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Yemen Geothermal Potential (Case history 1980 - 2021)

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ABSTRACT

Yemen has special location in the Middle East with a great geothermal potential because it is located at one of the most active plate boundaries and at the triple junction made up by the Gulf of Aden, Red Sea and African Rift system. This is the key factor in the formation of geothermal manifestations distributed in the country, where many Quaternary volcanoes can be found. The evaluation of the geothermal potential started in the early 80's where most studies were undertaken by government institutions with assistance from countries that had developed geothermal activities. The potential capacity was estimated to be 600 MW. In recent decades, there has been major growing in the geothermal development in the country but with slow in harnessing the potential significant resources. Five main geothermal fields have been identified in Yemen: (1) Al lisi and Isbil, (2) Al Qafr, (3) Damt, (4) Taiz and (5) Red Sea Coast. The most promising of these fields for electricity generation is Al lisi and Isbil geothermal field, where the first exploration well was allocated to be drilled in 2010, whereas the other geothermal fields have good potential for low and moderate enthalpy resources. The highest temperatures recorded were 96 °C from a boiling pool at Al Qafr and 68 °C from a fumarole at Al lisi and Isbil. The geothermal resources in other places are exploited in direct uses by private in tourism activities: hotels, balneology, swimming, and therapeutic applications, estimated to be1.0 MWt and 15 TJ/yr.

1. INTRODUCTION

Yemen is located at the south - western part of the Arabian plate. The geology of Yemen is dominated by the major structures made up by the triple junction Gulf of Aden, Red Sea and African Rift System, the most active tectonic plate boundaries (Fig 1). These tectonic plate's boundaries, which accommodate the relative motion between the Arabian African, Eurasian and Indian plates formed two of which active tectonic faulting systems N.NE and N.NW in the region trending parallel to the main Red Sea trend and Gulf of Aden. The majority of thermal zones in Yemen are parallel to the main Red Sea trend whereas the thermal features along the southern coastal plain parallel to the main Gulf of Aden trend, which connect to the opening of the Red Sea graben and the separation of the Arabian shield from Africa. The major tectonic elements associated with the surface manifestations of geothermal activity during the Cenozoic and Mesozoic have shaped the geological structures observed in the area today (Mattash, Pinarelli, et al. 2013).

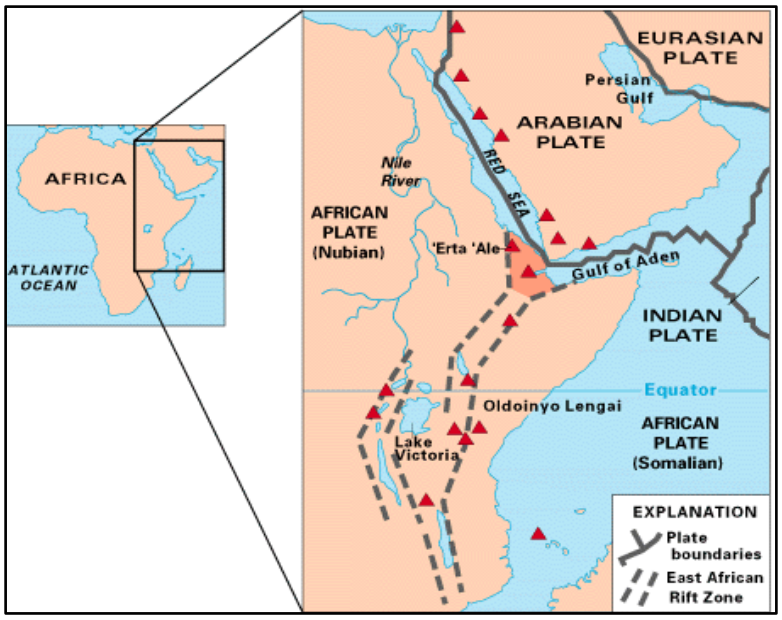

Figure 1: The map shows the triple junction where the Arabian African, Eurasian and Indian plates pulling away from one another.

This is the key factor in the formation of geothermal manifestations distributed in the country, where many Quaternary volcanoes can be found. Fumaroles, steams, thermal springs and hot domestic wells were found mainly in the western part along with Tertiary and

Quaternary rocks formations as shown in Fig 2. Therefore, more than hundred thermal spring have been recorded and analyzed with surface temperature ranges from 38°C to 96.3°C (Minissale, Mattash, et al. 2007)

Five main geothermal fields have been identified in the western part of Yemen: Al lisi and Isbil (Dhamar province), Al Qafr (Ibb Province), Damt (Dhala province), Taiz (Taiz province) and the Red Sea Coast. The most promising for electricity generation is Al lisi and Isbil geothermal field where the first exploration well was allocated to be drilled in 2010, whereas the other geothermal fields have good potential for low and moderate enthalpy resources (Minissale, Mattash, et al. 2007). Several studies have been carried out since 1980 in the western Yemen, mainly in Al lisi and Isbil where the fumarole hot steams reached 68°C. More recent details geothermal studies started in 2000 in Al lisi and Isbil geothermal field (Geothermal mapping, geochemistry, hydrogeology, geophysics studies and environmental assessment) due to its potential for electricity generation purposes.

