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Geothermal Energy Resources in Jordan, Country Update Report

Abdelkarim Saudi, Ali Swarieh

Natural Resources authority, P.O. Box 7, code 11118, Amman-Jordan

Abdo_Saudi@hotmail.com, subsurface@nra.gov.jo

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ABSTRACT

Jordan is blessed with many thermal water resources spread along the Jordan rift Valley (springs & wells), in addition to thermal wells in the Central and eastern plateau.

Several investigations of geothermal energy in Jordan have been taken place over the last three decades. These studies were conducted and cooperated by the Natural

Resources Authority assisted by several foreign firms. Since three years, Geothermal project are still running and sub stages connected with foreign agency's such as the World bank, the main goal of these studies to evaluate the potential of geothermal energy uses in Central Jordan were there is hundreds of wells discharged thermal water 30- 45°C and estimate the maximum reservoir temperature which predicted by geochemical studies around 115 °C, in order to use for desalination the brackish water and evaporation process take into account the sustainable development.

Geothermal gradient map of Jordan shows two distinct regions of high gradients up to 50°C/km. the first region is in immediate vicinity of the east dead sea escarpment, where many springs discharged thermal water originates from the lower Cretaceous Sandstone. The second one is near the border with Syria and Iraq. In this region several thermal wells discharge water from the upper cretaceous limestone.

The thermal water of springs and wells in whole the country range in temperatures between 30 to 63°C.

The springs and wells are currently used for spas and recreation. Also they have been used as irrigation water in several agricultural activities. Since WGC2000 there is no additional direct use since that time.

1. INTRODUCTION

Geothermal resources in Jordan can be considered as one of those resources related to deep circulation of meteoric water along faults and fractures. They can be subdivided into two groups.

The first is connected with natural springs in sandstone rocks outcrops. These springs form the main surface manifestation of geothermal energy of Jordan. Other geothermal manifestations such as fumaroles, boiling and mud pools are not observed thus, there is no surface evidence that would indicate the existence of high temperatures at shallow depths.

The second group of geothermal resources are these discovered during oil and groundwater exploration within the deep aquifers in the eastern deserts and along to eastern margin of the Dead Sea Rift. The main resources of this group are Shuneh and Makheibeh well fields.

The location of nearly all the thermal springs and the hot boreholes are dictated by their proximity to the Dead Sea Rift. Thermal spring are distributed along the eastern escarpment of the Dead Sea Rift for distance about 200 km, from Mukheibeh thermal field in the north to Afra and Burbeitta thermal field in the south (Fig. 1). Most of the springs have temperature below 45°C except in two localities the temperature reaches up to 63°C (Zarqa Ma'in and Zara springs).

Thermal springs have been used for bathing and irrigation for many years. Recently several hotels (spas) were constructed at the thermal springs sites, for example Zarqa Ma'in spa. In the near future, it is planned to use the available thermal water to heat greenhouses for growing various types of plants, especially flowers and for fish farming, to provide the local market with fresh fish also Several Geosciences studies of geothermal waters in central Jordan, were carried out by NRA team during 2002- 2003 in order to evaluate their possible utilisation in the future.

The main conclusions of the studies as follows:

Mixing were identify between two water type, cold and thermal water, and the source of heating is deep circulation

Two main aquifer were delineated in the studied area, the first is (B2,A7)which consist of Wadi Es-Sir Limestone formation, (A7), in the Ajloun group, Wadi Um Ghudran formation (B1), and the Amman formation (B2) in Belqa group of the middle to upper cretaceous age.

The highest temperature predicted by using mineral saturation index for the reservoir about is 115 ° C.

The origin of the water by using stable isotope are obviously meteoric.

2. GEOLOGICAL SETTING

Sedimentary rocks cover almost the whole of Jordan, with Precambrian plutonic and metamorphic rocks only exposed in the south-west of the country. The thickness of there sediments increases in a north-easterly direction where progressively younger sediments are exposed (Bender,1974).

Unmetamorphosed Cambrian to Silurian sedimentary rocks unconformably overlie the Precambrian. These Paleozoic rocks consists mainly of clastics, with some thin carbonates, and dip gently north and north-east beneath the Cenozoic sequences. Younger Paleozoic sequences are not known at the surface but may exist in sedimentary basins.

Following peneplanation, Triassic rocks (continental clastics followed by marine clastics and carbonates) were deposited representing a transgression of the Tethys Ocean from the north-west. This pattern of north-west to south-east transgressions was repeated several times during the Mesozoic. Jurassic to lower Cretaceous sequences are predominantly clastics and marine carbonates, and these together with the Paleozoic sediments, form an important lower aquifer complex in Jordan.

