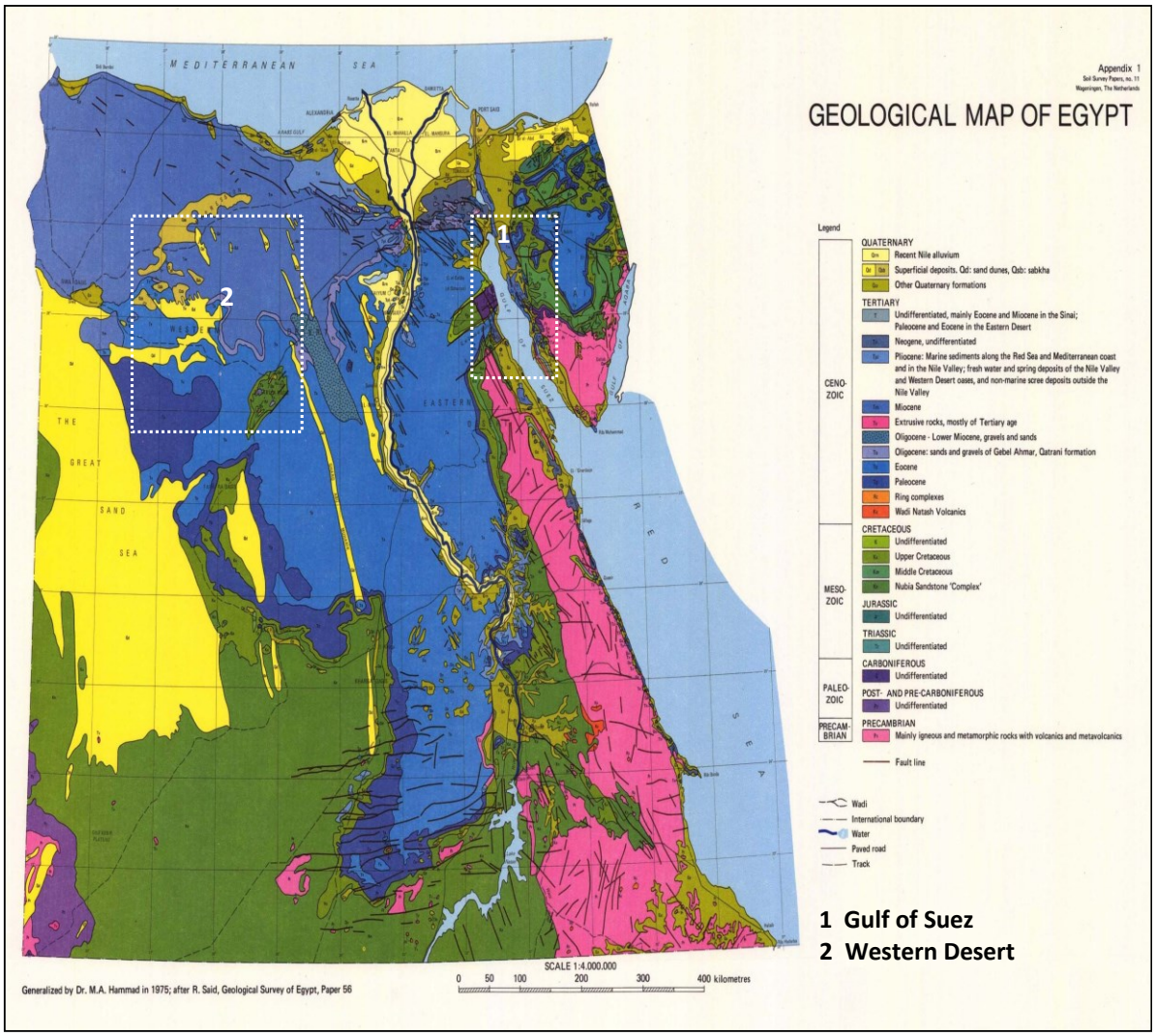


Figure 1. Geological map of Egypt showing the geothermal active areas.

2.1 Gulf of Suez

Most of the geothermal activities around the Gulf of Suez are related to the tectonic activity of the Red Sea area and Gulf of Suez rift (Boulos, 1990; Lashin and Al Arifi 2010; Abdelzaher, 2009; Lashin 2007, 2013). In general, the thermal activity around the Gulf of Suez is controlled by the structural elements affecting the whole Gulf area. The major geologic structures affecting the whole province are the NNW-SSE oriented faults. Many hot springs are found surrounding the coast of the Gulf of Suez. Some of these hot springs are located in the eastern coast, like Ayun Musa and Hammam Faraun, while others are found in the western coast (Ain El Sukhna) (see Fig. 2).

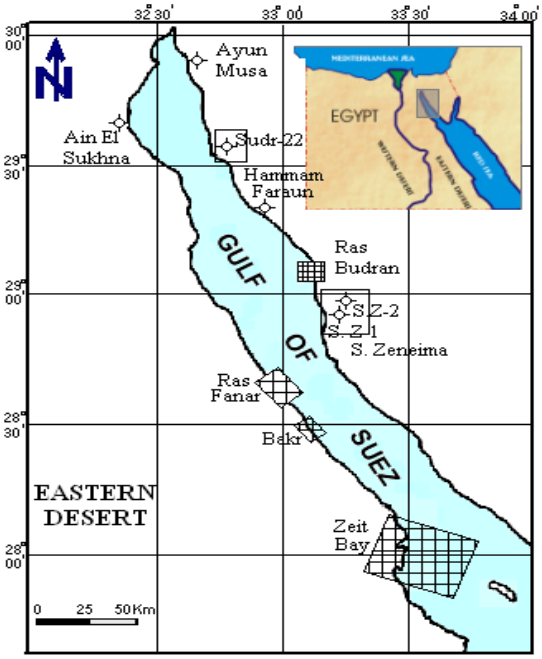


Figure 2. Location of the different hot springs and deep wells around Gulf of Suez.