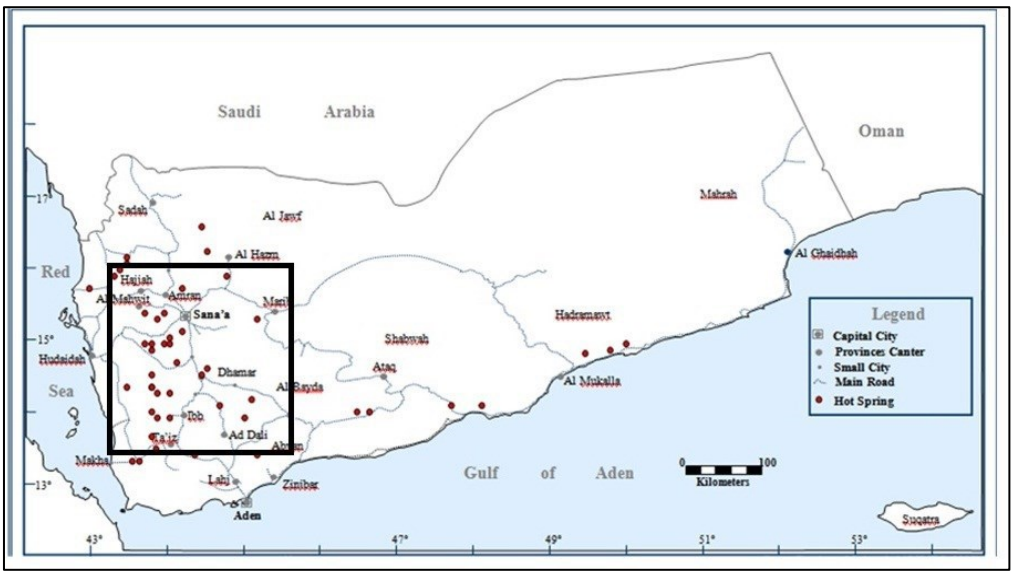

Figure 2: Hot springs distribution (dark red dots) in Yemen and the study area enclosed by the black square.

Other geothermal resources explored to determine their direct applications. Most of these studies are currently in the exploration stage such as in Al Qafr geothermal field, which was identified as the highest temperature water spring up to 96.3°C with travertine exposition. While Damt geothermal field composed many geothermal hot spring, in which the temperature ranges from 31°C - 52°C whereas it ranges in Taiz geothermal field from 32°C - 75°C in hot domestic wells. Moreover, the geothermal gradients wells in the western coastal areas drilled for the purpose of oil exploration showed that the average geothermal gradient was 70°C/km

2. OBJECTIVES OF THE STUDY

The main purpose of this paper is to summaries the scientific studies and works which have been carried out toward the geothermal development in Yemen including: 1) The investigations and explorations that started during the 80th until 2000 in order to evaluate the geothermal resources in Yemen. 2) The detail recent geothermal works and exploration includes; geothermal surface exploration, geothermal mapping, geochemical, hydrogeology and geophysical studies and environmental assessment which carried out by the geothermal development project team (YGDP) from 2000 up to now to estimate the geothermal potential for the electricity generation from the prospected geothermal field (Al lisi and Isbil) and explore other new geothermal field within the country.

3. HISTORY OF GEOTHERMAL EXPLORATION STUDIES IN YEMEN

A series of preliminary geothermal investigations have been carried out in the past two centuries in the western part of Yemen. National and international groups contributed in these activities. The first petrological and volcanology investigation was carried out in the western part of Yemen, particularly in Dhamar volcanic field. Dhamar is the most active volcanic area in the Yemen which referred by the annual seismology bulletin in 1994, as seismically unstable with numerous recorded historical events at sallow depth. The last strong destructive one occurred in 1982.

3.1 Previous studies (1980 -2000)

3.1.1 BRGM 1980

The first program of the preliminary studies accomplished in 1980 under the international cooperation activity with the French geological survey (BRGM) which has recommended that Dhamar area as a high priority geothermal target and suggested other geothermal zone in the southern part of Yemen as a medium and low enthalpy prospects (BRGM 1980).

3.1.2 ELC 1982

The second phase of the preliminary surface geothermal investigation in Yemen achieved in 1981 by an Italian Electro-consult company (ELC) and funded by the Yemen Mineral and Oil Company in Dhamar volcanic field, southwest of Yemen. The geothermal exploration included regional volcanology, geological studies, and geophysical (vertical electric soundings), hydrogeological, water chemistry and geochemistry exploration in Al lisi and Isbil area, Dhamar, southwest of the country.

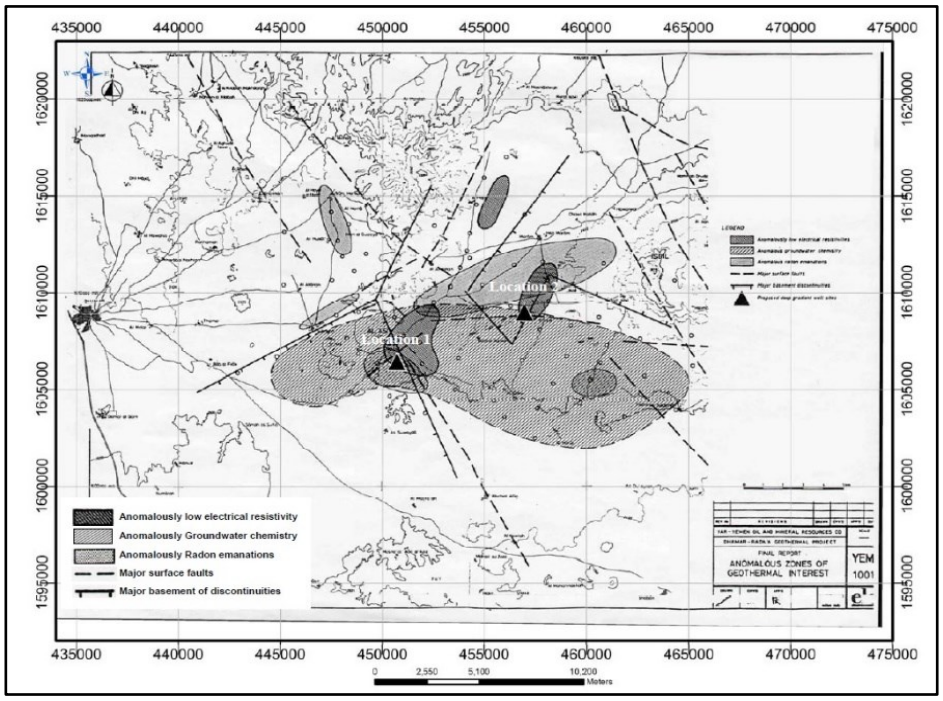

Figure 3: Map of anomalous zone of geothermal interest (ELC, 1982) shows the relation between anomalously low electrical resistivity, anomalously groundwater chemistry, and anomalously Radon emanations.