Widespread deposition of carbonates occurred in the upper Cretaceous, comprising a variety of marls, limestones and dolomitic limestones. Carbonate deposition continued into the Tertiary and the sequence forms a major upper aquifer complex in Jordan.

Basaltic rocks of Quaternary age are found in the north-east of Jordan and cover about one-seventh of the country. Minor basaltic intrusions are also found along the east escarpment of the Jordan Rift Valley, usually associated with faults.

The dominant feature of Jordan is the north-south trending Dead Sea Rift, which is one of the principal reasons for the existence of geothermal phenomena. This is a transform fault system more than 1000 km long linking the Zagros-Taurus zone of plate convergence to the north with the Red Sea to the south where crustal spreading occurs.

The Dead Sea Rift was formed in the Cenozoic break up of the once continuous Arabo-African continent. The plate boundary movement in Jordan took the form of strike-slip with a present total of around 105 km left lateral movement.

The Dead Sea trough is the main expression of the rift in Jordan. This is a deep morphotectonic depression in the form of a rhomb-shaped graben produced by left-lateral movement along bounding faults. The area began to subside in the Pliocene and has since accumulated possibly seven kilometers of sediments comprising lacustrine and fluviatile beds. The Dead Sea level lies 412m below sea level, which results in the acting as a sump for regional ground water flows, both cool and thermal over a wide area

3. GEOTHERMAL INVESTIGATIONS

Numerous studies about geothermal energy in Jordan have been carried out in the last thirty years or so. These studies were conducted and cooperated by the Natural Resources Authority assisted by several foreign institutions and companies. The investigations have generally concentrated on the Zarqa Ma'in and Zara geothermal field and are reviewed below:

The first study was undertaken by S.M.MacDonald and Partners in 1965 and comprised chemical analysis of samples from Zarqa Ma'in .

Bender, 1974, described the major and minor spring areas and provided chemical analysis of the Zarqa Ma'in thermal springs. In 1976, McNitt reviewed existing chemical data for the Zarqa Ma'in system and recommended further work, (a resistivity survey and drilling), to investigate the area.

On the basis of temperature and fluid chemistry, Marinelli, 1977, concluded that the east escarpment of the Dead Sea Rift and particularly the Zarqa Ma'in and Zarqa areas possessed the most favorable geothermal potential .

Truesdell, 1979, concluded that the Zarqa Ma'in and Zara Springs are fed by waters circulating deep within the Palaeozoic Sandstone aquifers and receiving heat from a normal geothermal gradient. He suggested that these waters exist at a maximum temperature of 110°C at depth and are cooled during their ascent by mixing.

Abu-Ajamieh, 1980, reported on major exploration exercise using a variety of exploratory techniques carried out by NRA in the Zarqa Ma'in - Zara thermal area, 1977-78. The main conclusion of this report was that an important geothermal reservoir is indicated in the area of the springs, most probably heated by the Hammamat Umm Hasan basalt plug. The moderate radioactivity of the waters was also noted.

Mabey, 1980, studied previous data of the Zarqa Ma'in -Zara area. Hakki and Teimeh, 1981, carried out a detailed geological study of the Zarqa Ma'in -Zara area. Their work related the hottest springs to the highest intensity of shearing in the area.

In 1981, G.M.Di Paola concluded that the existing geochemical and isotopic results of the Zarqa Ma'in area indicated that the temperature of the springs was most probably due to the uprising of deeply circulation waters in a normal geothermal gradient.

McEwen and Holcombe, 1982, applied terrain correction to the resistivity data reported by Abu-Ajamieh , 1980. The corrected data suggested that four areas of low resistivity existing in the Zarqa Ma'in -Zara area, but that none had lateral extent.

Flanigan and El-Kaysi, 1984, reported on preliminary audio-magnetotelluric studies in the Zarqa Ma'in - Zara area. They found that rocks in this area ranged from moderately conductive to very conductive.

Galanis et al, 1986, concluded that the heat flow in Zarqa Ma'in - Zara area is high,(up to 472 mW/m2), and that the area of highest heat flow is associated with the Zarqa Ma'in fault zone rather than the local basaltic eruptions.