Geologically, Ayun Musa area is generally flat with some minor topographic highs scattered in the area. The stratigraphic column of this area, as inferred from some drilled wells (Ayun Musa-2), is characterized by thick Paleozoic rocks (1,960 ft) unconformably overlying the Pre-Cambrian basement rocks. The Mesozoic rocks (quartzite, marl, sandstone and thin limestone beds of about 3,100 ft) are well represented in this area and covered by younger deposits of clays of Miocene age.

Hammam Faraun hot spring is located about 40 km to the south of Sudr area. Due to their proximity, the geologic setting of the Sudr and Hammam Faraun areas is nearly similar. The stratigraphic column is represented by well classified highly fractured Eocene rocks of considerable thickness (limestone, subordinate shales, marl interbeds and traces of sandstone), from which the springs flow, covered by thin sediments of the Miocene and Oligocene (gypsum, sandy marl and conglomerate), and the Pliocene and Post-Pliocene sediments. Ain El Sukhna hot spring, on the other hand, is located in the western coast of the Gulf of Suez. The stratigraphic succession of this area is represented mainly by Miocene deposits of reliable thickness (650 m) overlying a small clastic succession of the Jurassic rocks and underlying a big section consists of Recent and Post Miocene deposits (Lashin, 2013).

The information about this system is mainly driven from chemical analyses of collected water samples at the surface and from available temperature logs and bottom hole temperature data of some deep oil wells around the coastal areas of the Gulf of Suez. Away from Gulf of Suez, some other thermal springs (up to 35^{o}C) enriched with sulfur are located 25 km south of Cairo close to Helwan city.

2.2 Western Desert of Egypt

The western Desert of Egypt includes a famous series of depressions such as Baharia, Farafra, Dakhla, and Kharga oases, which represent important geomorphologic features and are most probably structurally controlled (Abdel Zaher & Ehara, 2009). In most of these oases, a large number of hot springs are flowing naturally from the Nubia Sandstone. The surface temperature range is relatively low suggesting low-enthalpy geothermal system (see Table 1a).

3. GEOTHERMAL RESOURCES & PAST/RECENT ACTIVITY

The geothermal fields of north-eastern Egypt provide a unique setting of high temperature combined with variation in chemical composition. The distribution of the thermal systems follows the tectonic patterns of Egypt.

3.1 Geothermal resources of Egypt

The geothermal activity in Egypt is recognized in different areas, in terms of small hot springs exposed at the surface or thermal deep wells. Nearly all the hot springs are detected around the coastal parts of the Gulf of Suez, around the Cairo-Suez road (Helwan hot springs) and in the Western Desert of Egypt (Fig. 3). A very good example of the thermal waters, which come from deep wells, are those located in the Western Desert (Kharga and Baharyia oases) (Lashin, 2013).

Table 1a. Temperature gradients for different wells and springs in Egypt (Morgan, 1983; 1985).

Map Key	Location	Temperature gradients (mKm^{-1})	Depth (m)
(A)	*Northern and Western Egypt*		
1	Northern Egypt oil wells	20.6 ± 2.9	114-4656
2	Abu Tartur	18.7 ± 1.0	10-235
2	Abu Tartur (phosphate)	74 ± 6 (8)	25-145
3	West Kharga	15.2 (1)	100-430
(B)	*Eastern Egypt (existing data and boreholes)*		
4	Gulf of Suez oil wells	26.9 ± 5.7	457-5198
	(Hammam Faraun hot spring)	48 (1)	5-80
5	Abu Shegala	30–50 (1)	20-200
6	Abu Dabbab	28.9 ± 2.9	20-200
7	Neweibi	20.3 ± 2.6	30-190
8	Sukkeri	18.9 (3)	60-240
9	Abu Ghalaga	18.8 (5)	100-225
10	Umm Samiuki	19.1 (2)	25-140
11	Barramiya	16.7 (1)	50-300
12	Genina	12.0 (1)	30-60
13	Homr Akarem	17.6 (2)	45-120
14	Gabbro Akarem	8.2 (3)	30-70
(C)	*Eastern Egypt (especially drilled regional gradient boreholes)*		
15	Wadi Ghadir	55.0	20-150
16	Aswan	13.9	20-100
17	Wadi Higlig	23.4	20-100
18	Berenice	21.5	35-100

The tectonic position of Egypt in the north-eastern corner of the African continent suggests that it may possess significant geothermal resources, especially along its eastern margin. The most promising areas for geothermal exploration in the NW Red Sea-Gulf of Suez rift system are located where the eastern shore of the Gulf of Suez is characterized by superficial thermal manifestations including a cluster of hot springs with varied temperatures (Abdel Zaher, 2011).

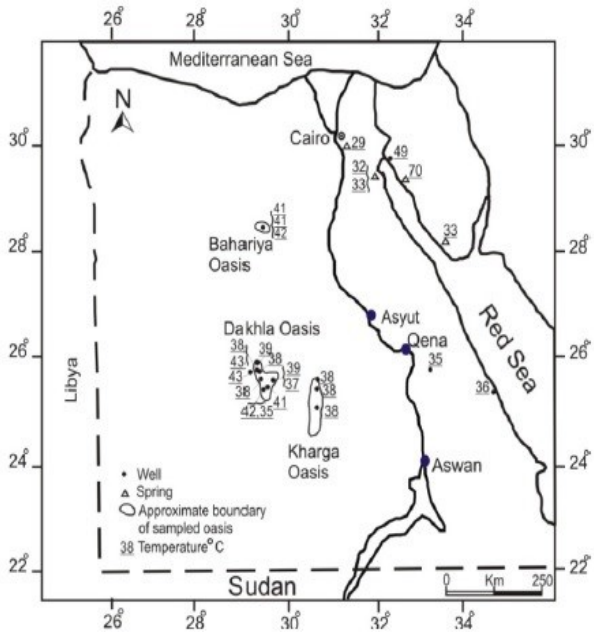


Figure 3. Location of different hot springs in Egypt with surface temperature indicated (Al Ramly, 1969).

