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GEOTHERMAL WATER IN JORDAN

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ABSTRACT

The main structural element governing the morphology, hydrology and hydrogeology of Jordan is the Dead Sea Rift fault Zone. It trends nearly N-S and forms an active part of the African-Syrian Rift, which extends from east Africa through the Red Sea, Dead Sea to south Turkey.

Sedimentary rocks cover almost the whole area of Jordan and have been subdivided into two major aquifers complex: upper and lower aquifers separated by more or less an impermeable sequence of marl and marly limestone of the Upper Cretaceous age. The upper aquifer complex consists of limestone, chert, and marly limestone of the Upper Cretaceous, while the lower aquifer complex consists mainly of sandstones of Lower Cretaceous and older ages.

The geothermal activity in Jordan is expressed entirely in the form of thermal springs. Other geothermal phenomena such as fumarolic activity and boiling mud pools or altered ground are not found. The location of nearly all thermal springs and anomalously thermal wells is dictated by their proximity to the Dead Sea Rift. Generally, they are distributed along a distance of about 200km on the eastern side of the Rift and discharge their water from the lower aquifer complex. The Zara–Zarqa Ma'in thermal springs are considered as the major geothermal manifestation in Jordan due to its high temperatures and flow rates. The heat source of the thermal water in the lower aquifer is a result of the deep circulation of water within the Paleozoic sandstones receiving heat from a normal to slightly elevated geothermal gradient.

Away from the Rift in Jiza region, many wells were drilled to the upper aquifer complex and discharge thermal water with temperatures up to 46°C. The dense faults net of the different trends in this area, strongly suggested that the two-aquifer systems are hydraulically connected. This allows the thermal water from the lower aquifer to flow up via faults (conduits) into the upper aquifer raising the groundwater temperature in the vicinity of these faults.

Thermal water sources in Jordan belong to low enthalpy geothermal sources, therefore, power generation is unlikely to be possible but they are quite suitable for direct uses such as; Spas, fish farming, space heating for selected constructions and other direct uses.

1. INTODUCTION

Jordan is one of the Middle East countries and has an area of about 90,000km^2 (Figure 1). It is located in the north-western part of the Arabian Peninsula and consists of three elongated distinctive topographic provinces trending in a general north-south direction. The Rift Floor Province forms the western part of the country. The floor elevation of the Rift rises from sea level at Aqaba at the Red Sea shore to about 240m above sea level (asl) in Wadi Araba, and falls to a round 750m below sea level (bsl) at the bottom of the northern part of the Dead Sea. To the north of the Dead Sea, it rises gradually to about 210m bsl at the shores of Lake Tiberius (Salameh and Bannayan, 1993). The highlands province located east of the Rift with a width ranging from 30 to 50km. The highlands rise in elevation to more than 1000m asl in northern Jordan and to more than 1200m asl in the southern part. These elevations drop sharply to the Rift in the west, but gradually towards the Plateau in the east. The Plateau province developed at the eastern toes of the highlands with land surface ranging from 1000m asl in the south to 700m asl in the northeast and in the middle Azraq Basin forms the deepest part of the plateau with an elevation of 500m asl.

This sharp variation in topography within a small country leads to great differences in its climate. Therefore, the highlands have a semi-arid Mediterranean climate, characterized by cold, wet winter and moderate dry summer. The plateau (desert) has an arid Mediterranean climate, with a dry cold winter and a hot summer. But the climate in the Jordan Valley and the Dead Sea can be classified as arid climate with a hot summer and a warm winter.

The main structural element governing the morphology, hydrology and hydrogeology of Jordan is the Dead Sea Rift fault zone. It trends nearly N-S and forms an active part (1100km) of the African-Syrian Rift, which extends about 6000km, from east Africa through the Red Sea, Wadi Araba, Dead Sea, Jordan Valley to south Turkey.

The Dead Sea Rift consists of two faults: The southern fault, Wadi Araba Fault and the northern fault, Jordan Valley Fault. Wadi Araba Fault starts from Gulf of Aqaba to the Dead Sea basin along its eastern shore and ends at its north-eastern corner. The Jordan Valley Fault starts in the south-western part of the Dead Sea and continues to the north along its western shore to the east of the Tiberius Lake.