In 1988, V.Myslil, re-evaluated the heat flow data presented by Galanis, 1986, and included other recent data and presented temperature gradient map and identified two favorable zones for future exploration (Fig. 2). The most favorable area was the east escarpment of the Dead Sea Rift, north of El-Lisan, where gradients of 50 °C/km could be expected. The second area was the region near the border with Syria and Iraq where temperature gradients of the order of 40 °C/km were identified.

D. Allen in 1988 reviewed and summarized all the previous geothermal investigations in Jordan and introduce proposal for future geothermal studies.

A. Swarieh, 1990, and 1992, stated in his MSc. thesis and in internal report/NRA that the presence of the thermal water in the shallow boreholes near Queen Alia airport is due to the water mixing between the thermal water of the lower aquifer (Lower Cretaceous Sandstone) and the fresh cold water of the upper aquifer (Upper Cretaceous Limestone). Also, related the heat sources in Zarqa Ma'in to the deep circulation process along the Zarqa Ma'in fault.

A. Swarieh, and R. Massarweh in 1993, studied the thermal springs in Wadi Iben Hammad, Karak region. The conclusion is that the heat source is more likely to be due to the heat storage in the saturated sandstone complex resulting in higher geothermal gradient.

A. Swarieh, and R. Massarweh in 1995, studied the major geothermal field in Jordan (Zara & Zarqa Ma’in). They describe the reservoir and the optimum use of this source of energy.

A. Swarieh, and R. Massarweh in 1997, studied the thermal water in Mukhiebeh and Shuneh thermal well fields. They concluded that the thermal water is a mixing water between the hot water of the deep aquifer and the cold fresh water of the upper aquifer.

Saudi in 1999, studied the thermal water wells near Queen Alia Airport, concluded that the maximum reservoir temperature for the Jordanian wells predicted by calculation of various geothermometers exceeds 100°C. The thermal fluids are well mixed with cold groundwater in the studied area.

A. Saudi, et al. in 2004, Several Geosciences studies of geothermal waters from the central Jordan, were studied in order to evaluate their possible use for desalinate the brackish water conclude that The highest temperature predicted by using mineral saturation index for the reservoir about 115 ° C and high Radon concentration locates on the faults intersections.

Also at the beginning of year 2004, the World bank award a grant for the NRA to implement Geothermal energy potential for future uses by hiring a foreign firms to re-evaluate and allocate the best site of drilling if the potential geothermal water is quit enough for attractive exploitation in the future taking into account the sustainable development.

In addition to the above studies, geothermal research has been carried out by Prof. E. Salameh and others at the Jordanian University/Amman. The general conclusion of these studies, (based on hydrochemical and hydrogeological data), is that the thermal waters of the Zarqa Ma'in - Zara system are the result of deep circulation in a relatively normal geothermal gradient.

4. GEOTHERMAL RESOURCES IN JORDAN

The geothermal investigations revealed a rich geothermal potential in low enthalpy resources spread amongst several geothermal fields.

The geothermal gradient map of Jordan shows two distinct regions of high geothermal gradients up to 50 °C/km. The first region is in immediate vicinity of the east Dead Sea escarpment, where many springs discharge thermal water originates from the Lower Cretaceous Sandstone forming three main geothermal fields. These fields are: Mukhiebeh thermal springs, Zara and Zarqa Ma'in thermal springs and Afra and Burbeitta thermal springs. The second one is near the border with Syria and Iraq. In this region several thermal wells discharge water from the Upper Cretaceous Limestone. In both regions, there are many wells (shallow and deep) discharging thermal water such as; shallow wells near Queen Alia airport, North shuneh well and Mukheibeh well field. Table-1 Shows some information on the main geothermal fields in Jordan

5. THE HEAT SOURCE.

The heat of thermal springs and wells is attributed to one or more of the following reasons:

1-Cooling of young bodies of basalt.

2-Deep circulation of water in a normal geothermal gradient.

3-Circulation of water in an abnormally high geothermal gradient related to crustal spreading across the Dead Sea Rift.

4- Friction associated with lateral movement of active faults related to the Dead Sea Rift.

5-Radioactivity, for example, the radiogenic heat production due to U238 disintegration series in the sandstone aquifer complex.

6- Heat storing horizon (thermal blanket) consisting partly of dry sandstone overlain by marls with heat conductivity of only about half that of wet sandstone results in temperature gradient of about twice the gradient of the whole sequence, maintaining herewith a constant heat flow.

