Review of the Geothermal Resources of Egypt: 2015-2020

Lashin A.[1,2,3]

[1] King Saud University, College of Engineering-Petroleum and Natural Gas Engineering Department, Riyadh 11421-Saudi Arabia.

[2] K.A.CARE Energy Research and Innovation Center in Riyadh.

[3] Benha University, Faculty of Science - Geology Department, P.O. Box 13518, Benha - Egypt..

arlashin@ksu.edu.sa

Keywords: Hot Springs, Exploration, Utilizations, Geothermal Resources, Egypt.

ABSTRACT

According to the announced Egyptian renewable energy plan for 2035, a sort of 67 GW representing about 45% of total generated electricity, will be added to the grid from PV, wind and other renewable resources. In the near future (end of the year 2022), Egypt intends to supply 20% of generated electricity from renewable sources (wind, solar and Hydro power). Till now the geothermal resources of Egypt are not scheduled, in the future plans of renewable energy, as a potential energy source.

The promised geothermal resources of Egypt are mainly located along the Gulf of Suez and the Red Sea and in some locations at the Western Desert of Egypt. The tectonic activity of the Gulf of Suez and the whole province of the Red Sea play an important role in controlling the thermal water. Other low enthalpy thermal springs, enriched with sulphur, are recognized away from the Gulf region, near Helwan city. In general the identified geothermal resources of Egypt can be categorized as low to medium enthalpy, however some high enthalpy spots are located in deep water associated with the rift of the Red Sea forming what called 'Red Sea Hot brines'. Although this is the status of the geothermal resources of Egypt, these resources could be utilized for many direct purposes as well as some low scales of power generation. This paper represents a review and update of the geothermal activities of Egypt within the last five years.

1. INTRODUCTION

Egypt represents the most populated energy market in the region and with the largest oil and gas consumer in the continent. Egypt is also an important non-OPEC fossil fuel producer and plays a vital role in international energy trade. The country is facing rapidly growing energy demand due to population growth, economic expansion and increased industrial output, among many factors. Egypt suffers from frequent power outages due to ageing infrastructure, and the lack of adequate generation and transmission capacity. 94% of total primary energy consumption in Egypt is from fossil fuels, while some energy comes from hydropower. The government aims to diversify the energy mix in favour of renewable energy resources and has set a target to achieve 20% of generated electricity from renewable energy by 2020 (RCREEE, 2019).

Egypt's fossil fuel energy resource endowments (including oil, natural gas and negligible amounts of low-quality coal) are limited, with a total proven reserves of 14.8 billion barrels (bbl) of oil equivalent petroleum energy (crude oil and natural gases), of which 3.4 billion bbl were in the form of crude oil and about 11.4 billion as natural gas (BP, 2017a). Egypt's economic development hinges on the energy sector, which represents 13.1% of overall gross domestic product (GDP). Egypt's average consumption of natural gas will grow to reach around 9 billion cubic feet per day (bcf/d) by 2020/21 because of Egypt's industrial development plan. To meet burgeoning energy demand, the Egyptian government has pursued an energy diversification strategy, known as the Integrated Sustainable Energy Strategy (ISES) to 2035, to ensure the continuous security and stability of the country's energy supply. This strategy involves stepping up the development of renewable energy and energy efficiency, in part through vigorous rehabilitation and maintenance programmes in the power sector.

Egypt is, therefore, committed to the widespread deployment of renewable energy technologies. It is planned to supply 53% of Egyptian electricity through mixing with other renewables resources by 2030. To date, the country's total installed capacity of renewables amounts to 3.7 gigawatts (GW), including 2.8 GW of hydropower and around 0.9 GW of solar and wind power. As specified in the ISES to 2035, the Egyptian government has set renewable energy targets of 20% of the electricity mix by 2022 and 42% by 2035 (IRENA, 2019). The total installed capacity of renewable energy sources is expected to reach 19.2 GW by 2021/22 and increase to 49.5 GW and 62.6 GW in years 2029/30 and 2034/35 respectively. Table 1 shows the development of installed electric capacity for the different renewable technologies from 2009 to 2035 (EU, 2015a).