The presence of active structural systems that characterizes the Gulf of Suez region is associated with block faulting where hot springs with temperatures up to 76°C issue at many localities along the eastern and western coasts of the gulf. The heat for these springs is probably derived from high heat flow and deep circulation controlled by faults associated with the opening of the Red Sea and the Gulf of Suez rift (Morgan et al., 1983 and El-Fiky, 2009).

Generally, a majority of geothermal resources in Egypt can be categorized as medium to low-temperature potentials and the most important are those located around the Gulf of Suez. However some places of high enthalpy resources are encountered in the off-shore deep marine areas of the Gulf of Suez and Red Sea.

The geothermal resources of Egypt can be classified as three main types;

1. Low enthalpy geothermal resources: Located mainly in the Western Desert of Egypt (Kharga and Baharyia oases), around the Gulf of Suez (e.g. Ayun Musa, Ain El Sukhna and Helwian sulfur springs) and in some locations in Sinai.

2. Medium enthalpy geothermal resources: Represented by some hot springs and geothermal targets around Gulf of Suez (e.g. Hammam Faraun). It produces geothermal water up to 76°C at the surface.

3. High enthalpy geothermal resources: Geothermal anomalies encountered in the rift of depo-centres areas of the Gulf of Suez and Red Sea.

3.2 Past/Recent Geothermal Activity

The geothermal activity of Egypt has received the attention of many researches from the mid of 1970 till now (Al Ramly, 1969; Issar et al. 1971; Morgan and Swanberg, 1979; Morgan et al. 1977, 1983 and 1985; Swanberg et al. 1983; Riad et al. 1989; Boulus, 1989 and 1990; Zaghloul et al. 1995; Feinstein et al. 1996; Hosney and Dahroug 1999; Hosney, 2000; Hosney and Morgan, 2000; and Abdelzaher and Ehara, 2009; Lashin and Al Arifi, 2010; Abdelzaher et al. 2011 and Lashin, 2013). The actual work was done by Boulos (1989). He was the first who studied the potentiality of the geothermal resources on an industrial scale. He presented a new idea for applying the ocean thermal energy conversion concept for generating the electricity (150–200 kWe) required for tourism development. A single-stage binary plant with ammonia fluid was suggested for this purpose.

However, the most recent and important work was that of Lashin (2013). He studied the geothermal resources encountered along the Gulf of Suez. He analyzed the temperature profiles collected for some hot springs and deep oil wells. Some important petrothermal parameters were measured such as thermal conductivity, specific heat capacity and heat flow. Geothermometers are applied and heat generation is estimated using the gamma ray spectrometry tools. A geothermal reserve study was enhanced for Hammam Farun hot spring. It gave a geothermal power potential of 12.4 MWt, that is considered economically good and supporting the idea of constructing a small binary power plant for electricity production.

A more promised geothermal work, including detailed geophysical investigation and geothermal reserve assessment was conducted by Abdel Zaher & Ehara, 2009 and Abdel Zaher et al. 2011. Furthermore, El-Fiky (2009) conducted a detailed geochemical and isotopic study concerning the main hot springs around Gulf of Suez. The whole geothermal system of the Gulf of Suez has been investigated to evaluate the origin of the dissolved constituents and subsurface reservoir temperatures.

Generally speaking, extensive geological, geochemical, and geophysical investigations were carried out for the geothermal systems in Egypt through the course of the last two decades, including geothermal reserve estimation and cost analysis studies. The following is the main characteristics:

3.2.1 Analysis of Temperature Data

Table 1a exhibits the different geothermal gradients as obtained from deep drilled wells in the Gulf of Suez, Eastern and Western Deserts of Egypt (Al Ramly, 1969). It shows a wide range of gradients from 8.2 to 74°C/km. It illustrates that Abu Tratur phosphates and Hammam Faraun hot springs attain high geothermal gradients of 74 and 48°C/km, respectively.

However, a more recent study by Lashin (2013) regarding analysing the temperature profiles of the different hot springs around Gulf of Suez and some deep oil wells assigns relatively medium gradient for Hammam Faraun (42.9°C/km). A number of compiled gradient, specific, heat capacity, thermal conductivity, heat flow versus depth plots are constructed (Figs. 4 and 5).