Among the above reasons it seems that the thermal water originates as groundwater in the Paleozoic sandstone to the east of the Dead Sea Rift escarpment. The water is heated by deep circulation in a moderately elevated geothermal gradient (may be 50°C /km) which would imply circulation depths of about 2 km. The water moves towards the rift, ascends through fractures and is cooled by mixing with local ground waters before issuing as thermal springs. The chemical type of mineralization of hot water indicates the groundwater circulation in Kurnub and Zarqa sandstone's (Lower Cretaceous and Triassic) with mixing of limited quantity from the deeper confined Protozoic aquifers.

Also the geochemistry studies and stable isotope analysis , (A. Saudi et al. 2004), all the ranges of ^{18}O and ^{2}H of all the samples are -6.74 to -5.06‰ and –34.90 to –24.85‰ respectively. These data do not show presence of any significant amount of magmatic water which generally has (^{18}O: +6 to +9‰ and (^{2}H: -40 to -80‰ (Pearson et al., 1980; Giggenbach, 1992). The possibility of oceanic origin of these waters is ruled out because its ^{18}O and ^{2}H are about 0‰, (Clark and Fritz, 1998) So the origin of these waters is obviously meteoric.

6. GEOTHERMAL UTILIZATION IN JORDAN

6.1 Present Utilization:

Geothermal energy is one of the alternative sources of energy which could be utilized for different purposes. Jordan is blessed with this energy source in several parts of the country.

Thermal water in Jordan has been used in direct uses as curative water tourist industry (Table 2). The therapeutic value of thermal waters in Jordan has been recognized since ancient times. Generally, thermal water has various properties and differ in its temperature and curative abilities.

A study carried out by Prof. E. Salameh, et. al 1991 shows that the thermal water resources in Jordan are very useful in treating several diseases in various degrees of success. For example, thermal water of Zara and Zarqa Ma'in springs is quite useful in treating Osteo Arthritis, Degenerative Disc and Post Traumatic. Thermal water of North Shuneh is good for cervical spondy losing, while the thermal water of Afra and Burbeitta is quite good in treating Degenerative Disc and Post Traumatic problems. In Zarqa Ma'in area the thermal water is utilized for medical purposes through a modern spa constructed in the area

6.2 Future Utilization

Thermal water in Jordan can be used in several direct uses such as:

1- Heating Greenhouses The existing greenhouses in Jordan are of the plastic tunnel type, unheated. The outside temperature dropping to about zero or below in winter

(November-February) thus greenhouses become unusable. Thermal water can be used to avoid such a problem to heat the greenhouses. Table 3 shows a summary of geothermal direct heat uses in Jordan.

2- Fish Farming At present several farms producing tilapia exist in Jordan. For example the Arab Fish Company farm consists of some 40 basins. It produces between 20 and 55 tones of tilapia per year. In winter, the temperature can not be maintained at a sufficient level to ensure the survival of the fingerlings and allow the growth of the fish.

Certain thermal water sources, such as at North Shuneh well would enable new projects to be developed using geothermal energy to maintain the water in the basins at a sufficient temperature in winter. It discharges 700 m^3/h of thermal water at 57°C. It is a very large potential , part of which could be used to feed a pilot fish farm breeding tilapia and possibly other species so as to diversify the production.

3- Refrigeration by Absorption The method of refrigeration by absorption allows one to create positive cold temperatures (from + 0.5 to + 5°C) for conservation of fruit and vegetables) or negative cold temperatures, for example, -25°C for conservation of meat or fish).

The temperature of the potential resources in the Zara area (100 to 120°C) enable one to envisage the creation of refrigerated warehouses for the conservation of fruit and vegetables (temperature maintained between + 0.5 and +5°C)