Hydroelectric energy

Hydropower is the most mature renewable energy source in Egypt, with major contribution from the River Nile, with the highest potential in Aswan where a series of power stations are located totalling 2,8 GW. During the 1960s-1970s, it covered almost 50% of the Egypt's total need from generated electricity. However, due to the increase in the share of thermal power stations, electricity from hydro resources represented only 7.2% of the total electricity generated in 2015/16 (EEHC, 2016a). An additional 2,4 GW of Hydroelectric energy will be added to the grid by the end of 2022 upon completion of the pumped storage hydroelectric plant initiated at 2015 at Attaqa area (Andritz, 2016).

Table 1: Evolution of installed renewable energy power capacity in GW (EU, 2015a and EEHC, 2016a).

Type of power station	2009/10	2021/22	2029/30	2034/35
Hydro	2.8	2.8	2.9	2.9
Wind	0.5	13.3	20.6	20.6
PV	0.0	3.0	22.9	31.75
CSP	0.0	0.1	4.1	8.1
Total	3.3	19.2	50.5	62.6

Wind Energy

Egypt is endowed with abundant wind energy resources, particularly in the Gulf of Suez area. This is one of the best locations in the world for harnessing wind energy due to its high stable wind speeds that reach on average between 8 and 10 m/s at a height of 100 m, along with the availability of large uninhabited desert areas. The Zafarana district is considered one of the largest onshore wind farms in the world and the best Egyptian region for wind development with a wind speed of 9 m/sec. A big wind farm is being installed with a total installed capacity of 0.55 GW. New promised areas for wind energy farming, are discovered at Beni Suef and Menya Governorates (east and west of the Nile river) and at the New Valley Governorate (El Kharga Oasis) with wind speeds between 5 and 8 m/s.

Solar Energy

Egypt hopes to install 6 GW of solar capacity by 2022. The solar atlas for Egypt indicate that the country enjoys between 2,900 and 3,200 hours of annual sunshine, with annual direct normal intensity of 1,970-3,200 kWh/m^2 and a total radiation intensity varying between 2,000 and 3,200 kWh/m^2 /year. The first solar thermal integrated combined-cycle power plant (integrated solar and combined gas cycle) was constructed in the Kuraymat area with a total capacity of 140 MW, including 20 MW as a solar component and 120 MW as a gas-fired combined-cycle plant (IRENA, 2019). In late 2015, it was announced that the Aswan government would establish 39 solar projects at a total cost of $3bn. Therefore, the national electric company has signed an agreement with New and Renewable Energy Authority (NREA) to build a 50-MW solar plant in Aswan.

Biomass Energy

Egypt has large resources of biomass from agricultural waste, animal dung and urban solid waste. A big project 'Bioenergy for Sustainable Rural Development Project, BSRD)' was initiated in 2009 with a fund sharing between the government and United Nations Development Programme and achieved remarkable progress in developing and providing Bioenergy Service Providers to support the market of bioenergy in the country.

Geothermal Energy

Till now there is no actual development of geothermal energy in Egypt. However, at the last few years, the officials are open eyes on the potentiality of these resources as a new renewable source, among other renewables, for possible energy production and other low-grade applications. Majority of geothermal resources of Egypt are encountered along the Gulf of Suez and in Western Desert and as high heat-generating rock of granitic composition in the eastern desert region. Other low enthalpy thermal springs, enriched with sulphur, are recognized away from the Gulf region, near Helwan city.

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

2. GEOLOGIC SETTING & CLASSIFICATION

The promised geothermal resources of Egypt are mainly located along the Gulf of Suez, the Red Sea and in some locations at the Western Desert of Egypt. The tectonic activity of the Gulf of Suez and the whole province of the Red Sea play an important role in controlling the thermal water (Boulos, 1989a,b,1990; Lashin and Al Arifi 2010; Abdelzaher, 2009; Lashin 2007, 2013; Chandrasekharam, et al. 2016). These resources are represented by a number of thermal springs that are occur along the eastern and western margin of the Suez Gulf (Hammam Faraun, Ayun Mousa and Ain El Sukhna) and the western desert oases. Those thermal springs on either side of the Gulf of Suez are high-temperature springs (51–70 ^oC) while those in other localities are warm springs with temperatures varying from 35^o to 42^{o}C (Chandrasekharam, et al. 2016). The high heat-generating rocks of granitic composition are also encountered in the eastern desert region.

The geological setting of the hot springs around the Gulf of Suez is structurally controlled by the tectonics of the Gulf of Suez, while the thermal springs in the Western Desert of Egypt is controlled by the stratigraphic position or the rock units.