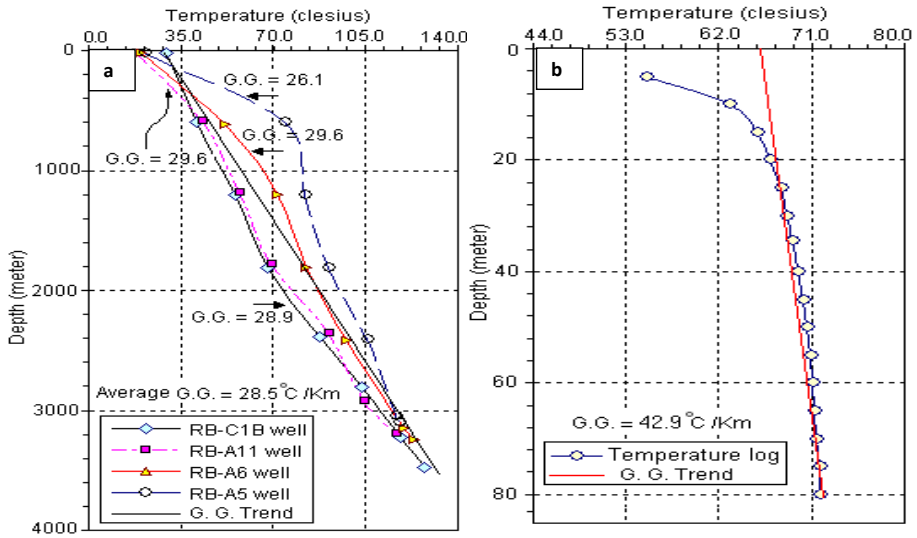


Figure 4. The temperature profiles and the average geothermal gradient wells in A) Ras Budran field, and B) Hammam Farun Hot spring, Gulf of Suez (Lashin, 2013).

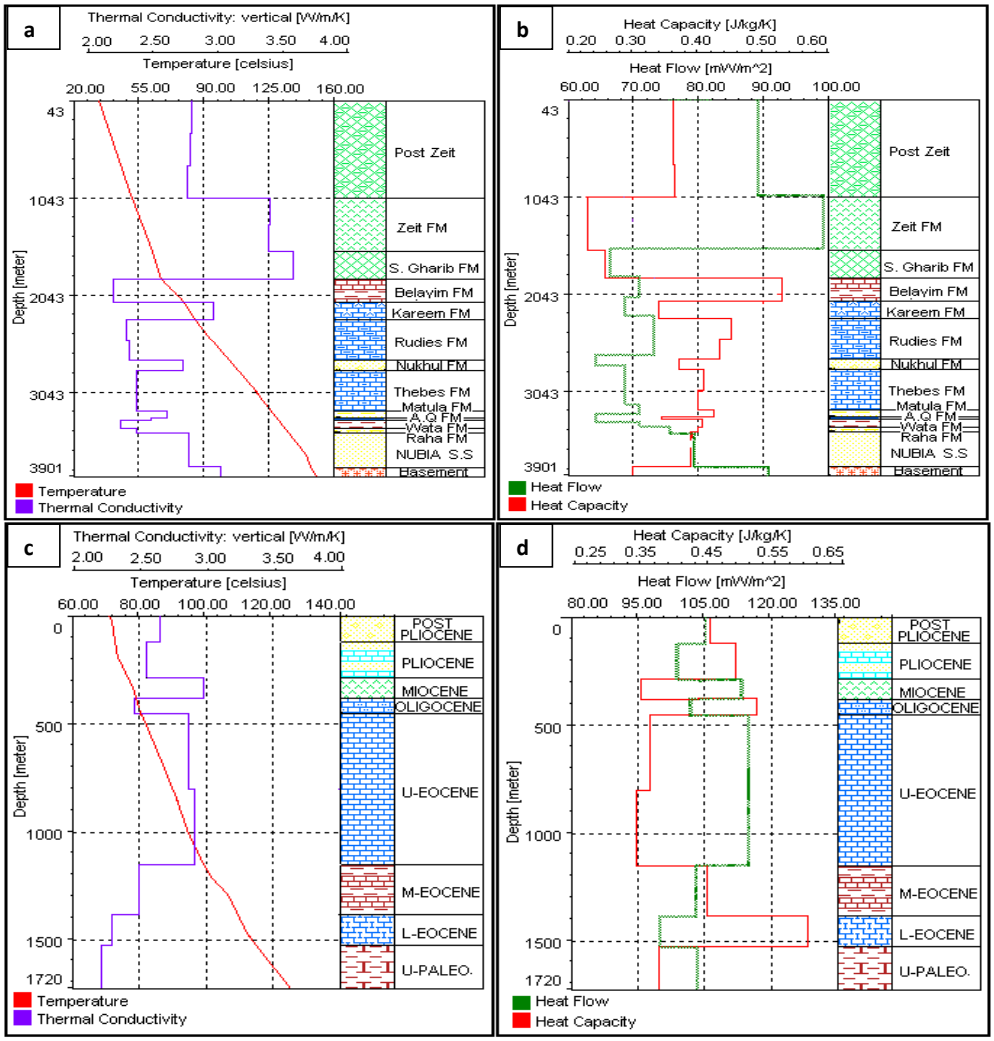


Figure 5. A and B) Thermal parameters of wells in Ras Budran field, and C &D) Thermal parameters of Hammam Faraun-Sudr area, Gulf of Suez (Lashin, 2013).

Normal geothermal gradients are observed in the Zeit Bay and Ras Burdan fields, which range between 22.48°C/km to 29.8°C/km and 26.1°C/km to 29.6°C/km for both fields, respectively. Meanwhile, medium geothermal gradient is represented by Ras Fanr wells (39.7°C/km). Low average geothermal gradient of 19.7°C/km is given for S. Zeneima field and relatively higher gradient in the order of 45.7°C /km is recorded at Bakr oil field (Lashin, 2013).

The complied plots (Fig. 5) show that the evaporites and rock salt units in the Gulf of Suez (Zeit and South Gharib Formations and some members in Belayim Formation) along with the basement rocks exhibit the highest estimated thermal conductivity values in W/m/K (3 - 3.5), the highest heat flow values in mW/m2 (80 - 100) and the lowest specific heat capacity values (< 0.30 J/kg/K).