The general objective is to overall evaluate the possible geothermal potential in the area. The main result of ELC study indicated that there are more than two anomalous zones of geothermal interest which are E-SE of Al lisi volcano and south of Maram village. The study recommended drilling two initial geothermal exploratory boreholes to the depth of 1200 m on the sites of the study area where the anomalous zones of the geothermal interest. The first well location as shown in Fig 3 was supposed to be in the intersect of three anomalous zones (low resistivity, ground water chemistry, and radon emanation anomalous) while the second location settled in the intersection of two anomalous zones (low resistivity and of ground water chemistry anomalous). The hydrogeological and geochemistry studies of ELC suggested that a deep cretaceous sandstone reservoir exists at 1200 m depth with high water flow direction from east toward west and temperature properly around 150°C (ELC 1982).

3.1.3 EXXON 1989

The third phase of the geothermal related exploration was drilling several oil and gas exploration wells in Dhamar and the western red sea coastal area in 1988 by Exxon (Exploration Production Mideast Company). The first oil exploration and production well drilled in 1988 in Risabah area (Dhamar) which planned to the depth of 2743 m in order to obtain a brief information about the lithology. As expected from the seismic survey to find the sedimentary rocks (sandstone or limestone) for hydrocarbon source as in the geological program. Unfortunately, volcanic rocks were found for the whole depth and that was the reason to stop drilling at the depth of 1625 m as it is not promising result for oil (YGSMRB 1989). Electric log and temperature profiles performed by Schlumberger company and show the bottom temperature recorded was 105°C and the extrapolated equilibrium bottom hole temperature was 115°C which indicated a high thermal gradient and heat flow.

3.2 Recent geothermal studies (2000 - 2021)

In this period 2000-2021, the geothermal situation in Yemen has improved substantially compared with the previous decades. The geothermal detailed studies in Yemen started in 2000 with more focus of the western part of Yemen. The western part of Yemen is one of the most active areas in the Arabian plate boundaries. Geothermal manifestations and Quaternary volcanoes are mainly distributed in these areas.

Table 1: Geothermal detailed studies in Yemen

	Type of Study	Al lisi and Isbil	Al Qafr	Damt	Taiz	Red Sea
1	Geology and geothermal mapping	✓	✓	✓	✓	
2	Geochemistry study	✓	✓	✓		
3	Hydrogeology study	✓				
4	Geophysical study	✓				
5	Environmental assessment	✓				
6	Temperature gradient measurements	✓				✓
7	Well location and site prepation	✓				
8	Drilling					

Geothermal fieldworks and water/gas samplings carried out initially for hundred thermal springs and domestic well to overall evaluate the geothermal potential for the whole country. The studies include geothermal surface exploration (geothermal mapping), hydrogeological and geochemistry studies, geophysical studies and environmental assessment for the western of Yemen and Red Sea coastline as shown in Table 1. Based on these studies five geothermal fields have been primarily identified: Al lisi and Isbil, Al Qafr, Damt, Taiz and Red Sea coast geothermal fields. Al lisi and Isbil is the most promising geothermal field for electricity generation, and other fields have good potential for low and moderate enthalpy resources.

3.2.1 Al lisi and Isbil geothermal field

Geology and geothermal mapping

The geological and geothermal mapping work for Dhamar region, Al lisi and Isbil geothermal field, carried out by the geothermal project team in (YGDP) in late 2009 in order to produce the geology and geothermal map scale 1: 50,000 for the interest area.

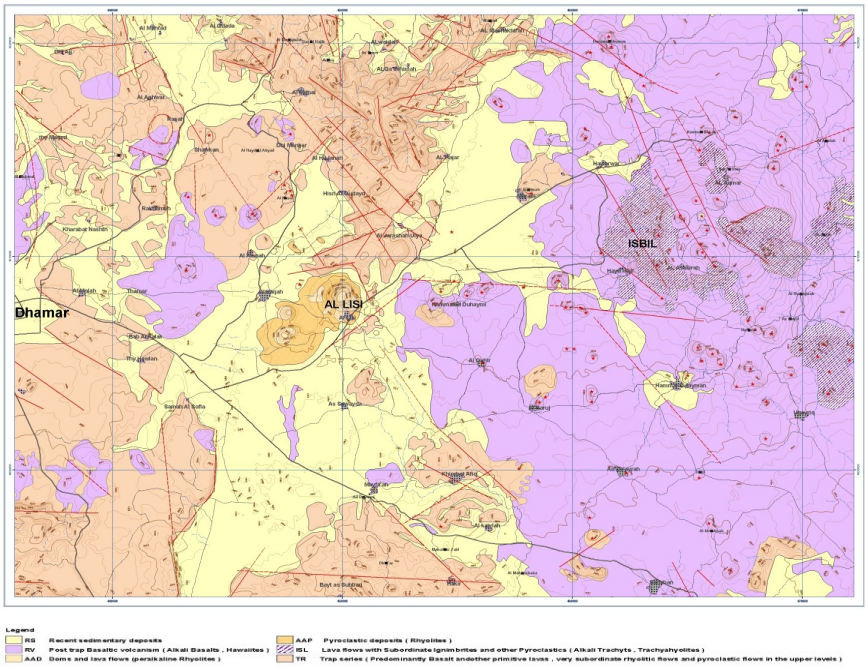

Figure 4: Geological mapping work for Al lisi and Isbil geothermal field 1:50,000 (Al-Sabri et al., 2015).

