Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Geothermal Energy Development: the Tunisian Experience

Mouldi Ben Mohamed

Regional Commissariat for Agricultural Development, CRDA Ariana, Cité Bouchoucha, Le Bardo, 2000, Tunisia

mobmo@mailcity.com

Keywords: Geothermal resources, direct application, oases, greenhouses, balneology, hammams.

ABSTRACT

The use of geothermal energy in Tunisia is limited to direct application because of the low enthalpy resources, which are localized mainly in the southern part of the country. For thousands of years, geothermal water has been used in bathing, and many of the geothermal manifestations in the country have the name of Hammam or bath, which reflects the main use of geothermal water over the centuries. Now, most of the resources are utilized for irrigation of oases and heating greenhouses. The government's policy in the beginning of the 1980's was oriented toward the development of the oasis sector, which is supplied with geothermal water for irrigation. Therefore, boreholes are operating mostly to complete the irrigation of oases after cooling the water in atmospheric cooling towers. Generally, when the water temperature is less than 40-45°C, it is used directly for oasis irrigation.

The government started using geothermal energy for greenhouse farming in 1986, which was considered a promising and economically feasible application, by planting one ha in the southern part of the country. The results of this experiment were encouraging, and thus the cultivated areas has today increased to 244 ha. The utilization of geothermal resources is increasing very fast showing a real boom in greenhouses areas. Nowadays, heating greenhouses in southern parts of Tunisia is considered as the only experience in the world in terms of development in this field in the difficult desert conditions. By the end of 2016, the greenhouses areas will reach 350 ha.

1. INTRODUCTION

In Tunisia, because of the low enthalpy resources, the use of geothermal energy is limited to direct utilization, especially in agriculture. The resources are localized mainly in the southern part of the country (Kebili, Gabes and Tozeur regions) and utilized mostly for agricultural purposes. The government's policy in the beginning of the 1980's was oriented to the development of the oasis' sector, and the main aim was to supply oases with geothermal water for irrigation. Therefore, over 80 boreholes were drilled in the southern part of the country. In 1986, the State started using geothermal energy for greenhouse farming by planting an area of 1 ha. The results of this experiment were very encouraging and thus, the areas today have increased to 244 ha. The purpose is to determine the main direct uses of geothermal energy in Tunisia, to describe the present status of geothermal utilization and to analyze the impediments to the agricultural operations. The study starts with the history of the geothermal resources in Tunisia. Following this, the utilization of groundwater in agriculture and the future outlook for bathing, tourism and spas, washing and animal husbandry is discussed.

2. HISTORY OF GEOTHERMAL RESOURCES IN TUNISIA

Tunisia is a North African country with a small total area of 164,000 km². The arable land is only about 5 million ha, with rare and sometimes non renewable resources. Geothermal resources are taken from the 'Continental Intercalaire' aquifer: the deep aquifer or CI, which is characterized by relatively hot water between 30 and 80°C at depths reaching 2,800 m. The resources are located in a reservoir of 1,000,000 km² which extends to Algeria and Libya. In Tunisia, it covers the regions of Kebili, Tozeur, Gabes and the extreme south in a reservoir of 80,000 km². The CI aquifer is one of the largest confined aquifers in the world, comparable in scale to the great artesian basin of Australia. The principal areas of recharge are in the South Atlas mountains of Algeria and Tunisia and the Dhahar mountains of Tunisia. Radiocarbon analysis has shown that the geothermal water is about 20-50 thousand years old and is of sulfate-chloride type (Agoun, 2000). The flow rate varies from 70 to 200 l/s, the salinity from 2 to 4 g/L and the water is utilized mainly for agriculture purposes. Because of the limited area of the oases in the past, the geothermal resources were initially exploited for bathing. Since they are low enthalpy resources, the use of geothermal energy is limited for washing and there was no reason to use it for oases irrigation (Figure 1). This was in the beginning of the 1950's and 1960's. After that, these resources were utilized for oasis's irrigation for the first time because of the abundance of water in some oases and the large expansion of areas. The important period of drilling boreholes was in the middle of the 1980's and in the beginning of the 1990's. Till now, over 80 wells were drilled in the country. The most number is in the regions of Kebili (35 boreholes), mostly to complete the irrigation of oases after cooling the water in atmospheric towers and heating greenhouses.

Figure 1: Geothermal borehole in Souk Lahad locality, Kebili area.