Two theories were used to explain the formation of the Dead Sea Rift: vertical movement (Graben tectonics) and horizontal movement (Plate tectonics). Detailed investigations have proved the horizontal movement theory, where the Arabian plate has been continuously moving to the north (Quennell, 1956; Freund et al. 1970; Abed, 1982; Girdler, 1983 and others).

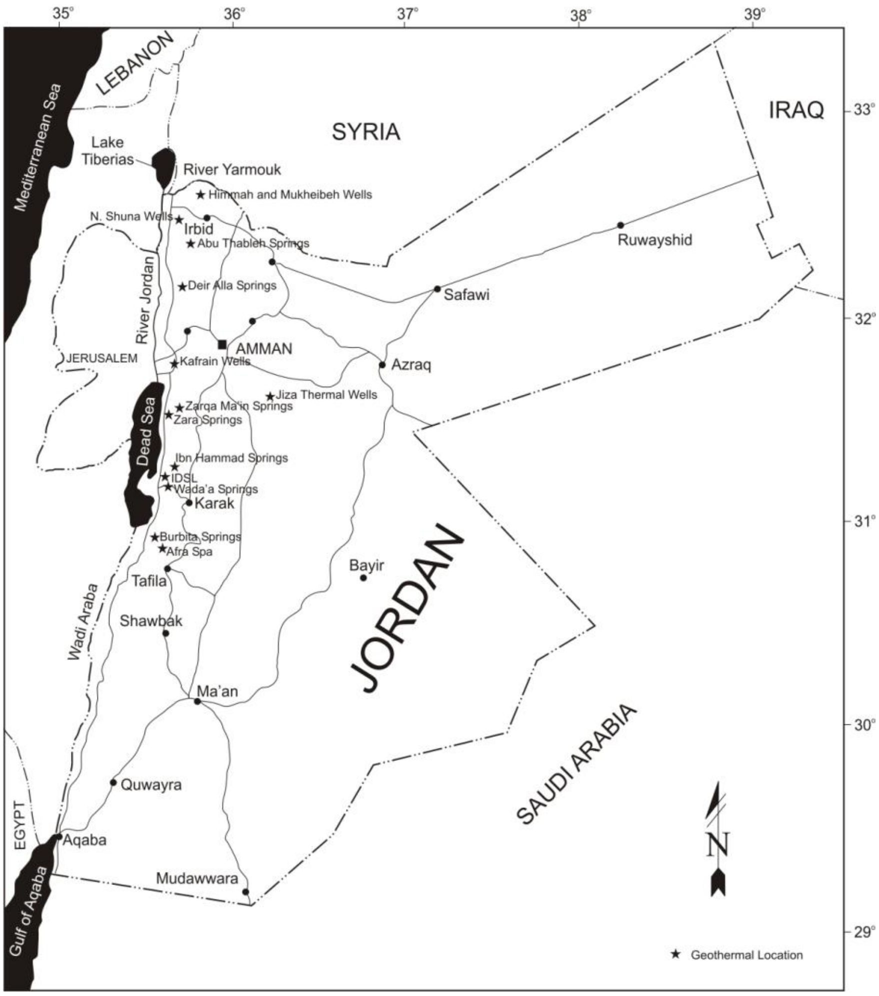

FIGURE 1: Jordan and geothermal resource locations

The left-lateral strike slip displacement along this transform boundary was estimated in Jordan at about 107km by Quennell (1956). In former literature, it was assumed that the movement has taken place in two stages: the first (62km) which should have started in Eocene (Girdler, 1983) or started in the Mid-Miocene time, before 15-17 million years, (Garfunkel et al. 1981) and the second stage (45km) started in Pleistocene (5 million years) and still going on (Quennell,1956; Abed 1982). Results from the Midyan peninsula (Bayer et al. 1988; Purser and Hoetzl, 1988) and from Ocean spreading in the Gulf of Aden (Gass, 1979) document a more or less continuous movement since about 12 million years ago.

As a result of the major structures and the continuous northward movement of the Arabian plate, faults of different trends and ages have developed in Jordan. The different trends are due to different stress fields resulting from the different tectonic movements in different ages. The main fault trends are N-S sinistral strike-slip faults, E-W dextral strike-slip faults, NW-SE tensional faults and NE-SW compressional faults. The crossing of the fault systems acted locally as conduits for the Neogene-Pleistocene basaltic intrusions and flows. Several of the E-W faults are traceable for tens or hundreds of kilometers from the Rift to the east. The offset along these faults generally decreases eastward where they are associated with or merge into monoclinal flexures (Figure 2).