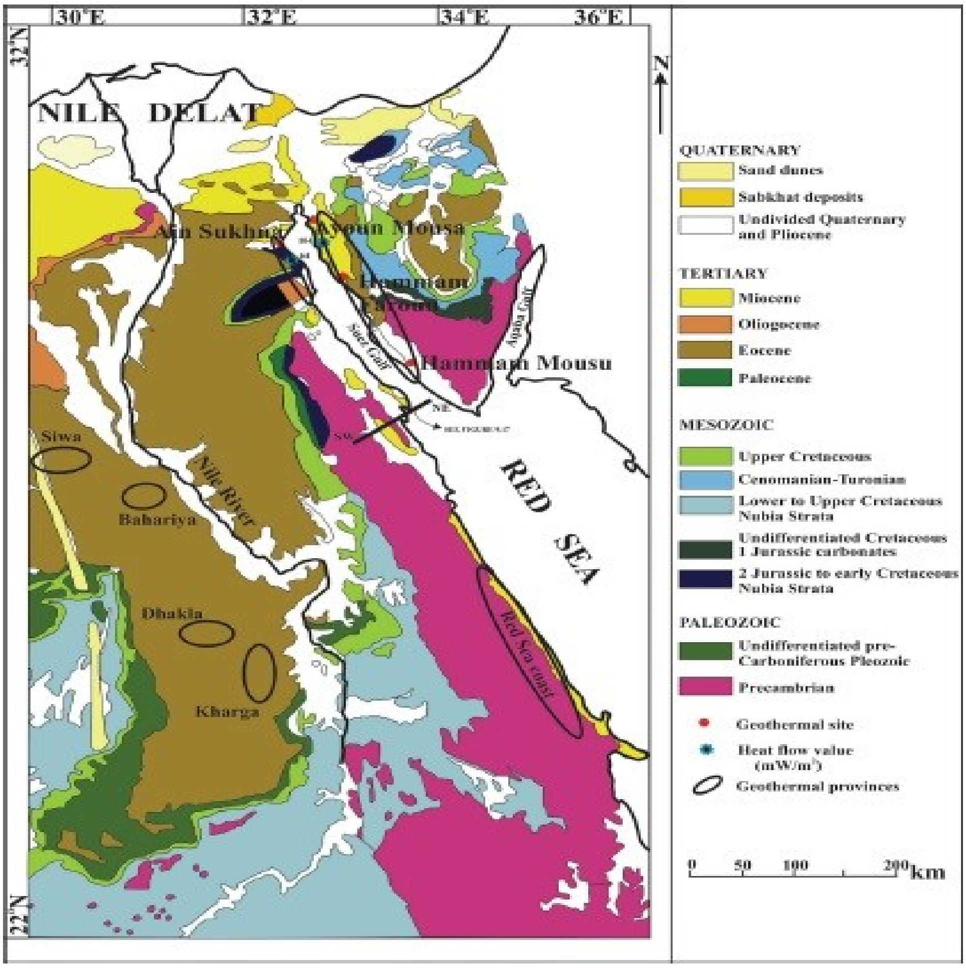

Figure 1: Geological map of Egypt showing the main geothermal activity (Chandrasekharam, et al. 2016).

Ayun Musa Hot spring is located in a flat area with minor topographic highs. The generalized stratigraphic column is represented by thick Paleozoic rocks, that unconformably overlying the Pre-Cambrian basement rocks. The Mesozoic clastic rocks are well represented in this area and covered by younger deposits of clays of Miocene age. Hammam Faraun hot spring is flowing from highly fractured carbonate Eocene rocks. This carbonate section is covered by a thin section of Miocene and Oligocene and the Pliocene and Post-Pliocene sediments. Ain El Sukhna hot spring is located in the western coast of the Gulf of Suez. The geology of the area is represented by thick Miocene rocks (650 m) topped by a big section of Recent and Post Miocene deposits and overlying a small clastic Jurassic rocks (Lashin, 2013). Some other thermal springs (35 ^{o}C) enriched with sulfur are located close to Helwan city, south of Cairo. In the western Desert of Egypt some low-temperature thermal springs are encountered (Baharia, Farafra, Dakhla, and Kharga). These hot springs are structurally controlled and flowing naturally from the Nubia Sandstone (Abdel Zaher & Ehara, 2009). High generating granites and related intrusives with high radioactive element content are extensively found in the eastern desert of Egypt, close to the Red Sea coast (Fig. 2). These late-stage granitic melts were enriched in uranium and thorium and accessory minerals such as zircon, titanite, monazite, thorite and uranothorite (Chandrasekharam, et al. 2016).