The rock units, where the shale (Watta Formation) and the argillaceous limestone lithology (Thebes Formation) dominate, show low thermal conductivity (< 2.5 W/m/K) and heat flow (< 65 mW/m^2) and high specific heat capacity (> 0.50 J/kg/K). Some rock units of the Nubia S.S Formation exhibit intermediate petro-thermal characteristics. In Hammam Faraun-Sudr area the estimated formation temperature reaches 128°C at a depth of 1,720 m, which is considered high as compared with other comparable depths. Both of the thermal conductivity (2.8 W/m/K - 3 W/m/K) and the heat flow (105 mW/m2- 120 mW/m^2) increase in front of the U. Eocene rocks suggesting that, these rocks are the possible reservoir of the upcoming geothermal hot water (Lashin, 2013). In the Western Desert of Egypt, the analysis of temperature data reflects low temperature gradients between 15 and 19 mKm-1, which were measured in sediments of low thermal conductivity and therefore low heat flow is indicated (Abdel Zaher and Ehara, 2009).

3.2.2 Geochemical analyses & Heat Generation

A number of geo-thermometric studies are enhanced for the geothermal water is Egypt. The most recent ones are those of El-Fiky (2009) and Lashin (2007, 2013). Based on geo-thermometers, Lashin (2013) pointed out that Hammam Faraun area attains the highest recorded subsurface formation temperature (94.86°C) and heat flow (121.67 mW/m^2) values among the other studied areas; the values that are in harmony with the average temperature (95°C) and heat flow (116 mW/m^2) values obtained from the analysis of temperature data. A more detailed geochemical and isotopic analyses was carried out by El-Fiky (2009) for the thermal water of Gulf of Suez. He pointed out that the relations between Na, K, Mg, Br, SO4 and Cl strongly confirm the mixing process and contribution of sea water where the plotted points are located along the mixing line between thermal waters and sea water end member (Fig. 6).

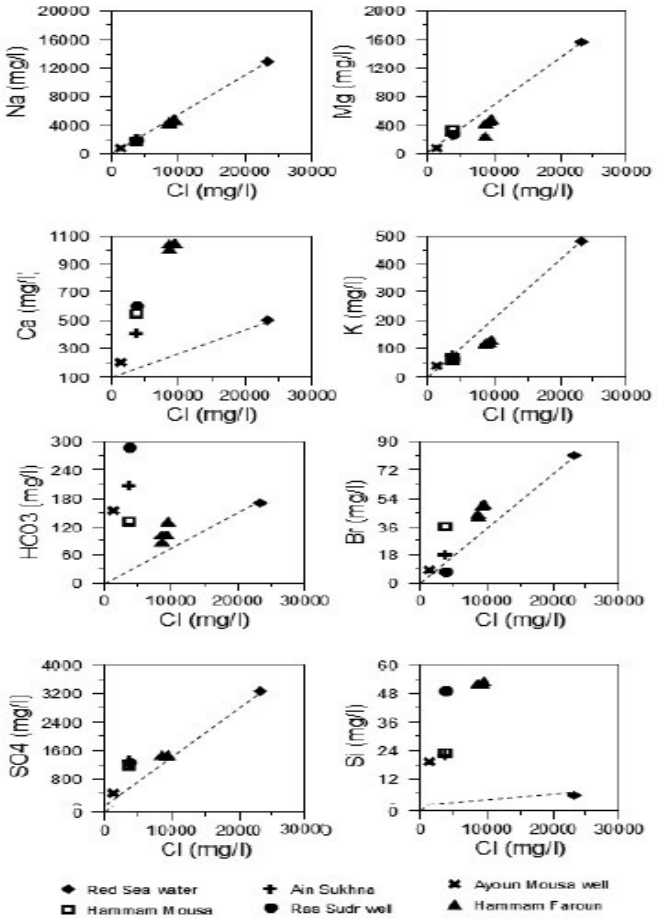


Figure 6. The relations between Na, K, Mg, Br, SO4 and Cl for the hot springs, Gulf of Suez-Egypt (El-Fiky, 2009).

Meanwhile, thermal waters that are enriched with Ca, are plotted above the mixing line due to the dissolution of carbonate rocks. Thermal waters discharged at Hammam Faroun show high Ca levels, which are possibly derived from faulted, dolomitic Eocene limestones commonly encountered at this locality. According to the relations of the ions it is suggested that the initial aqueous solution was a mixture of sea water and local meteoric water (El-Fiky, 2009).

The isotopic study revealed that the thermal waters from the Gulf of Suez area are depleted in $_{18}O$ and $_{2}H$ and fall on the Global Meteoric Water Line (GMWL) and below the local eastern Mediterranean Meteoric Water Line (MMWL) with d-excess values ranging between 3.42 and 10.6%, which is similar to the groundwater of the Nubian aquifer in central Sinai and the Western Desert of Egypt and suggesting a common origin (Fig. 7). This indicates that these waters are paleo-meteoric water which recharged and flushed residual saline water in the Nubian aquifer under different climatic conditions than the modern ones (El-Fiky, 2009).

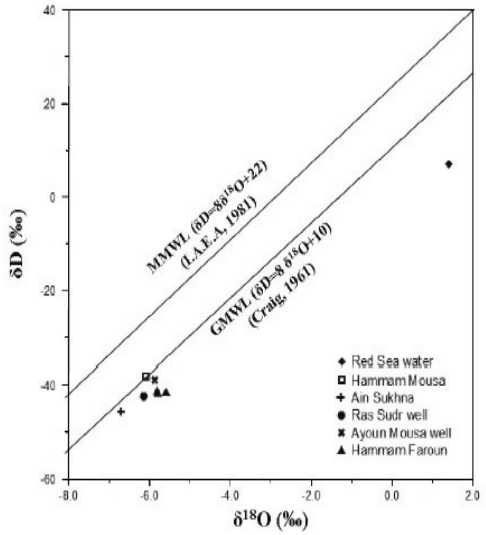


Figure 7. Plot of $_{18}O$ and $_{2}H$ for the hot springs, Gulf of Suez-Egypt (El-Fiky, 2009).