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Geothermal resources are estimated to be 4,850 L/s, 85% are localized in the south part of the country (see Table 1).

Table 1: The geothermal resources in Tunisia

Regions	Geothermal resources (L/s)	Contribution (%)
Kebili	1,100	23
Gabes	1,682	35
Tozeur	635	13
Gafsa/ Sidi Bouzid	697	14
Total south	**4,114**	**85**
Mahdia (Center)	278	6
Others (North)	458	9
Total country	**4,850**	**100**

3. DIRECT GEOTHERMAL UTILIZATION IN TUNISIA

The direct utilization projects exploiting geothermal energy exists in at least 80 countries. The main utilization categories are swimming, bathing and balneology, space heating and cooling, agricultural applications such as greenhouse heating, aquaculture and industrial applications. Over two third of this energy use is for space heating, swimming and bathing (Lund, 2007). In Tunisia, according to Ministry of Agriculture and Water Resources, the General Direction of Water Resources report (DGRE, 2005), about 1,143 millions m^3 are exploited from geothermal resources, 76% of which are used for agricultural purposes, 19% for water drinking and 5% for industry and tourism. This exploitation differs from region to region. In the case of Kebili region, 98% of geothermal resources are utilized for agricultural purposes (71% for oases and 27% for greenhouses), the remaining part (2%) is used for bathing (hammams), tourism and pools, washing and animal husbandry (Ben Mohamed and Said, 2008). Till the year 2010, the use in greenhouses heating in this region increased due to the increasing of greenhouses areas. Consequently, the use of geothermal energy in greenhouses increases from year to year. Figure 2 shows the different direct geothermal uses in the area in 2009.

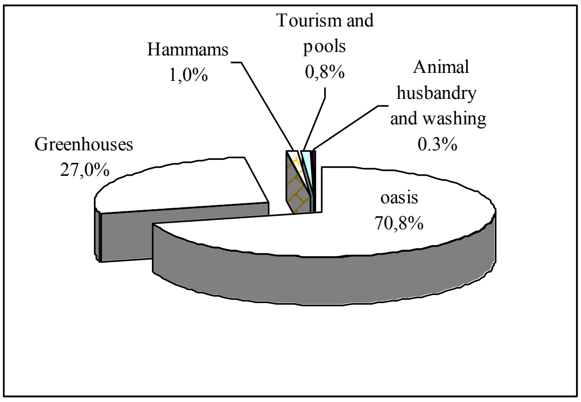

Figure 2: Geothermal uses in Kebili area (2009)

3.1 The oases irrigation

Since they are located in the southwestern part of the country, the Kebili and Tozeur regions are characterized by desert climate (arid). The annual precipitation is irregular and generally less than 100 mm. The maximum temperature is about 55°C (July) and minimum temperature is about –7°C (December). Then, the temperature range is very high. These difficult conditions require a large amount of water needs to maintain the humidity inside the oases system, mainly during the summer period. Thus, the major part of the geothermal water is used to complete the irrigation of 24,600 ha of oases. The water temperature varies from 27°C to 80°C. Generally, water less than 45°C is used directly for irrigation or cooled by means of multiple ponds or cascaded as shown in Figure 3. By using this cooling system the temperatures can drop by 5-10°C to reach 35°C.

Figure 3: The water cooling system (Cascade of Oum Somaâ locality, Kebili area).

When the water temperature exceeds 40-45°C, it is cooled by means of atmospheric towers before being used for irrigation purposes (Figure 4). In normal conditions, the temperature decreases to 30-35°C. However, these towers have the disadvantage of losing water via evaporation, estimated at 5-8% of the total flow rates. This technology needs a big exploitation cost by the years: the electricity cost for ventilation, the maintenance and the gardening.

Figure 4: The water cooling system (Cooling atmospheric tower, Kebili area).

The Gabes area, located in the south-eastern part of the country, is characterized also by arid climate but since this region is close to the Mediterranean Sea, it has fresher climate than the two regions mentioned before (Kebili and Tozeur). The temperature range is less extensive because of the air humidity. The water temperature in the CI aquifer varies from 40°C to 69°C and the major part of the geothermal water is used to complete the irrigation of the oases. More than half of the oasis areas in the southern part of the country receives complete geothermal water irrigation. The soil is irrigated by submersion method (see Figure 5). In this case, water is transported through a sandy furrow to parcels causing high water wastage due to infiltration, evaporation and physical characteristics of the soil (light soil, sandy and salty soil).