Therefore the volcanic areas classified as the following; 1. Trap series (recent sedimentary deposits overlain by sequence of pyroclastic pumice flow deposits with different degrees of welding ignimbrites) 2. Post - trap basaltic volcanic (fissure volcanism lava flow, domes and cones), 3. Central volcanic deposits represented by pumice clasts, 4. Isbil volcanic complex (lava flows, subordinate ignimbrites sheets and pyroclastic fall deposits), 5. Al lisi Volcanic complex (tuff cone, lava domes, rhyolitic obsidian). The main structural faults are mainly trend NNW-SNE direction parallel to the main Red Sea fault, some other faults were found with NNE and E-W direction that are parallel to the main fault of the Gulf of Aden as shown in the geological map in Fig 4.

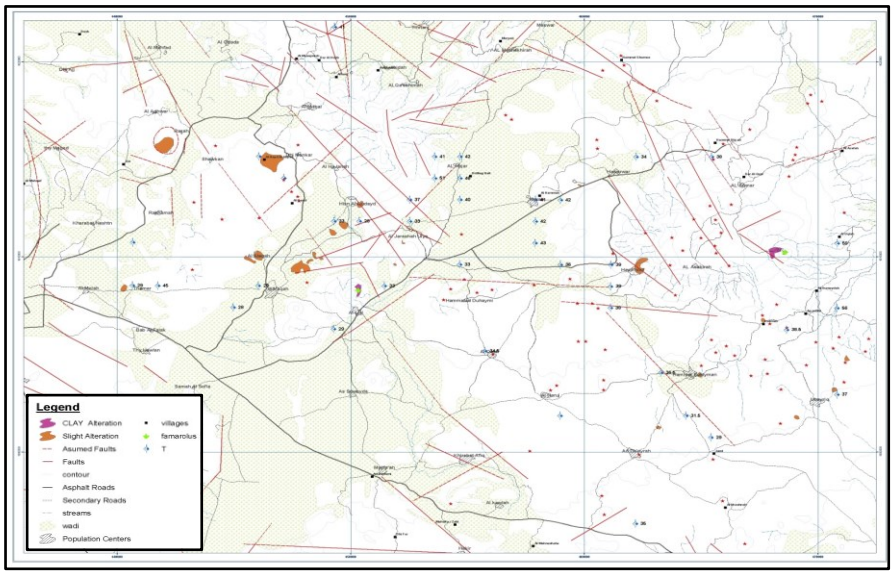

Figure 5: Geothermal mapping work (1: 50,000) for Al lisi and Isbil geothermal field (Al-Sabri et al., 2015).

Then the geothermal map produced as well with the scale 1:50,000 and shows more details about the geothermal manifestations distribution in the study area as shown in the geothermal map in Fig 5. The highest recorded temperature in Al lisi hot spring is 89°C and the steam temperature in Isbil fumarole is 43°C. Moreover, more than hundred domestic wells were analyzed and the temperature ranges from 21°C to 59°C while the depth ranges from 40 m to 350 m. Slight hydrothermal surface alteration and extensive clay alteration are distinguished where volcanic rocks have been completely replaced by secondary minerals indicates the presence of hydrothermal systems beneath and the geothermal activities in the study area. Calcite veins, quartz veins, clay, opalitic alteration and sulphides mineralization (pyritic or limonitic) observed in the study area (YGDP, 2013).

Geochemistry studies

National and international scientific activities and publications in this field were continuously developed in the last two decades. The recent publication and update geochemical study for thermal springs in the western region of Yemen in practically around the Quaternary volcanic area (Al lisi and Isbil) started in 2001, 2007 and 2008 to select the best thermal anomalous area to eventually drill an expletory well for further development of geothermal generation in Yemen. Extensive field works carried out during these years by the Yemeni geothermal project team at (YGSMRB) and the Italian Council for Research at the Institute of Geosciences and Earth Resources (CNR) and Department of Earth Sciences at the university of Florence (UNIFI) with the main focus on the north to east Dhamar province, in particular Al lisi and Isbil area, after previous work and investigations had established. Surface temperature, pH, electrical conductivity, ammonia and silica perceptions were directly measured in larger possible number of wells while the chemical analysis done for the anomalous in either high temperature, pH or conductivity. The sampling including the thermal springs, fumaroles, several CO2 rich gas vents and domestic shallow wells that latter on are analyzed for major, minor, trace components and isotopic ratios at the laboratories of UNIFI and CNR in Italy. The result indicates that thermal anomaly discovered in this area is mainly caused by local high conductive heat flow which undoubtedly related to the presence of cooling magma associated with the Quaternary volcanic which in turns have possibly generated active hydrothermal system inside the volcanic sequences (YTS). In addition this shows that the most reasonable area for the first drilling is between the two Quaternary volcanoes of Al lisi and Isbil at the central part of Yemen volcanic Plateau (YVP), where the expected temperature gradient is greater than 150 °C/km (Minissale, Vaselli , et al. 2013). This area which located by the two volcanoes has already considered anomalous by (ELC 1982) where they found several areas with anomalous electrical conductivity underground that associated also to some anomalous water chemistry in the aquifer as well as Radon emission from the soil as shown in Fig 6.