Heat generation estimated from available gamma ray (GR) and the natural gamma ray spectroscopy (NGS) logs for deep radioactive sedimentary and granite rocks around the Gulf of Suez indicates that is a good linearity is between the heat production (A in $\mu W/m^3$) and the gamma ray (API) along a wide range of datasets (0 -150 API) in all wells. In general, heat generation factor is low and has no contribution to the geothermal activity in the Gulf of Suez (Fig. 8). However, the heat production factor increases in the carbonate lithology (up to 3.20 $\mu W/m^3$) and is proportional to the shale volume (Lashin, 2013).

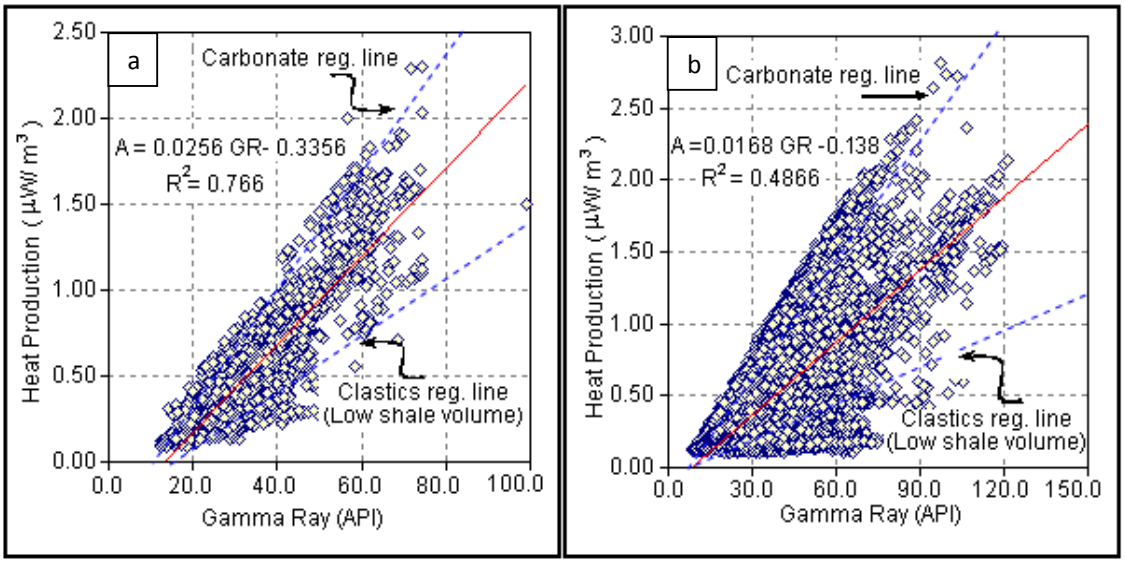


Figure 8. Heat production-gamma ray relationship in Ras Budran field, Gulf of Suez A) RB-1 well and B) RB-A7 well.

3.2.3 Geophysical Exploration

In general, the geophysical exploration of geothermal resources is not adequate. Few geophysical investigations are made for the some geothermal resources around the Gulf of Suez. The most important work was that of Abdel Zaher, et al. (2011). An integrated gravity and magneto-telluric reconnaissance survey were carried out over the geothermal region of Hammam Faraun using 16 MT stations in order to infer the subsurface densities and electric resistivity that can be related to rock units. A conceptual model and numerical simulation were made to determine the characteristics and origin of the heat sources beneath Hammam Faraun hot spring. It showed that the origin is due to high heat flow and deep ground water circulation in the subsurface reservoir controlled by faults (Figs. 9 and 10; Abdel Zaher, et al. 2011).

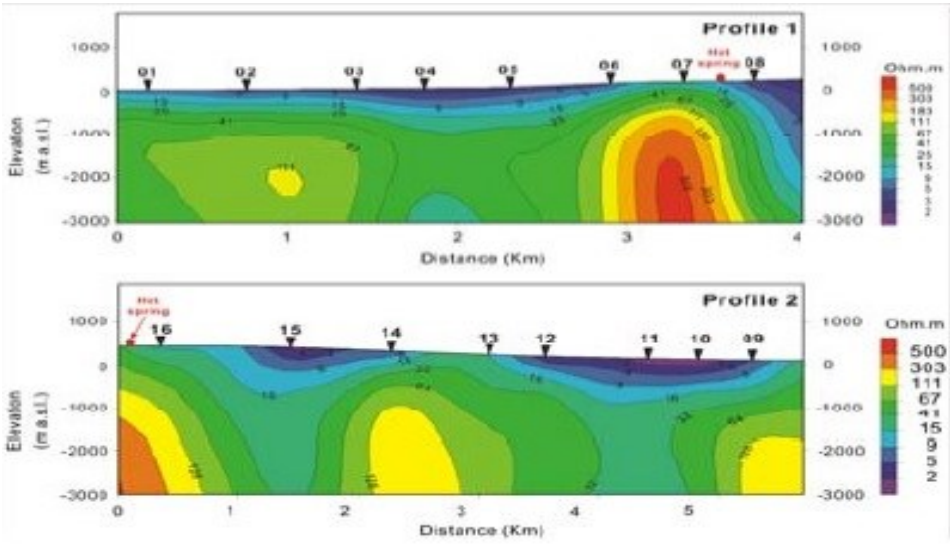


Figure 9. Apparent resistivity cross section versus depth using Bostick 1-D model , Hammam Farun area (Abdel Zaher et al. 2011).