A drawdown of the water level is noticed due to the overexploitation of geothermal water caused by the big oases demand for irrigation. Indeed, many of the artesian wells are now pumped. For the period 1982-2000, the studies in the Kebili area, for example, showed a drawdown between 9 to 40 m (Ben Baccar, 2007).

Figure 5: The oases irrigation system.

For saving purposes, the government encourages farmers to install and utilize PVC pipelines for irrigation by subsidizing 40 to 60% of the total investment. The Tunisian policy in the agricultural field and especially in its hydraulic aspects was oriented since the beginning of the 1990's to give more importance, responsibilities and decision making to the non-governmental organizations. In that way, many organizations related to management of water resources, called GDA: Agricultural Development Group, are operating and they contribute effectively to the management and the distribution of water. In the same policy of water saving, a project called APIOS (amelioration of irrigated areas in south oasis) started in 2001 by the installation of concrete canalization for irrigation and a drainage system. The project covers about 20,000 ha of oases with a total cost of 30 million dinars co-financed by Japan authority. The objectives are to ameliorate the irrigation frequency, to ameliorate the oasis's efficiency and productivity and to valorize the water resources since they are rare.

3.2 The greenhouses heating and irrigation

The use of geothermal energy for heating greenhouses can reduce operating costs and allow operation in colder climates where greenhouses would not normally be commercial. Geothermal heating of greenhouses started in Iceland in 1924. By the end of 1970 some glasshouses were heated in Yugoslavia. Other countries followed the experience and nowadays, there are around 1,000 ha worldwide using geothermal energy for heating (Ben Mohamed and Said, 2008).

Tunisia is one of the leading countries in using geothermal water for heating plastic greenhouses. The utilization of geothermal energy started in the country as an experiment, the results were very encouraging and led to the idea of a Geothermal Utilization Project in Agriculture (PUGA-project, TUN/85/004) financed by the United Nations Development Program. In 1986 the government started to use geothermal energy in greenhouses in the southern part of the country. After one year, many projects were created in several places. Nowadays, the exploitation of geothermal resources for heating greenhouses in the southern part of Tunisia is considered as the only experience in the world in terms of development in this field of the difficult desert conditions.

3.2.1 The evolution of the greenhouse areas in Tunisia

Tunisia occupied the first place in the world in 2002 with 102 ha (Lund, 2002), the total area of geothermally heated greenhouses has increased considerably. Indeed, starting with 1 ha as an experiment in 1986, the area reached 21 ha in 1988 of which 51% were in the region of Kebili and 111 ha in 2005. Today, the total implanted area is 244 ha in which 224 ha are really exploited. Figure 6 shows the evolution of the greenhouse area in the country and in Kebili area.

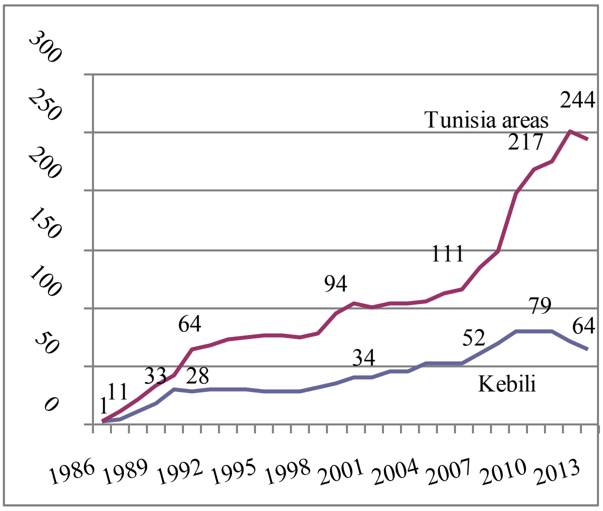

Figure 6: The evolution of the greenhouse area in Tunisia (ha)

3.2.2 The greenhouse cropping system

The utilization of the greenhouse area in Tunisia is based on three cultivations periods, the first is the autumn season "before season", from September to December; the second is the spring season "after season" from late December to June, and the third season is the "continuous" from September to June. The exploitation is more than one time per year and lasts nine months. About 252 ha were raised in the country in 2014 giving a rate of intensification of 113%. The cropping system as shown in Figure 7 is composed principally of tomatoes and snake melons with, respectively, 57% and 23%. Melons represent 12%, watermelons 3% and others, generally peppers 5%. Also in the past years, tomatoes and snake melons were the main vegetables crops due to their commercial value and their facility of selling for export.