Sedimentary rocks cover almost the whole area of Jordan with a thickness of more than 5000m in Azraq Basin. The Precambrian basement rocks are only exposed in the south-west of the country (Aqaba region). The sedimentary sequence in central Jordan has been subdivided into two major aquifer complexes: upper and lower (Salameh and Udluft, 1985; Sawarieh, 2005). The upper aquifer complex consists of limestone, chert, and marly limestone of the Upper Cretaceous age. This main aquifer complex is known as B_2/A_7 aquifer and is considered as a major source for fresh water for domestic use in Jordan. The lower aquifer complex consists mainly of sandstone of Lower Cretaceous and older ages. The two aquifer systems are separated by more or less an impermeable sequence forming an aquitard known as $A_{1\text{-}6}$ and consists of about 400m of marl and marly limestone of the Upper Cretaceous (Table 1). Most of the recharge enters the upper aquifer in the structurally high outcrop areas along the western highlands, where rainfall is relatively high. Generally, groundwater flows to the east within this aquifer. The main recharge source to the lower aquifer is the downward leakage from the upper aquifer system in the eastern parts of Jordan. The groundwater flows in the lower aquifer from the east towards the Dead Sea in the west.

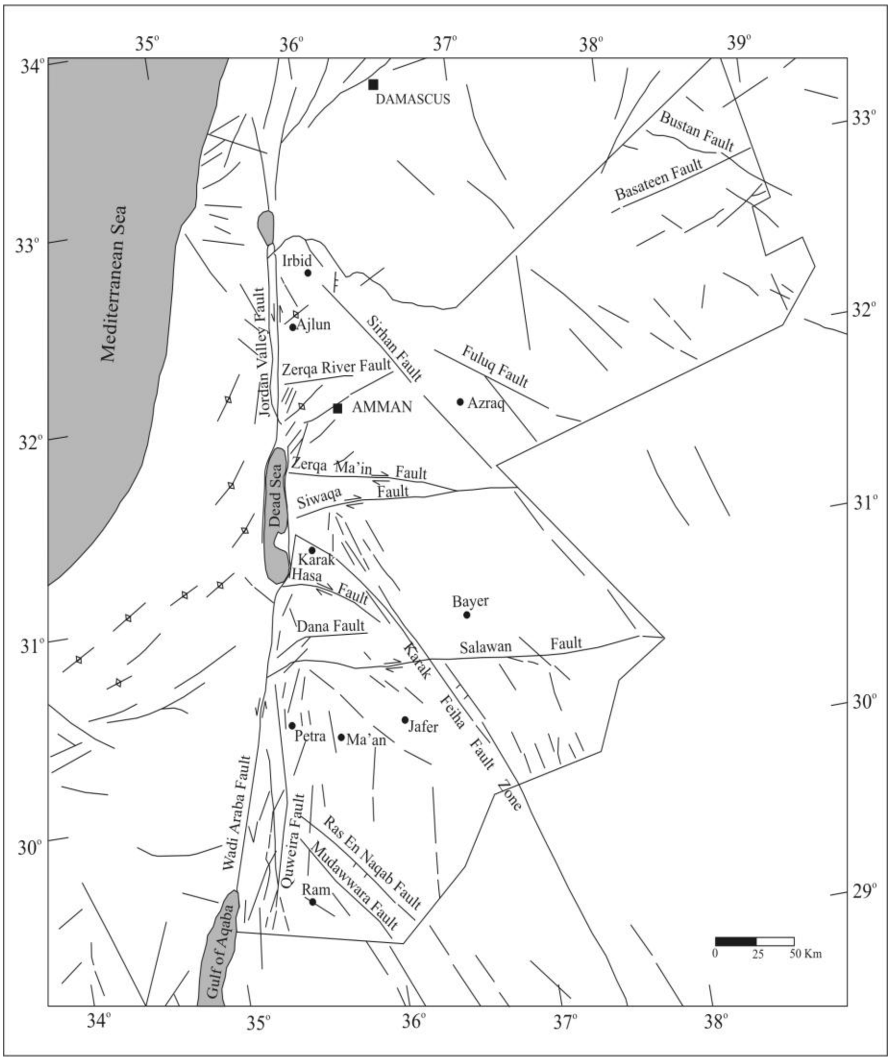

FIGURE 2: The structural map of Jordan (Sawarieh 2005).