3.2.4 Geothermal Potential Estimation

No actual reserves estimation is made for the whole geothermal system in Egypt. However, a geothermal resource assessment was made for Hammam Faraun area due to its unique geothermal characteristics (Lashin, 2007, 2013 and Abdel Zaher et al. 2011). According to Lashin (2007, 2013), a figure of 12.4 MWt thermal power potential is given for Hammam Faraun area, assuming

geothermal reservoir temperature of 95°C, turbine conversion efficiency factor of 0.26, 50 years work for the proposed geothermal plant and a recovery factor of 0.20. On the other hand, Abdel Zaher, et al. 2011, based on the numerical simulation, concluded that a little bit higher value of geothermal potential of 19.8 MWt is given for the Hammam Faraun hot spring area, assuming a reservoir thickness of 500 m, the initial temperature was 130oC and a 30 years reservoir production. Additionally, the geothermal reservoir was assumed to contain hot solid rock and single-phase liquid water. The estimated range of geothermal potential at Hamma Faraun area (12.4 - 19.8 MWt) is economically good and supporting the idea of constructing a small binary power plant for electricity production.

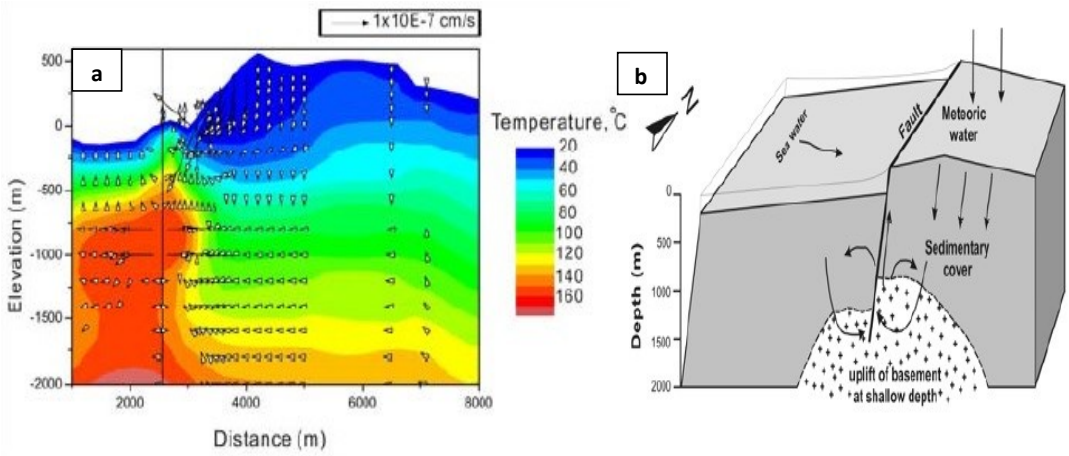


Figure 10. A) East-West temperature distribution slice and water velocity pattern of the Hammam Faraun hot spring at a natural state, and B) Schematic diagram showing a conceptual model of the hydrothermal system of Hammam Faraun hot spring (Abdel Zaher, et al. 2011).

4. GEOTHERMAL UTILIZATION

Recently, there is no installed geothermal plants for power generation in Egypt. Some direct applications are already installed in the last 10 years.

4.1 Low-grade direct applications

Direct utilization of thermal water in ancient Egypt goes back to thousands of years, where many of the old Egyptians used to utilize the warm waters arising from hot springs for domestic uses. Warm lakes in the houses of wealthy people are prepared especially for swimming and medical purposes. Some papyruses are found in the western desert of Egypt recording such usage.

Recently, some direct low-grade geothermal applications are now in use in Egypt. The most common forms of utilization are; district heating, fish farming, agricultural applications and green houses. Some refreshment and swimming pools are already constructed along the eastern coastal parts of Gulf of Suez. These pools are mainly used for touristic and medical purposes. Figure 11 shows the thermal-based pools in Ayun Mousa area along the north eastern part of Gulf of Suez (Kaiser and Ahmed, 2013). The geothermal water that came from the hot spring is the main feed for these pools.



Figure 11. Swimming pools and refreshment areas in Ayun Mousa area, the Gulf of Suez-Egypt (Kaiser and Ahmed, 2013).

In the Western Desert of Egypt, majority of the green houses in the oases of Baharia and Dakhla are completely based on thermal waters. Furthermore, in winter a very primary aspect of district heating is based on using the hot water from the deep artesian thermal wells.

A good example of such utilization is Kifar-1 well. This well is located at Qattara depression in the northwestern desert of Egypt and considered one of the most productive flowing water wells in this area (Fig. 12) . The well discharges a huge amount of warm pure and fresh water (T= 57^{o}C and TDS 464 ppm) under a high pressure of 5 kg/cm^{2}. The well discharges water from the interval thickness of 8 m (1,166 – 1,174 m) at a rate of 406 m^{3}/hr. The difference in temperature of the discharged water from Kifar well and air temperature by night reaches to 47^{o}C in winter and 37^{o}C in summer. The well is used for heating, greenhouses and drinking purposes (Boulos, 1989).

4.2 Power generation (Kalina Binary Plant)

Generating electricity from low-to-medium temperature geothermal fluids (binary plant) and from the waste hot waters coming from the separators in water-dominated geothermal fields has made considerable progress since improvements were made in the binary fluid technology. Binary plant technology is a very effective and reliable mean for converting the energy available from water-dominated (85-170°C) geothermal fields into electricity (Dickson and Fanelli, 2004).

The most famous is the Kalina cycle, which was developed in the 1990s and utilizes a water-ammonia mixture as a working fluid. It can be designed into a small-sized mobile plant which, can help in meeting the energy requirements of isolated areas. The convenience of these small mobile plants is most evident for areas and communities, which have no high voltage transmission lines in the vicinity and that would be too expensive to connect to the national electric grid. By selecting suitable secondary fluids and by obtaining the minimum temperature limit, binary systems can be designed to utilize geothermal fluids in the temperature range below 170°C.