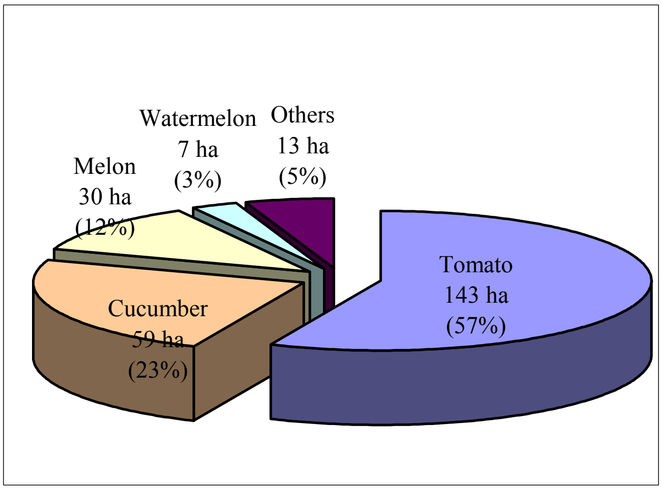

Figure 7: The greenhouse cropping system in Tunisia

3.2.3 The greenhouse productions

The greenhouses heated by geothermal energy generate better quality and higher yields than the unheated ones. Production increased from year to year due to the increase growing areas and good yields of some farms, especially big ones. The total production from heated greenhouses in the country is estimated to 35,500 tons in 2013. It grew from 10,000 tons in 2001 to 16,300 tons in 2008 to reach 35,500 tons in 2013 (see Table 2).

Table 2: The total production in the country (2013)

Regions	**Physical area (ha)**	**Occupied area (ha)**	**Average of greenhouses by farm**	**The total estimated production (tons)**	**Average Yields (tons/ ha)**
Kebili	64	65	3	3,500	54
Gabes	151	139	43	29,300	211
Tozeur	29	48	9	2,700	56
Total	**244**	**252**	**7**	**35,500**	**113**

Big farms located in the Gabes region generate the best yields in the country (4 times the small farms) which cross 200 tons per ha but small ones located in the Kebili and Tozeur regions generate less yields with an average of 55 tons per ha. From 2004 to 2013 it varied as shown in Figure 8 with an average of 22,500 tons per year.

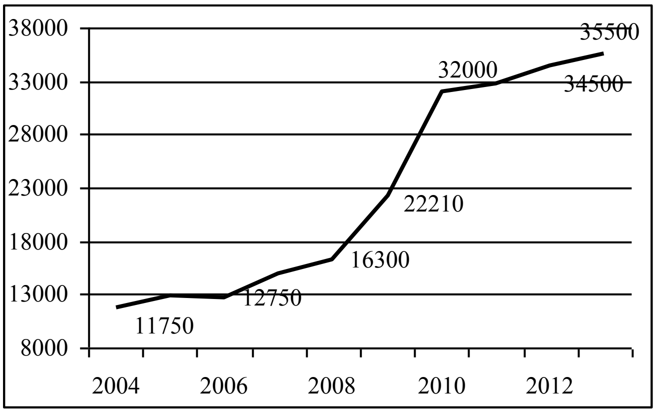

Figure 8: The evolution of greenhouse production (tons)

3.2.4 The greenhouse vegetable export, economics and social development

The greenhouse sector represents a good place in the development of the southern regions of the country. It is considered economically feasible since it contributes for the amelioration of the level life of farmers by generating good incomes and devises via export. Indeed one unit of greenhouse generates an income from 2,500 to 3,000 TND (Tunisian dinars). This means an income from 50,000 to 60,000 TND per ha. Growers are well attached to their greenhouses which allow a flux in the treasury (money entrance during all the period of the year). The work is one of the most principal factors defining the process of the production system inside the farm. Greenhouse farms, especially medium and big farms are generators of employment (about 7 permanent employments and 400 seasonal days-work by one ha). The export quantity remains under the objectives of the strategy, which projects a 50% export of the total production. About 40% of the productions were exported in 2013 mostly are tomatoes; mainly from big farmers of the Gabes region (94%). The prices given for Tunisian tomatoes product are high in the European market due to the high quality and taste. Small farmers, such as those in the Kebili and Tozeur regions, need to be organized in groups, companies or cooperatives to share the transport cost and consequently to minimize their total costs.