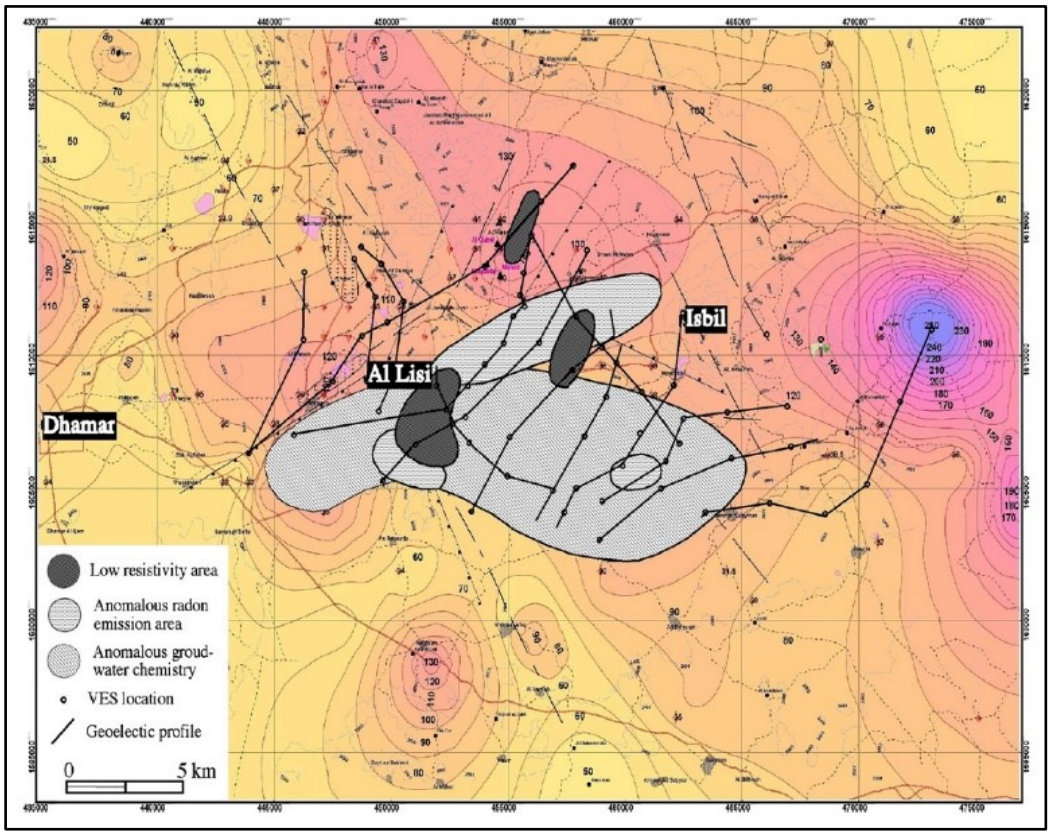

Figure 6: Calculated temperature map at 1,000 m depth, low resistivity areas and chemical anomalies as reported in ELC (1982).

Hydrogeology and hydrology studies

In 2006, hydro-geological study implemented in Dhamar region (Al lisi and Isbil area) by the National Water Resources Association (NWRA). The objective of this study was to prepare the water resources assessment plan for Dhamar plain with focus on the areas, which have good potential in geothermal energy. The study indicated that the depth to groundwater has been lowered drastically from 80 m to 100 m in last 40 years at the rate of 2.0 to 2.5 meters per year, which attributed due to alarming groundwater abstraction due to the high demand for water for both domestic and agriculture purposes. The water flows direction is N-S and NNW-SSE. The main sources of recharge are direct recharge from rainfall, indirect recharge from the floods. The estimate annual average total of recharge at about 17 Mm3/year comparing with total annual groundwater abstraction reached 181.3 Million cubic meters (Mm3) in Dhamar plain. The main productive aquifer within Dhamar plain are confined to the volcanic and quaternary alluvial despite and hydraulic conductivity of their rocks is higher than the surrounding rocks (NWRA and YGSMRB 2010).

Geophysical study

The recent study for geophysical exploration in Al lisi and Isbil geothermal field was done in 2010 by Geological Survey and Mineral Resources Board (YGSMRB) in cooperation and financial support of Federal Institute for Geosciences and Natural Resources (BGR). According to (Al-Qubatee and Kalpercamp 2010) the study aimed to reinterpretation the previous geophysical survey in Al lisi and Isbil to delineate best location for drilling an expletory geothermal borehole. Two previous geophysical surveys that were reinterpreted which are; (1) the geothermal exploration study (ELC 1982) which represent by 83 vertical electric sounding, schlumberger array with half current electrode spacing (AB/2) between 1000m to 3000m, (2) the geophysical investigation study (YGSMRB & BGR, 2007) which represent by 5 vertical electric sounding, schlumberger array with half current electrode spacing (AB/2) 2000m. The study recommend drilling an exploratory deep geothermal gradient well, to the depth about 1250m below soil surface, in one of the three selected locations as in Fig 7. The three locations were represented by five sites of vertical electric sounding (VES) which have the lowest electrical resistivity and suitable for exploratory drilling.