3. PAST/PRESENT GEOTHERMAL ACTIVITY

El Dayel (1988) Exploration and evaluation of geothermal resources of Egypt has received the attention of many researches from the mid of 1970 till now. Extensive geological, geochemical, and geophysical investigations are carried out for the geothermal systems in Egypt through the course of the last decades, including geothermal reserve estimation and cost analysis studies (Morgan and Swanberg, 1979; Morgan et al. 1977, 1983 and 1985; Boulus, 1989a,b and 1990; Zaghloul et al. 1995; Feinstein et al. 1996; Hosney and Morgan, 2000; and Abdelzaher and Ehara, 2009; Lashin and Al Arifi, 2010; Abdelzaher et al. 2011 and Lashin, 2007, 2013, 2015; Chandrasekharam, et al. 2016 and Abdel Zaher et al. 2018).

The first work done regarding the geothermal resources in Egypt were that of Morgan et al., 1983 and Boulos 1990. They recognized that the presence of active structural systems at the Gulf of Suez region is associated with block faulting where hot springs with temperatures up to 76^{o}C are represented 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. They analysed the temperature from surface thermal water and many deep oil wells and finally provided a detailed geothermal gradient and heat flow mapping for northern Egypt. Boulos (1989) further studied the potentiality of the geothermal resources in an industrial scale. He presented a new idea for applying the ocean thermal energy conversion concept for generating the electricity (150–200 kW) required for tourism development. A single-stage binary plant with ammonia fluid was suggested for this purpose.

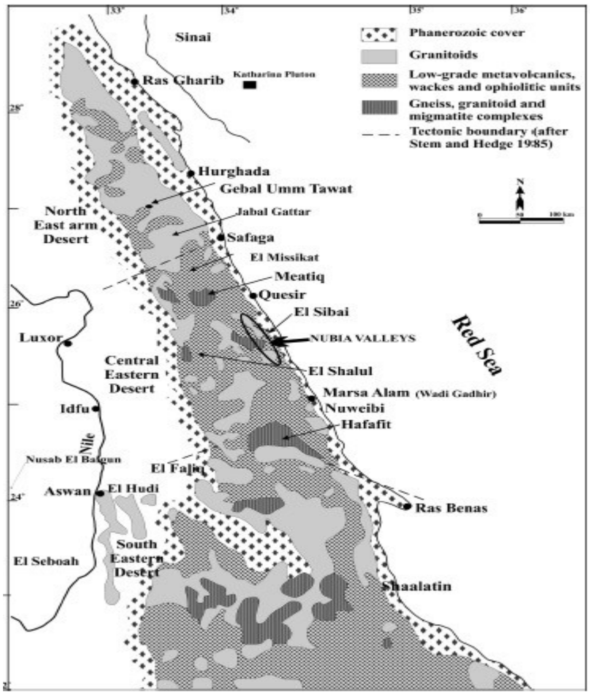

Figure 2: Distribution of granites and associated rocks in the eastern desert of Egypt (Lundmark et al. 2012; Chandrasekharam, et al. 2016).

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. 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. The isotopic study revealed that the thermal waters from the Gulf of Suez area are depleted in 18O and 2H and fall on the Global Meteoric Water and below the local eastern Mediterranean Meteoric Water Line, similar in characteristics to the groundwater of the Nubian aquifer in central Sinai and the Western Desert of Egypt and suggesting a common origin. This indicates that these waters are paleo-meteoric water which recharged and flushed residual saline water in the Nubian aquifer under different climatic conditions.

Abdel Zaher & Ehara, (2009) and Abdel Zaher et al. (2011) conducted a detailed geophysical investigation of the Gulf of Suez and geothermal reserve assessment. An integrated gravity and magneto-telluric reconnaissance surveys 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.

Lashin (2013) 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 are 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.