TABLE 1: Aquifers within the sedimentary sequence of Central Jordan

Age	**Group**	**Formation**	**Hydrogeology**
Tertiary	Belqa 350m	B4: Umm Rijam	AQUITARD
Upper Cretaceous		B3: Muwaqqar Chalk-Marl	
		B2b: Al Hasa Phosphorite	UPPER AQUIFER
		B2a: Amman Silicified L.st.	
		B1: Wadi Umm Ghudran	
	Ajlun 500m	A7: Wadi es Sir	
		A5-A6: Shueib	AQUITARD
		A4: Hummar	
		A3: Fuheis	
		A1-2 Na'ur	
Lower Cretaceous	Kurnub 220m	K: Kurnub	LOWER AQUIFER
Permo-Triassic	Zarqa 170m	Dardur Sandstone	
		Ma'in Sandstone	
		Umm Irna Sandstone	
Middle to upper Cambrian	Ram 250 m	Umm Ishrin Sandstone	
Lower Cambrian		Burj Dolomite-shale	

2. GEOTHERMAL WATER IN JORDAN

An important feature of present geothermal activity in Jordan is that it is expressed entirely in the form of thermal springs. Other geothermal phenomena such as fumarolic activity, boiling and mud pools or altered ground are not seen. Thus there is no physical evidence from surface manifestations of the existence of high temperatures at shallow depths.

The location of nearly all thermal springs and anomalously hot thermal wells (Mukheibeh, North Shuneh, Jica wells and TDS-1) is dictated by their proximity to the Dead Sea Rift. Generally, they are distributed along a distance of about 200km on the eastern side of the Rift, extending from Yarmouk River in the north to Tafileh in the south with temperatures ranging from 30 to 63^{o}C (Figure 1). The thermal water of these sources discharges from the lower aquifer complex except for Mukheibeh well field which discharges from the upper aquifer complex (B2/A7). Zara thermal springs at the Dead Sea Shore together with Zarqa Ma'in thermal springs (up to 63^{o}C) about 4km to the NE, form the main geothermal manifestation in Jordan.

Away from the Rift in Jiza region, about 30km east of Zara–Zarqa Ma'in thermal springs, many wells were drilled into the upper aquifer complex (<400m depth) in the last three decades, mainly by the private sector for agricultural purposes. Most of these wells discharge thermal water with temperatures up to 46^{o}C, despite that the upper aquifer is known as a major source for fresh cold water in Central Jordan.

3. HEAT SOURCES:

Many investigations of the geothermal energy potential in Jordan have taken place over the last four decades. Most of these studies were done for, or directed by the NRA. Thermal waters of Zara-Zarqa Ma'in have been subjected to many studies regarding their chemistry, heat source, therapeutic properties and their potential as a source of energy. On the contrary, few works have been done on the shallow thermal wells in Jiza region, Central Jordan.

Several possible heat sources were presented in these studies to explain the high temperature in Zara-Zarqa Ma'in thermal springs field. The presence of the Late Cenozoic basaltic lavas in the area led earlier investigators (Bender, 1974 and Abu Ajameih, 1980) to conclude that the thermal water is heated by a crustal magma body or solidified hot pluton that represents the intrusive roots of the lavas. But the radiometric-age determinations show that the lavas are too old (1.8 ±.1 million year) and of too small volume, less than 1km^3 (Duffield, et. al., 1987). Also, the chemistry of the thermal water suggests that it is probably equilibrated with crustal rocks of about 110^{o}C (Truesdell and others, 1983). Therefore, a magmatic heat source for this thermal water seems unlikely.

Hakki and Teimeh (1981) related the hottest springs in Zara-Zarqa Ma'in to the highest intensity of shearing in the area, friction associated with lateral movement along faults. Galanis and others (1986) concluded that the heat flow in Zara-Zarqa Ma'in area is high ($\leq$ 472 mW/m^2) and that the area of highest heat flow is associated with the Zarqa Ma'in fault zone rather than the local basaltic eruptions.

Salameh (1986) suggested a heat stowing horizon consisting partly of dry sandstone overlain by marls with heat conductivities 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.