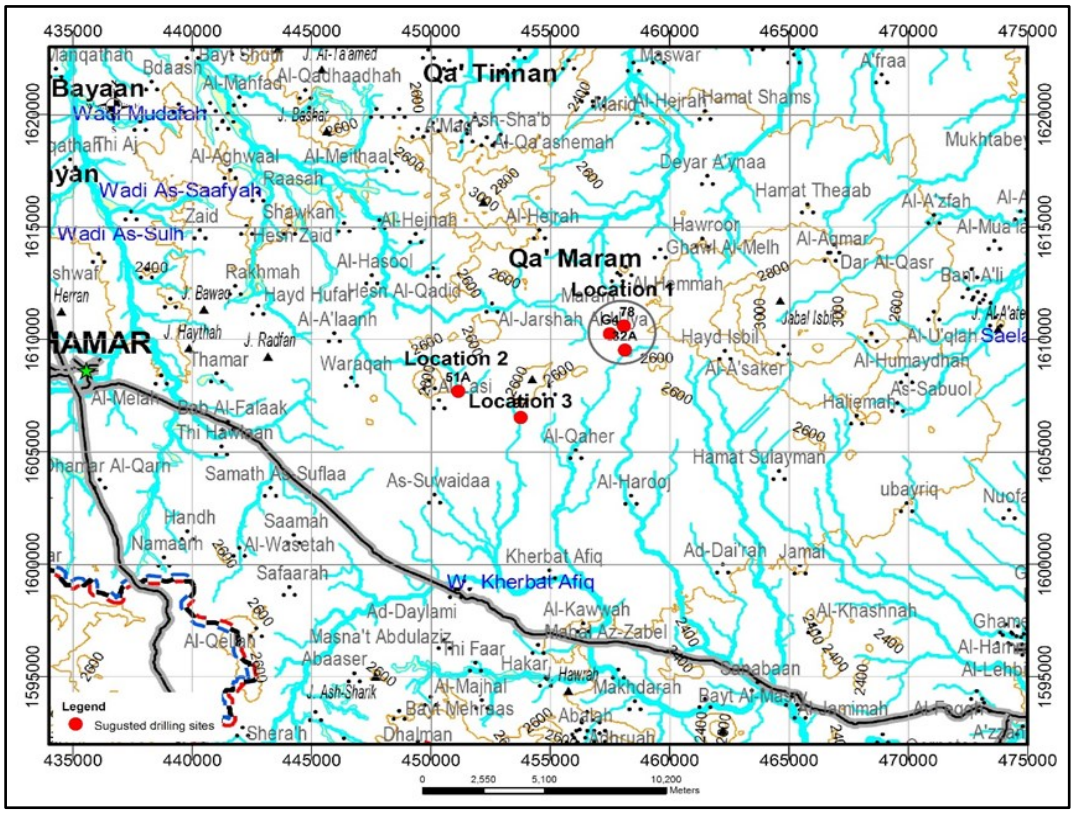

Figure 7: Topographic map of the study area (NWRA, 2009) include the recommended sites for drilling an exploratory deep geothermal gradient well.

Environmental study

The study presents an assessment of the potential environmental impacts (EIA) of the prospected drilling project in Dhamar governorate (Al lisi and Isbil). The EIA includes all the followings: 1) a definition of the administrative and legal framework for the protection of the environment in Yemen; 2) a description of the proposed project and an analysis of potential environmental impacts; 3) Potential and development of the environmental management plan including mitigating measurements for potential negative impacts and the environmental monitoring plan and 4) a description of the surrounding environment including topography, geology, hydrology, soil, climatic conditions, plant and animal diversity, land use, economic and social components such as population, education, transportation, water supply. The environmental assessment of the exploratory drilling project showed that it has a positive economic and social impact. It represents a qualitative step in the field of geothermal indirect utilization (electricity) and other direct uses such as space heating greenhouses and creating new jobs opportunities. In contrast, there are some potential negative effects that can adversely affect such as the potential impact on the aquifer, the quality of water, soil, traffic and noise, as well as gases emissions, which may directly affect the surrounding area of the site, especially in the absence of control devices of potential emissions and non-compliance with public health and safety. Therefore, adopting a sound and effective environmental management plan will promote positive impacts and reduce negative impacts. On the other hand, this study included an analysis of options and alternatives and the adoption of the best available technology, which is positively reflected on the surrounding environment and the project (Jazem , et al. 2011).

Temperature gradient measurements

This research presents the thermal temperature gradient and heat flow measurements, which carried out in 2012 in Dhamar Quaternary volcanic field (Al lisi and Isbil) by the geothermal project team. The data collected from shallow boreholes used to interpret conduction and the results used to estimate the geothermal reservoir temperatures. It indicates that temperature increases more rapidly with depth, hence, higher heat flow is found near to active fumaroles on the NE flank and at the top of Al lisi with temperatures ranging from 82 °C to 86 °C which has a good agreement with the geochemical study in the area (Al Kubati, et al. 2017).

3.2.2 Al Qafr geothermal field

Geology and geothermal mapping

Al Qafr geological and surface hydrothermal alteration mapping started by the Yemeni geothermal team in 2011 with the scale of 1:50,000. The aim of the study is to find out the relationship between geothermal activities, tectonic setting and structural patterns of the targeted area. The main manifestations mapped including thermal spring, boiling pool and travertine deposits along with slight hydrothermal alteration. Geology of the area is mainly composed of Tertiary basalts, Cretaceous sandstone (Tawilah Group), with small outcrops of sandy limestone and Quaternary deposits of travertine, pediment deposit and alluvium. Structural features represented by several extensional faults and fracture system striking NW-SE, almost parallel with the main red sea trend which have a significant influence on the distribution of the geothermal manifestations. Therefore, surface hydrothermal alteration and

manifestations distribution are found concentrated in the central part of the study area with linear trending in the same direction as the major fault system NW-SE as shown in Fig 8. Different hydrothermal alteration products including quartz, calcite, zeolite, albite and clay mineralization are recognized in the area (Al-Kohlani, et al. 2015).