According to Lashin (2013), downhole pumps can be used to utilize the reservoir thermal waters of Hammam Faraun area to produce water with temperature more than 85°C. This thermal water can be used for operating Kalina power plants. On the other hand, the surface low component of geothermal water coming from Hammam Faraun can be used for other direct heat applications.

5. DISCUSSION

According to the world energy assessment report, prepared by UNDP, UN-DESA and the World Energy Council published in 2000, the standard tariff cost of geothermal energy per kWh is very completive with other renewable energy forms (Fridleifsson, 2001). However, some local conditions should be taken in consideration such as, how far is the geothermal resources from the populated areas, topography, the energy demand, types of thermal fluids, etc.

The current average tariffs for electricity in Egypt are in the range from EGP 0.20/kWh (US$ 0.01 to 0.10/kWh). These tariffs cover the generation costs of electricity plus its transmission, distribution and retailing (Al Sobky et al. 2009). However, a governmental subsidence is provided for some industrial and agricultural activities.

Based on the work of Lashin et al. 2014, a primary estimate of the tariff of the geothermal-based energy is given to be EGP 0.72/kWh (US$ 0.12 kWh). This figure should be taken in consideration with regard of the future demand of energy in Egypt. The clean environmental impact of such type of energy is another key consideration.

Tables from 1 to 8 list the statistical analysis of low/high and direct/indirect geothermal applications of geothermal resources in Egypt.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

The Gulf of Suez is characterized by the presence of some hot springs around its coastal areas. The temperature of the surface geothermal water coming from these springs is not so high, but still accessible for small-scale economic utilization, especially for Hammam Faraun area.

Future development of geothermal power plants along the coastal parts of the Gulf of Suez is reasonable. A binary geothermal-based power plant should be constructed for Hammam Faraun hot spring. Enough power potential, to be used in an industrial scale and limited electricity production can be obtained from Hammam Faraun area, by selecting suitable secondary fluids and by obtaining the minimum temperature limit to operate the binary systems (temperature range below 170°C). Other low temperature utilizations (heat pumps, greenhouses, fish farming and swimming pools, etc) can be considered also. More attention and extensive scientific work should be done to develop the area around Hammam Faraun spring for touristic purposes from one hand, and for constructing new communities fed with the geothermal-based energy, from the other hand.

In general, a detailed field mapping, geochemical and geophysical exploratory work is needed in future to better define the potentiality of the geothermal resources in Egypt.

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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	24,700	-	2,320	-	Nil	Nil	140	-	27,160	-
Under construction in December 2014	-	-			-	-	Nil	Nil	-	-	-	-
Funds committed, but not yet under construction in December 2014	-	-	2,300	-	720	-	-	-	920	-	3,940	-
Estimated total projected use by 2020	-	-	27,000	-	3,040	-	-	-	1,060	-	31,100	-

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)] (MWt)	Annual Utilization		
		Flow Rate (kg/s)	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. Flow (kg/s)	Energy[4)] (TJ/yr)	Capacity Factor[5)]
			Inlet (Reservoir T)	Outlet (Surface T)	Inlet	Outlet (Discharge)				
Hammam Farun (Gulf of Suez)	B	-	128	76	-	-	20	-	-	-
Ayun Mousa (Gulf of Suez)	B	-	93	48	-	-	-	-	-	-
Ain Sukhna (Gulf of Suez)	B	-	63	35	-	-	-	-		-
Kifar-1 well (Western Desert)	H , D	-	63	57	-	-	-	-	-	-
Dakhla Oasis (Western Desert)	B , G	-	-	33 - 44	-	-	-	-	-	-
TOTAL										

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

Use	Installed Capacity[1)] (MWt)	Annual Energy Use[2)] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3)]
Individual Space Heating[4)]	0.3	3	?
District Heating[4)]	1.5	15	?
Air Conditioning (Cooling)	-	-	-
Greenhouse Heating	1	10	?
Fish Farming	-	-	-
Animal Farming	-	-	-
Agricultural Drying[5)]	-	-	-
Industrial Process Heat[6)]	-	-	-
Snow Melting	-	-	-
Bathing and Swimming[7)]	4	60	?
Other Uses (specify)	-	-	-
Subtotal	6.8	88	-
Geothermal Heat Pumps	-	-	-
TOTAL	6.8	88	

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)	
Exploration[1)]	(all)	-	3 (Hammam Faraun, Kifar-1, Ayun Mousa)	-	-	80 m (H. Faraun) 1147 m (Kifar-1 well)
Production	>150° C	-	-	-	-	-
	150-100° C	-	-	-	-	-
	<100° C	-	3	-	-	1250 m
Injection	(all)	-	-	-	-	-
Total		-	3	-	-	Up to 1250 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	-	-	- Benha - Suez Canal Universities (5 persons)	-	-	-
2011	-	-	- Benha - Suez Canal Universities (5 persons) - National Institute of Geophysics and Astronomy (4 persons).	-	-	-
2012	-	-	Benha - Suez Canal Universities (5 persons)		-	-
2013		-	- Benha - Suez Canal Universities (5 persons) - National Institute of Geophysics and Astronomy (4 persons).	-	-	-
2014	-	-	- Benha - Suez Canal Universities (4 persons) - National Institute of Geophysics and Astronomy (4 persons).	-	-	-
Total	-	-	9 persons /5 Years	-	-	-

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

	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
Period	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	Nil	Nil	Nil	Nil	Nil	Nil
2000-2004	-	25,000	1,000,000	-	-	-
2005-2009	40,000	20,000	500,000	-	-	-
2010-2015	50,000	-	500,000	-	-	100%