Myslil (1988) re-evaluated the heat flow data presented by Galanis, 1986 and included recent data and presented temperature gradient map (Figure 3) and identified two favorable zones for future exploration. The most favorable area was the eastern escarpment of the Dead Sea Rift, north of El-Lisan where gradients of 50^{o}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^{o}C/km were identified.

An alternative hypothesis that the waters are heated during deep circulation through crust with normal or slightly elevated geothermal gradients appears more likely. Isotopic and chemical properties of the thermal water indicate an origin in the Paleozoic sandstones, which extend to depths of 2500-3500m below the level of the Jordanian plateau. The geothermal gradient in these sandstones is normal, thus circulation to 2.5-3 km could produce the estimated temperature of about 100^{o}C. By this model, deep circulation in nearly flat lying Paleozoic sandstones is directed upwards along the deep faults to feed the hot springs and wells. This suggests that a widespread resource of moderate temperature thermal water exists in the Paleozoic sandstones of Jordan. Zara-Zarqa Ma'in thermal field is controlled by tectonic, so the feeding system follows the vertical faults, which acts as conduits for the rapid ascent of hot waters from deep confined aquifers. This up flow can feed laterally some permeable layers where aquifers can be developed on more or less large characteristic temperature curve with rapid increase of temperature followed by an inversion of the gradient.

It is well represented on the temperature profile of GTZ-3 well (1100m) in Zara area, where the out flow seems to be localized at the depth interval from 242.5 to 318.5m, which lies in the Triassic sandstone. The temperature decrease from 55.4^{o}C in the out flow zone to 51^{o}C at the down hole. Therefore, the only way to find hotter water is to intercept the vertical feeding system. Truesdell and others (1979 and 1983) concluded that the Zarqa Ma'in and Zara springs, are fed by deep circulating water. The maximum temperature of this water at depth is about 110^{o}C cooling down during ascendance and by mixing with shallower cold water before it discharges as thermal springs.

This interpretation for the heat source is similar to that reported by Mazor and others (1980) for many thermal springs elsewhere in the western side of the Dead Sea Rift and appear to reflect a regional similar geothermal regime along this major structural zone.

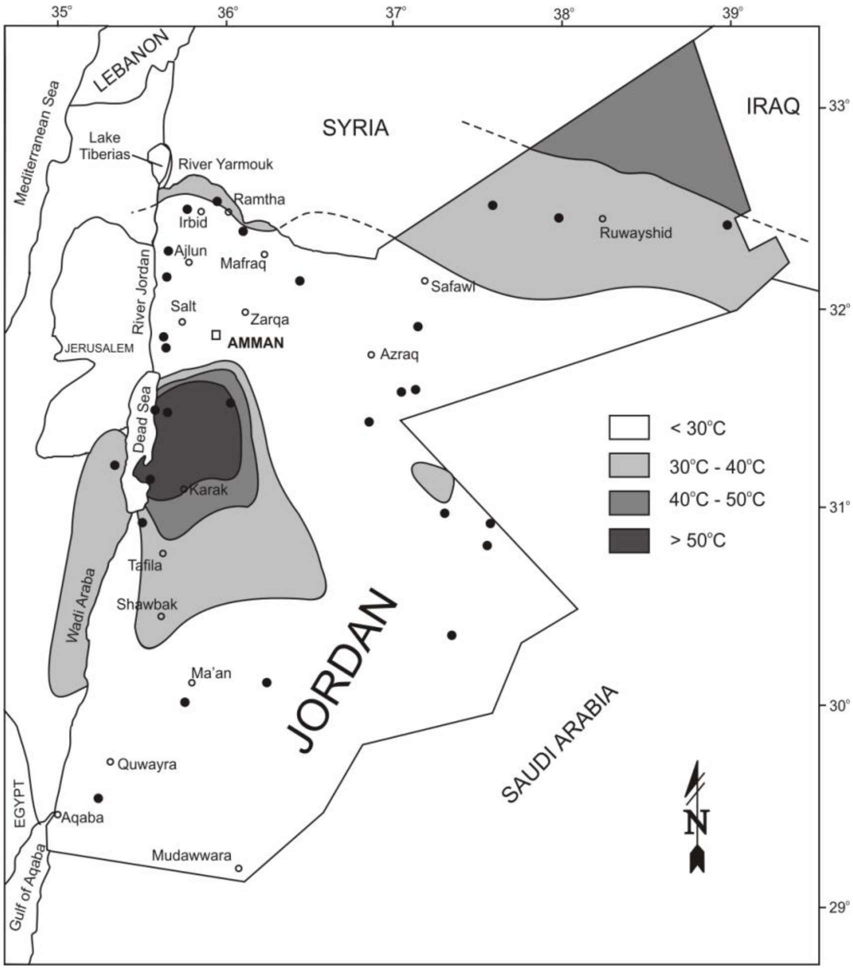

FIGURE 3: Geothermal gradient map of Jordan
(Modified from Myslil, 1988)