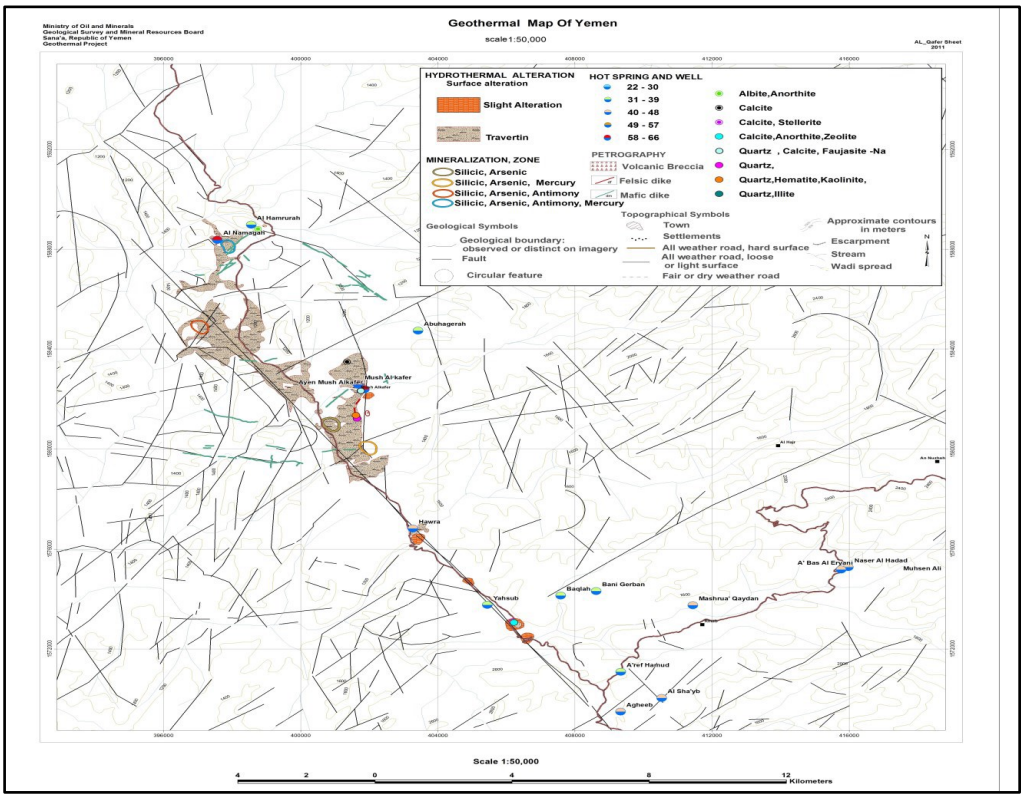

Figure 8: Geothermal mapping work (1:50,000) of Al Qafr geothermal field (by the geothermal project team)

Geochemistry study

Geochemistry studies in Al Qafr area carried out during the period from 2001 to 2009 by the Yemeni, Italian and German team (YGSMRB-CNR-BGR). Water/gas samples have been collected and analysed at the laboratories at the Earth Sciences Department in Florence University and the Institute of Geosciences and Earth Resources laboratories, Italy. Some of the samples were analysed at the Institute of Geosciences and Natural Resources in Germany. Major, trace elements and Isotopes are determinate through the laboratories analysis, whereas NH4, pH, conductivity and temperature measured in the field. The result indicates that water samples from the western region of Yemen are associated with CO2 rich gas which increases the water-rock interaction processes and led to a higher alteration degree in the area such as ion-exchange reaction with Na-rich silicates. These waters thus turn to be Na-HCO3 type in composition (Mattash, Al-Ganad, et al. 2001). The significance of the oxygen and deuterium isotope ratios indicates the meteoric origin of the waters. Equilibrium temperature evaluation of the thermal reservoirs has been performed by using different liquid phase geothermometers shows that temperatures range between 70 °C and 140 °C, the highest values being measured in Mosh Al-Kafer hot spring in Al Qafr area which is one of the hottest hot springs identified so far in Yemen.

3.2.3 Damt geothermal field

Geology and geothermal mapping

The study area is located in the western part of the Yemen, south of the capital Sana'a. The geological and geothermal map for Damt area with scale 1:50,000 produced by the geothermal project team in 2010. The rock units consist of the pegmatite, sandstone, volcanic rocks (Rhyolite, Ignimbrite and Tuff) and basalt rocks (Quaternary). The general trends of the major faults are NE-SW and NW-SE. Geothermal manifestations such as; hot springs, travertine outcrop (Harada) and slight alteration is very abundant in the study area as shown in Fig 9. More than fifty Haradas covered the area in which the most important is the large Harada (80 m high) located in the center of Damt town.

Figure 9: Geothermal manifestations (Harada) and hydrothermal alteration in Damt geothermal field in Yemen (Source: Google earth 2017).

Geochemistry study

The geochemical study in Damt area started in 2007 by the Yemeni-Germany team and in 2009 by the Yemeni-Italian team for the purpose of estimating the subsurface temperature and define the chemical properties of the fluid. Fifteen thermal springs and other hot and cold domestic wells selected to be analyzed in Germany and Italy laboratories whereas, temperature, PH and conductivity were measured during the field trips to the study areas. The surface temperature ranges from 31°C to 52 °C and pH measured ranges from 6.4 to 9.4. The results of the chemical analyses indicate that this water belong to the Ca-bicarbonate-Cl-Na water type which mainly caused the high erosion in the ground to form Travertine deposition. The thermal springs in Damt, like everywhere else in the country, restricted to direct uses for swimming pool and hot bathing which can be better utilized for greenhouse and CO2 or H2S gases exploitation. The radon measurements in 2011 in this area shows that as the temperature increased the radon ratio decreased in hot springs and domestic wells.

3.2.4 Taiz geothermal field

Geology and geothermal mapping

Geothermal exploration in Taiz started in 2011, after the drilling process for the first geothermal well in Al lisi and Isbil area postponed due to the political and financial issues as mentioned below. The study area divided into smaller zones: Aldyrabi, Asyani, Algandyah, Reysain - aldhubi and southeast of Taiz. The purpose of the current study is to explore more alternative geothermal fields within the western part of Yemen. The map scale 1:50,000 accomplished for all these areas by the geothermal project team during 2011 to 2014. The rock's type classified into Tertiary volcanic (Basalt, Rhyolite and Tuff) and Tawilah Sandstone group and Quaternary deposits. The dominated structural features trend NE – NW, which are parallel to the main Red Sea fault. Geothermal manifestations such as hot springs and hydrothermal alteration (high to slight) are widespread in the mapped area. Silica minerals (opal), calcite veins, veins of quartz, Zeolite minerals and travertine deposits are found. The temperature in hot springs and wells range from 32°C to 75°C (Al-Sabri , et al. 2015).

3.2.5 Red Sea geothermal field

The Red Sea coastal geothermal field is one of the potential fields in Yemen. Thermal springs distributed in the area mainly influenced by two main tectonic structures; NW-SE and E-W trending which parallel and related to the Red Sea and Gulf of Aden rift systems. The surface temperature of the springs average 48 °C and pH is 7.0 while the type of thermal springs are Ca-Na-Cl type of water. Various studies carried out in the 80th by the Yemeni Oil companies for the purpose of Oil and gas exploration. Therefore, eight deep Oil boreholes drilled up to 3000 m of depth such as Al-Auch-1, Zaydiah-1, Abbas-1, Salif, Hudaydah-1, Hudaydah-2, Kathib-1and Kathib-2. The temperature logs obtained from these boreholes show that geothermal gradient are relatively high up to 190°C at 2458 m depth as shown in Fig 10. The estimated deep temperature gradient in wells which drilled along the western coastal line showed an average geothermal gradient 70°C/km (Al Kubati, et al. 2017).