3.2.5 The greenhouse heating system

Temperatures less than 12°C during two successive days disturb the physiological behavior of plants. Paradoxically, temperatures higher than 30°C can provoke irreversible damage to crops. Normally, temperature variation should not exceed 5-7°C. In the south this is difficult to obtain, as the risk of temperature variation is frequent. In order to solve this problem, the use of geothermal water is a good solution, which can improve the climate inside greenhouses principally during the night. The heating is through pipes lying on the ground between the crops (Figure 9).

Figure 9: The greenhouse heating system

Generally, an average of 8-10 loops of polypropylene pipes is used per house and they are connected with the system by an easily operated valve. For heating greenhouses in the country, 34 wells are operating to supply about 50 different sites where 613 farmers are operating. Table 3 shows the distribution of projects and farmers by area.

Table 3: The distribution of greenhouse projects, farmers and boreholes

Regions	Projects number	Farmer number	Boreholes number for greenhouses
Kebili	24	448	14
Gabes	16	69	13
Tozeur	10	96	7
Total	**50**	**613**	**34**

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The exploited total area heated by geothermal water is 224 ha; the temperatures vary from 45 to 80°C. The need for greenhouse heating is only six months, mostly during the night from November to April. The duration heat lasts 14 hours per day. Farmers open the heating system in the afternoon when they finish working and stop it the next morning when they reach the farm (Ben Mohamed, 1995). Normally, the total amount of geothermal water needed for heating greenhouses is approximately 60,000 m3/ha for six months period but the real amount can go over this volume.

3.2.6 The greenhouse irrigation system

After the thermal water has been used for heating greenhouses, a small part is collected in concrete ponds for subsequent use for irrigation after being cooled. These ponds need to be large to store all the cooled water until it is used for irrigation. In many projects, farmers utilize very small and simple ponds with plastic linings, which are cheaper and very practical. Their dimension varies from 40 to 80 m^3. Generally, these ponds are also used for the irrigation of an open field area (oases) close to the greenhouses. The need for water irrigation during the growing period is very low compared to heating. In that way, farmers utilize a localized system (dropping system). Water circulates inside a perforate pipeline lying on the ground. The chemical composition of the geothermal water used in irrigation must be monitored carefully to avoid adverse effects on plants because of the relatively high salinity in the region (from 2 to 4 g/L).

3.2.7 Geothermal return water

The combination of heating and irrigation is practiced only in Tunisia. From the borehole, water goes directly through the pipes lying on the ground inside the greenhouses for heating. For new projects, only 10% of the total heating water is sufficient for greenhouse irrigation and the rest is collected during the night in a big pond outside (Figure 10). Then it is used for oases irrigation. But for old projects, the need for irrigating a greenhouse reaches sometimes 15% of the total heating volume. The needs average for heating and irrigating a mono-tunnel greenhouse of 500 m², in normal conditions, is respectively 0.3 and 0.03 L/s (Ben Mohamed, 2005). The rest or what is called 'the return water' which represents 90% (0.27 L/s) should supply the oases surrounding the area, but this is often difficult to achieve because of the conflict between users, especially when there is no relation between oasis's farmers and greenhouse's farmers and due to some old irrigation system projects. That's why it is indispensable to constitute an organization or a company for water uses to reduce conflicts between users.

Greenhouse heating occurs during the night, while irrigation occurs during the day. Therefore, it is necessary to store the return water in ponds to be used later for irrigation purposes. This is why two types of ponds should be installed in a greenhouse project. The first pond is small and used for irrigation of crops inside the greenhouses. The second is bigger, used to store the return water from all the greenhouses for oasis irrigation. The storage capacity should be at least equal to the total volume of return water for two or three successive nights (Saïd, 1997). In order to facilitate the water supply to the oasis, the storage pond should be located at a relatively high level. Otherwise, water must be pumped and farmers will pay an additional cost. It is important to note that the location of a greenhouse project near the oasis is preferred and a combination greenhouse-oasis must be considered for better utilization of the return water. The best idea is to attribute greenhouses to the same farmers exploiting oases closely.