Between the years 2002-2007 three geothermal studies were carried out and concentrated on shallow thermal wells in Central Jordan for heat source and possible future utilization.

In the years 2001-2003, the NRA conducted a study on the shallow thermal wells in Jiza region. In the course of this project, geological, hydrological, hydrochemical and geophysical investigation were made. The main outcome of this work is that the thermal water in the area is a result of a mixing process between different types of water (meteoric origin) and the highest temperature predicted by using mineral saturation index for the deep aquifer is about 115 ° C.

Sawarieh (2005), presented a detailed hydrogeological and hydrochemical study on thermal water in Central Jordan (PhD thesis). The study concluded that the thermal water in shallow thermal wells in Jiza region is resulted from mixing between the thermal chloride water of the lower aquifer complex with the bicarbonate water of the upper aquifer complex via conduits (faults) raising water temperature in the vicinity of these faults (Figure 4).

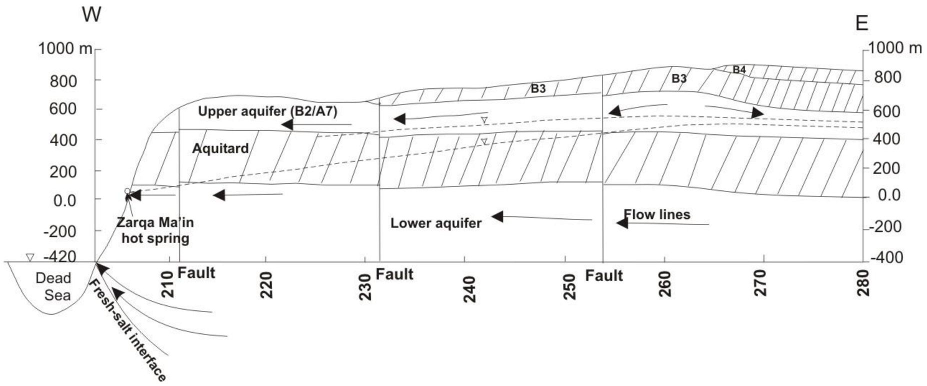

FIGURE 4: Groundwater flow model of the western parts of Central Jordan (Sawarieh, 2005)

During 2004-2005, Joint venture project was carried out by West Japan engineering consultants, Inc. and GeothermEx, Inc USA to evaluate all the available data and information related to the geothermal fluids in Jordan. Their study based mainly on the available data from NRA and Sawarieh studies and concentrated on the shallow thermal wells in central Jordan. The study presented a model refereeing the presence of the thermal water in the shallow wells in central Jordan to local convection within the upper aquifer with out any mixing with the lower aquifer water.

4. THERMAL WATER UTILZATION

Thermal water sources in Jordan belong to low enthalpy thermal heat sources, therefore, power generation is unlikely to be possible in Jordan except in the north-eastern parts of Jordan where high geothermal temperatures were reported in oil wells.

Thermal springs have been used in bathing and in irrigation since ancient times. Recently, several hotels (Spas) were constructed on the thermal spring's site. The experiments carried out on the curative ability of the thermal water in Jordan show very good results in treating several diseases (Salameh, etal., 1991). Several research projects are running now on utilizing thermal water in fish farming and green houses. The future outlook for thermal water utilization in Jordan is to use them in the following uses:

1. Space heating for constructions near these sources.
2. Doubles systems for Air conditioning and heating in big constructions like Queen Alia Airport and the Spas.
3. Protected agricultural activities (green houses to produce flowers, Mushrooms and strawberries for example)
4. Fish farming projects to provide the local market with fresh fish.
5. Constructing big and modern spas for medical treatment and relaxation, like the one built in Zarqa Ma'in area.

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