EL-Rayes et al. (2015) utilized the geographic information system (GIS) and remote sensing (RS) techniques are used to determine the spatial association between the hydrogeochemical and seismological evidences of well-known geothermal fields in South Sinai. GIS and RS tools are used to integrate and determine the spatial association between thermal exploration and environmental evidence layers in South Sinai for geothermal resource exploration. The geothermal evidences (topographic features, structural lineaments, seismic activities and the hydro-geochemical characteristics of thermal water) are collected and analyzed to locate new predicted geothermal sites in South Sinai. The hydrochemistry of the newly predicted thermal sites exhibits similar pattern of the known thermal waters. Such observations are used as indicators to locate six predicted new occurrences of geothermal fields in South Sinai. The seismicity of newly predicted geothermal sites is precisely assessed to understand the behaviour of recent tectonic movement. The seismicity pattern of well-known and newly predicted geothermal sites show that the majority of earthquakes have focal depths ranging between 3 and 33 km and have micro- to moderate magnitude ($0.5 \geq Mb \leq 4.5$).

More recently Chandrasekharam, et al. (2016) studied the hydrothermal systems around the Gulf of Suez and EGS represented by high heat-generating rock of granitic composition in the eastern desert region. The radioactive heat production (RHP in mW/m^3) by these granites has been calculated using the heat generation constant (amount of heat released per gram of U, Th and K in per unit time) and the uranium, thorium and potassium concentrations. The average heat generation by the granites is 18 lW/m3, and the average heat flow value is 220 mW/m2. This high value is apparently due to the occurrence of uranium-rich mineral phases and secondary uranium deposits in the younger granites and related rocks in the eastern desert.

Abdel Zaher et al. (2018) investigated the airborne gravity and magnetic geophysical data for the preliminary exploration of geothermal potential in Siwa Oasis. Siwa Oasis is a part of the greatest northern depression in the Egyptian Western Desert, located just 50 km east of the Libyan border. It represents one of the most interesting potential candidates for the development of the Northern Western Desert of Egypt. The derived geothermal gradients range from 21 to 27 °C/km and the heat-flow values range from 49 to 64 mW/m^2.

4. ECONOMIC CONSIDERATIONS, UTILIZATIONS AND FUTURE DEVELOPMENTS

With a rapidly growing population of 100m people and a host of major energy-intensive industrial facilities, Egypt requires a large supply of power to maintain growth. Most of the country's domestic energy needs are supplied by oil and gas, with natural gas as the largest single source (53%) and oil at 41%. Hydropower is 3% of the total, coal 2% and other renewables 1%. The production cost of electricity in Egypt averaged USD 0.05 (EGP 0.85) per kilowatt hour (kWh). A five-year plan to phase out internal subsidies in the electricity sector was officially endorsed. Steps were taken in July 2014 to implement a comprehensive five-year subsidy reform initiative, which includes annual tariff increases for most user segments on 1 July each year until 2018. Annual tariff increases have been deemed necessary by the government to eliminate subsidies, the effects of which have been exacerbated by currency devaluation. Therefore, moving rapidly towards renewable energy resources (Wind, Solar, geothermal, etc.) is a must for Egypt to overcome the problem of energy deficiency and annual increasing of tariff.

To achieve the promised Egyptian vision 2030 of replacing the traditional energy resources with other renewable ones, it was very important for the officials to update the energy and power sector strategies and plans regularly to reflect new developments. The country aims to double its installed electricity capacity by 2020 from its current level of around 50 GW, through the introduction of renewables, coal and nuclear power. However, increasing the sharing of renewables in power generation as high as 53%, will eliminate the need for coal and nuclear-related imports, thus strengthening the country's energy security. Several wind and solar resource assessments have been conducted; however, they have not been supplemented with sufficient detail to ensure bankability of projects.

Nowadays, the investment in the renewable energy sectors is gaining momentum, such that the total installed capacity of renewable energy stands at 3.7 gigawatts (GW) (mainly 2.8 GW of hydro and 0.887 GW of solar and wind) with a commitment from the government to develop an additional 10 GW of wind and solar projects by 2022, whereby renewables would contribute to 20% of the electricity mix (IRENA, 2018a). The future plans of 2035 include installing 52 GW of both large-scale and distributed on-grid renewable energy (IRENA, (2019).

Regarding the geothermal energy, till now there is no actual development and utilization of these resources. Power generation from geothermal plants is yet installed in Egypt Some direct low-grade geothermal applications are now in use is Egypt in the form of district heating, fish farming, agricultural applications and green houses, besides the presence of some refreshment and swimming pools along the eastern coastal parts of Gulf of Suez. Most of these thermal pools are mainly used for touristic and medical purposes. Majority of the green houses in the western desert of Egypt (Baharia and Dakhla oases) are based on thermal waters (Lashin et al. 2015).