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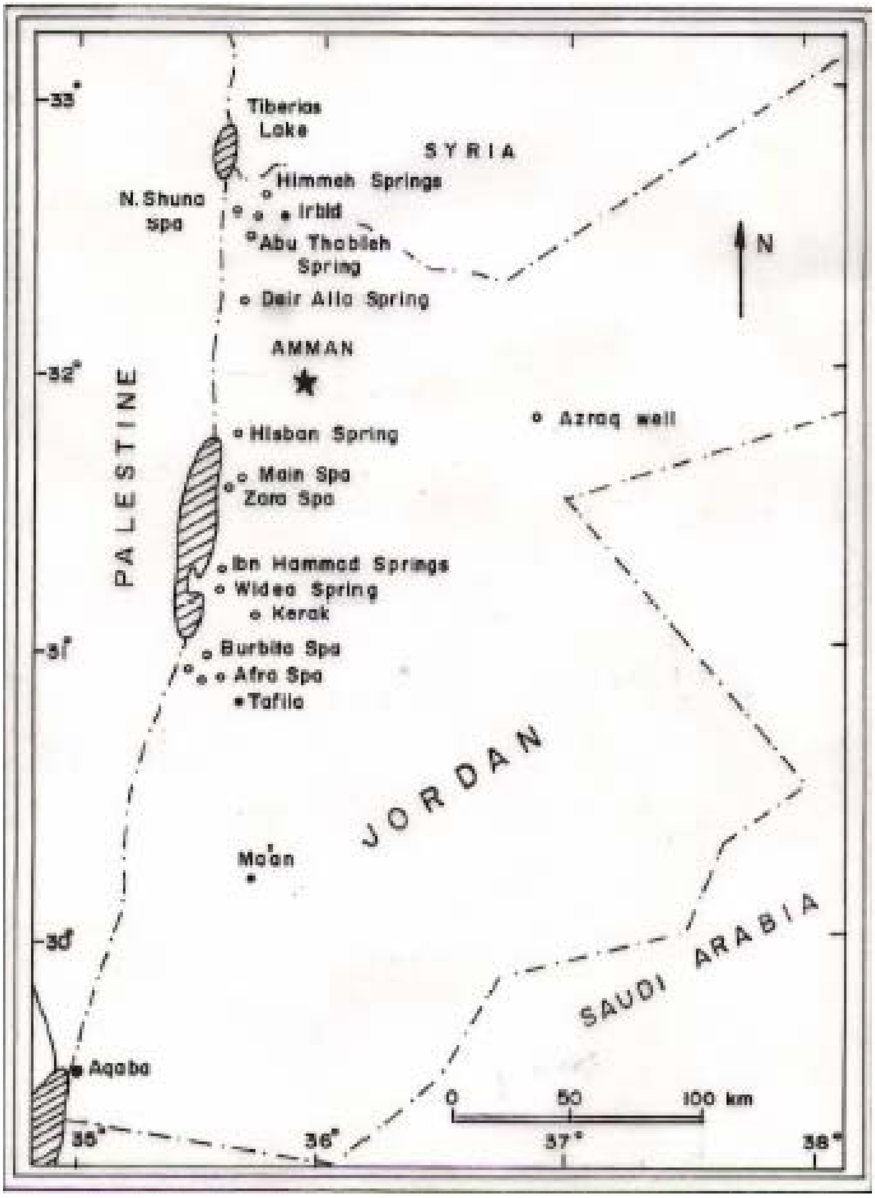