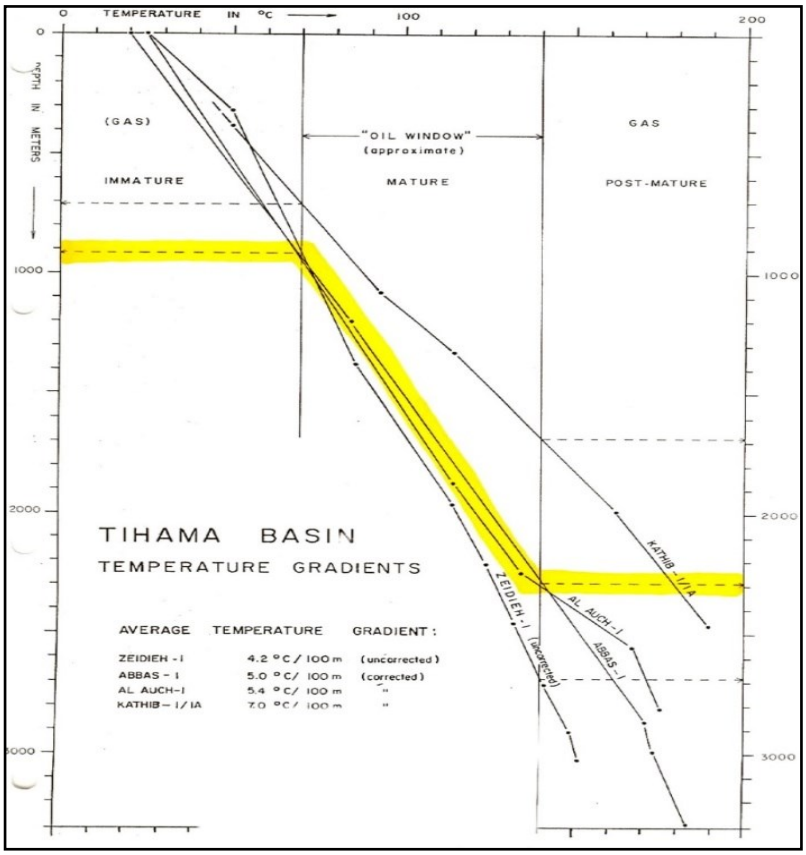

Figure 10: Tihama basin temperature gradients in the Red Sea geothermal field (data from Oil drilled wells).

4. DRILLING PROJECT IN AL LISI AND ISBIL GEOTHERMAL FIELD

The prospected geothermal drilling project in the area between the Al Lisi and Isbil volcanoes proposed to GEF in 2006 and approved in 2008, was ready to start at the end of 2010. According to the budget, the target was identified at 1500 m, where temperatures between 150 °C and 200 °C was expected to be found. The previous exploration studies were completed by governmental institution (GSMRB, MWE and MEE), with the scientific and technical assistance by international partner (GEF/UNEP, BGR and CNR). Reykjavik Energy Invest (REI) signed an agreement in 2008 for technical assessment to the project. Based on the available geological, hydrogeological, geochemical and geophysical data on a country scale, Al Lisi and Isbil geothermal field offers the best evidence of promising resources for near-term exploitation. Nevertheless, the project ceased and stopped at the early pre-drilling stage at the end of 2010. The main barriers and challenges of this promising drilling project must be identified in several obstacles, including: political instability, financial constraints and lack of policy and regulatory framework of geothermal development. Finally, the civil unrest occurring in Yemen since 2010 has abated the drilling process, which placed the project in the standby for a few years ahead.

5. GEOTHERMAL UTILIZATION IN YEMEN

The first and older evidence of the geothermal utilization in Yemen was during the ancient period's time. The thermal water used due to their curative effects and recreational purposes in the form of balneology and bathing. The best hot springs known in Yemen called Hammam Ali (Ali's bath), name given for many hot springs which mainly used to take baths for relaxation and recovery. Geothermal springs, which located in areas of tourist attraction has become an important source of local and regional tourism industry. The overall potential capacity estimated to be 600 MW (Qasem 2018). However, the utilization of the resources still limited to direct applications by private tourism activities for entertainment and balneology, which estimated to be 1.0 MWt and 15 TJ/yr (Davidson 2000). Today, the use of geothermal resources in tourism activities (hotels, swimming and therapeutic applications) has increased through constriction of hotels and recreational facilities in several areas within the country.

6. SUMMARY

Yemen is one of the countries in the Middle East with greater geothermal potential, which affected by the opening of the Red Sea and the Gulf of Aden as well as by the African rift valley. The earliest geothermal preliminary study in western part of Yemen started in the early 80th for the purpose of evaluation of the resource potential. Since 2000, more geothermal details studies (Geological and Geothermal mapping, Geochemistry, Hydrogeology, Geophysics and Environmental) carried out under international cooperation activities to start the development of geothermal energy in Yemen. These studies together confirmed that Al lisi and Isbil geothermal field is the most promising for electricity generation where the temperature 150°C - 200°C were estimated to be found at the depth of 1500 m. It was in 2010 that the first exploration geothermal well was allocated to be drilled in Al lisi and Isbil. The continuous geothermal exploration extended to other geothermal fields Al Qafr, Damt, Taiz and Red Sea Coast in western part of Yemen. Efforts to develop these geothermal resources by surface exploration are also being performed by national and international scientific in

order to assess the energy potential and possible use of geothermal resources for indirect or direct utilization. However, until now, no electricity from geothermal resources has been produced and no exploratory or production geothermal well has been drilled in the country. The key challenge that geothermal development faces related to political instability, financial constraints and regulatory policy. Historically hot springs in Yemen has been directly used mainly in balneology and bathing since the ancient time until now.

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