Power generation from the geothermal sources can be viable is deep wells are drilled at taping temperature more than 150°C. Binary plants are the most appropriate technology for generating energy. Hammam Faraun area is the best candidate area for installing the first power plant in Egypt. The area is accessible, characterized by high potentiality and high geothermal gradient. Lashin (2013) conducted a resources assessment study at Hammam Faraun area in the Gulf of Suez. He concluded that a figure of 12.4 MWt thermal power potential was 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. However, a little bit higher value of geothermal potential of 19.8 MW was 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, based on the numerical simulation (Abdel Zaher, et al. 2011).

The Gulf of Suez is characterized by presence of good thermal springs with the maximum recorded surface temperature at Hammam Faraun area. The first action taken regarding exploring and developing the geothermal resources around Gulf of Suez is taken by Ganoub El-Wadi Petroleum Holding Company (GANOPE). In April 2016 GANOPE and NREA have signed a Memorandum of Understanding to explore and utilize geothermal energy around Gulf of Suez. In general, no actual utilization of geothermal energy is recognized in Egypt. Even heat pumps that can be used for both heating and cooling are yet installed. A vey fair figure of direct use is found in Ayun Mousa spring-Sinai, represented by swimming and refreshment pools.

5. SUMMARY

With a rapidly growing population of 100m and increase of demand on energy Egypt has a promised vision 2030 of replacing the traditional energy resources with other renewable ones. The country aims to double its installed electricity capacity by 2020 from its current level of around 50 GW, through the introduction of renewables (wind, solar, geothermal) ,coal and nuclear power. Many wind and solar farms are now installed in Egypt with a reasonable renewable contribution of energy.

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, close to Helwan and in the Western Desert of Egypt. Till now there is no actual development of geothermal energy in Egypt. However, at the last few years, the officials are open eyes on the potentiality of these resources as a new renewable source, among other renewables, for possible energy production and other low-grade applications. With its good geothermal reserves, Hammam Faraun area is a good prospective area for potential geothermal utilization and applications. However, more geochemical and geophysical exploratory work is needed in future to better define the potentiality of the geothermal resources in Egypt

REFERENCES

Abdelzaher, M. and Ehara, S. : Geothermal Resources in Egypt. *J. Geotherm. Res. Soc. Japan*, **31** (3), (2009), 155-166.

Abdel Zaher, M., Nishijima, J., Fujimitsu, Y., and Ehara, S.: Assessment of Low-Temperature Geothermal Resource of Hammam Faraun Hot Spring, Sinai Peninsula, Egypt. Proceedings 36th Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 31 - February 2, (2011).

Abdel Zaher, M., Saibi, H., Mansour, K., Khalil, A., Soliman, M.: Geothermal exploration Using Airborne Gravity And Magnetic Data at Siwa Oasis, Western Desert, Egypt, *Renewable and Sustainable Energy Reviews*, **82 (3),** (2018), 3824-3832.

Andritz, G.: Gift of the Nile. www.andritz.com/resource/blob/237908/ef7d565c0115edd7d71b1a7a0cc7ce0f/

hydronews-africa-04-egypt-data.pdf (2016).

Boulos, F.: Geothermal development of Hammam Faraun Hot Spring, Sinai-Egypt. International Conference On Applications Of Solar And Renewable Energy, (1989a), 12 P.

Boulos, F.: Groundwater of Nubian Aquifer System of Western Egypt- A Source for Geothermal Energy. proc. 11th New Zealand Geothermal Workshop, (1989b), 297-300.

Boulos, F.: Some Aspects of the Geophysical Regime of Egypt in Relation to Heat Flow, Ground Water and microearthquakes, chapter, 6 In: Said R (1990): The geology of Egypt, (1990), 61-89.

BP (British Petroleum): Renewable Energy Statistical Review 2017, BP, London, www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/renewable-energy.html, (2017a),

Chandrasekharam, D., Lashin, A., Al Arifi, n., Al Bassam, A., Varun, C.: Geothermal Energy Potential Of Eastern Desert Region, Egypt. *Environmental Earth Sciences*, **75 (8),** (2016), 1-15

El-Fiky, A.A.: Hydrogeochemistry and Geothermometry of Thermal Groundwater From the Gulf of Suez Region, Egypt. *JKAU: Earth Sci.,* **20 (2),** (2009): 71-96.