Figure 1.Location of geothermal resources in Jordan

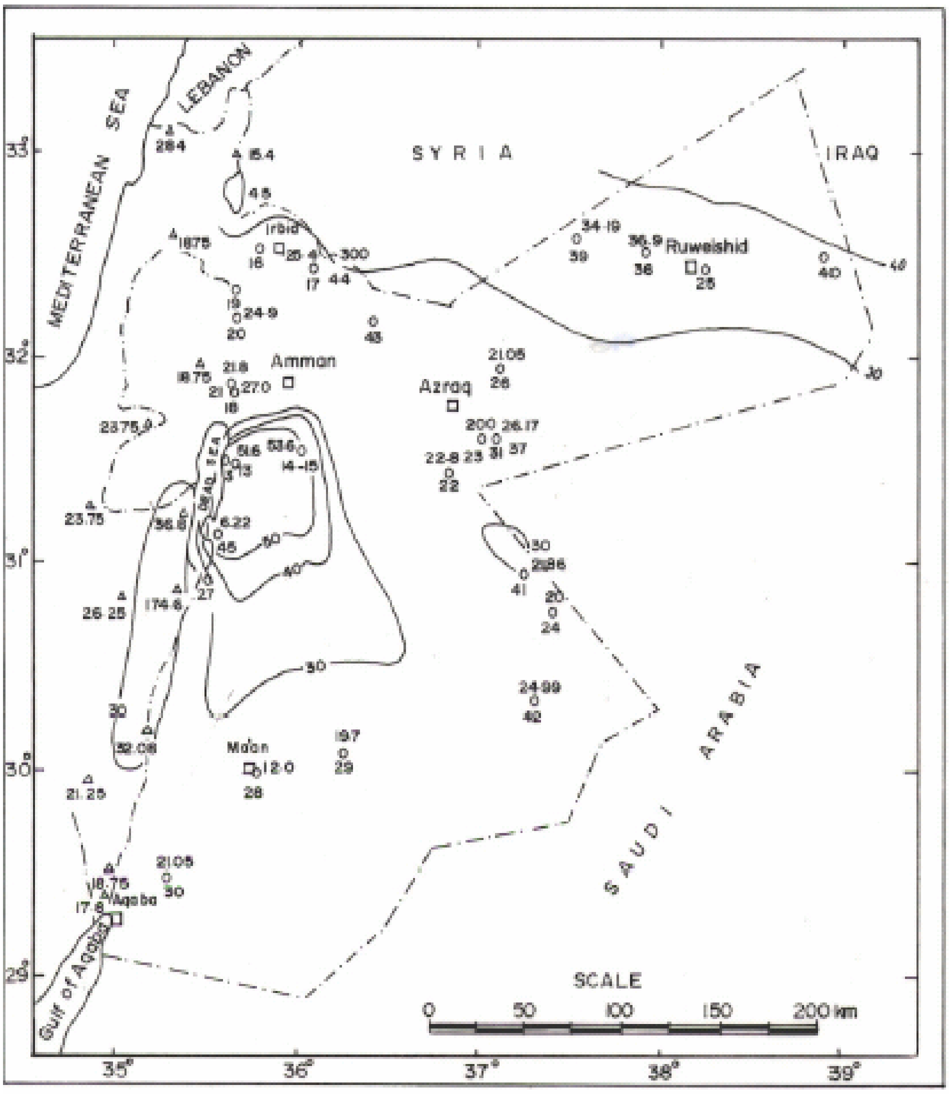

Figure 2.Geothermal gradient map of Jordan (Myslil,1988)

TABLE 1. GENERAL INFORMATION FOR THE GEOTHERMAL FIELD IN JORDAN

Name of the Geothermal Field	Temp. (C)	Flow Rate (m3/hr)	TDS (ppm)	Remarks
Himmeh springs	38-44	300-3000	650-885	Two major springs, high H2s concentration
Mukheibeh wells	30-41	200-6000	600-800	Seven artesian wells, high H2s concentration
North shuneh well	57	700	775	Artesian well, high H2s concentration
Queen Alia Airport	30-45	30-100	700-1800	Many private wells for Agriculture uses.
Zara Springs	34-55	1-255	950-1200	44 springs, high H2s & Radon concentration
Zarqa Main springs	30-63	1-350	1800-2500	60 springs, high iron oxides concentration
W. Ibn Hammad springs	35-41	1-25	600-900	9 springs, high iron oxides concentration
TS- 1d thermal well	50	400	9100	Artesian well, high H2S & and iron concentration
Burbetta spring	39	315	590	High CO2 concentration
Afra spring	45-47	376	570	Three springs, high iron oxides and Radon concentration
Smeika thermal well	57	50	640	High H2S concentration

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2004.

Locality	Maximum Utilization						Capacity [3]	Annual Utilization		
	Type	Flow Rate	Temperature (C)		Enthalpy [2] (kj/kg)			Ave. Flow	Energy [4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(Tj/yr)	Factor [5]
N. Shuneh Well	B	194	57	30			22.0	55.5	197.7	.29
Himmeh	B	833	40	25			52.3	138.9	274.8	.17
Zarqa Main	B	500	58	30			58.6	200	739	.40
Zara	B	167	42	30			8.40	50	79	.30
Burbeitta	B	87.5	39	25			5.12	60	111	.68
Afra	B	104	43	28			6.54	70	138.5	.67
Total		1844					153.3		1540	.42

TABLE 3. SUMMRY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2004

Use	Installed Capacity [1] (MWt)	Annual Energy Use [2] (TJ/yr=10 12 J/yr)	Capacity Factor [3]
Greenhouse Heating	nd	-	-
Fish and Animal Farming	nd	-	-
Bathing and Swimming	153.3	1540	.42
TOTAL	153.3	1540	.42

TABLE 4. TOTAL INVESTMENTS IN GEOTHERMAL IN (2004)US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1990-1994	0.2	-	-	-	-	100
1995-1999	0.2	-	.075	-	0.375	0.675
2000-2004	0.6	-	.075	-	0.125	0.875

TABLE 5. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2000 TO DECEMBER 31, 2004 (excluding heat pump wells)

1) Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)					
Production	>150° C					
	150-100° C					
	<100° C		11[2]			2.25
Injection	(all)					
Total			11			2.25

2): Wells drilled for irrigation purposes only, the temp. 32-44 C.

TABLE 6. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

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

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000	3		2			
2001	3		2			3
2002	10		2			3
2003	10		2			3
2004	10		2			3
Total	36		10			12