EEHC (2016b), Egypt Renewable Energy Plan, http://auptde.org/Article_Files/Egypt.pdf.

EL-Rayes, A.E., Arnous, M.O., Aboulela, H.A.: Hydrogeochemical and Seismological Exploration for Geothermal Resources in South Sinai, Egypt Utilizing GIS and Remote sensing. *Arab J Geosci*, **8**, (2015), 5631–5647.

EU (European Union) : Integrated Sustainable Energy Strategy" for Technical Assistance to Support the Reform of the Energy Sector (TARES), European Delegation of the European Union to Egypt, http://eeas.europa.eu/archives/delegations/egypt/press_corner/all_news/news/2016/20160718_en.pdf, (2015a).

Feinstein, S., Kohn, B.P., Steckler, M.S., and Eyal, M.: Thermal History of the Eastern Margin of the Gulf of Suez, I. Reconstruction from borehole temperature and organic maturity measurements. *Tectonophysics***, 266,** (1996), 203-220.

Hosney, H.M., and Morgan, P.: Geothermal Behavior and Tectonic Setting in the Northern Gulf of Suez, Egypt. *Journal of Environmental Sciences*, **19**, (2000), 55-74.

IRENA: Renewable Energy Outlook EGYPT. Public Report, 120p.http://enterprise.press/wp-content/uploads/2019/06/IRENA_Outlook_Egypt_2018_En.pdf, (2019) 120p.

Lashin, A: Evaluation of the geothermal potential around the coastal parts of the Gulf of Suez, Egypt, using well logging and the geo-thermometer data. *J. Appl. Geophys*., **6 (2),** (2007), 215-248.

Lashin, A: A Preliminary Study on the Potential of the Geothermal Resources Around the Gulf of Suez, Egypt. *Arabian Journal of Geosciences*, **6,** (2013), 2807–2828.

Lashin. A..: Geothermal Resources of Egypt: Country Update. Proceedings World Geothermal Congress, Melbourne, Australia, 19-25 April (2015).

Lashin, A., and Al Arifi, N.: Some Aspects of the Geothermal Potential of Egypt. Case Study: Gulf of Suez-Egypt. World geothermal congress, Bali, Indonesia, 25-29 April, (2010).

Lundmark A.M., Andresen A., Hassan M.A., Augland L.E., Boghdady G.Y.: Repeated Magmatic Pulses in the East African Orogen in the Eastern Desert, Egypt: An Old Idea Supported by New Evidence. *Gondwana Res*, **22**, (2012), 227–237.

Morgan, P., and Swanberg C.A.: Heat Flow And The Geothermal Potential Of Egypt. Pageoph, V. 117 (1978/1979). Birkhauser Verlag, Basel, (1979), 213-225.

Morgan P, Blackwell DD, Farris JC, Boulos FK, & Salib P.G.: Preliminary Geothermal Gradient and Heat Flow Values for Northern Egypt and The Gulf of Suez From Oil Well Data, In: Proceedings, Int. Cong. Thermal Waters: Geothermal Energy and Volcanism of the Mediterranean Area, Nat. Tech. Univ., Athens, Greece, 1, (1977), 424-438.

Morgan, P., Boulos FK, Hennin S.F., EI-Sherif A.A., El-Sayed A.A., Basta N.Z. and Mele Y.S. : Heat flow in Eastern Egypt: The Thermal Signature of A Continental Breakup. *Journal of Geodynamics,* **4,** (1985), 107-131

Morgan, P., Boulos F.K., and Swanberg, C.A.: Regional Geothermal Exploration in Egypt. *Geophysical Possessing*, **31,** (1983), 361-376.

Perston, M., and Croker, A.: Renewable Energy in Egypt: Hydro, Solar And Wind. Norton Rose Fulbright (http://www.nortonrosefulbright.com), (2013).

RCREEE (Regional Centre for Renewable Energy and Energy Efficiency): Egypt Country Profile of Energy. http://www.rcreee.org/content/egypt, (2019).

Zaghloul, Z.M., Shaaban, F.F. and Yousef, A.F.: Subsurface Quaternary Geothermal Reservoir in the Nile Delta Area. *Journal of Environmental sciences*, **9**, (1995), 187-204.