Figure 10: Type of big ponds to store the return water

Due to the bad design of some greenhouse projects, water couldn't easily reach the ponds. The farmers dispose of the water close to the fields and often in the drainage system producing a waste of water resources (Ben Mohamed and Said, 2008). Normally the return water should supply the old oases or the new ones close to the greenhouses project, but, sometimes, there are conflicts between the users. For instance, the total amount of water returned from the greenhouses to the oases in Kebili region represents only 50% of the available water.

3.2.8 The greenhouse geothermal strategy

Eighty five percent of geothermal resources in Tunisia are localized in the southern part of the country. These resources are able to create 378 ha of greenhouses heated by geothermal energy of which, about 65% of the projected area is implemented.

Greenhouses were attributed in the beginning to small farmers with two units of houses. The first experiment was in the Limagues locality in the Kebili region, where 1 ha was planned in 1986, then many small projects in the southern part of the country where established. Development of the greenhouse sector has been very fast, at least for some small farmers starting with two houses, who now have five or even 10 greenhouses. Some big farmers, started with only 10 greenhouses, now they have 40 greenhouses and more. The increasing area is in the Gabes region where some big farmers are successfully operating. Utilization of the geothermal resources will, without a doubt, increase in the future after implementing the final phase of the geothermal greenhouse strategy. By the end of 2016, the total area will reach 320 ha, which represents more than 85% of the strategy.

3.3 Balneology in Tunisia

Balneology is the use, for therapeutic purposes, of thermal water defined as underground water, naturally pure, with a stable physico-chemical composition and recognized therapeutic qualities. People have used geothermal water for bathing for many thousands of years. The history of thermal water in Tunisia dates for thousands of years. It witnessed a significant development during the Roman period when resorting to hot waters was a cult, an art to cure people and an art of life. Geothermal water has been used for a long time for bathing and many of geothermal manifestations in the country have the name of ''Hammam'' what means bath, which reflects the main use of geothermal resources in the centuries. There are more than 70 hot springs in Tunisia, 28 are located in the northwest region (Ben Dhia and Bouri, 1995) where hot springs are preferably associated with tectonic activity (faults and fissures) and the natural flow rate is usually small (less than 10 l/s). They are used mainly for curative treatment and bathing. Temperatures of waters in these springs exceed 40°C and some springs are above 50°C. Whereas, according to the 'Thermalism office', Tunisia has more than 80 thermal manifestations including 50 inventoried hot springs with the required physical and chemical composition for thermal treatment in various therapies. The number of thermal bath visitors has been increasing year after year, an indication of the importance which Tunisians give to those beliefs. For instance, in 2001, about 2.5 million people seeking treatment visited these thermal baths. Balneology is a very significant development engine in tourism, regional development and soft medicine.

Bathing is very practiced and spread all over the country, especially in the south where two areas are called hamma (Gabes and Tozeur regions) because of the hot water in these places. In the Kebili area, for example, there are around 10 traditional baths using 1% of the total amount of geothermal water. Generally, they are small baths with a similar design with two small covered pools (two for ladies and two for gentlemen), two sitting rooms, two dressing rooms, and one pray-room. Surrounding the hammam, there are often parking, a cafeteria and small stores for shopping. The hammams, to be developed and accepted, must have better services such as living rooms for visitors coming from outside the region and spending more than one week. People visit the hammams to cure or prevent diseases, to relax and reduce stress, to clean and to spend time (mostly in Ramadan) but, never to be in solitude, to reduce weight, to quit smoking or to meet people.

Figure 11: The thermal station in Korbous locality.

The most famous thermal stations or spas in the country are Korbous, Djebel-Ouest, Hammam Bourguiba and the Djerba spas. Thousands of citizens visit the stations every year, not only for bathing and having curative treatments, but also for fun and recreation. Some pools in different hotels of the country are supplied by hot water for touristy purposes. A small amount of water is used for hotels and swimming pools.

3.4 Animal husbandry

Geothermal water is also used for animal husbandry (dromedary, sheep and goats). Animals, especially dromedary, like warm water better than cold water. In addition, warm water is so demanded in wintertime because of the salty taste and gives more appetite for the animals, which are crossing many kilometers to reach hot sources.

3.5 Washing activity

As mentioned before, the geothermal resources have been exploited for the first time for bathing and washing. This was in the beginning of the 1950 and 1960s. Generally, ladies are washing clothes, wool and heavy things such as winter covers. Thermal water is transported through furrows to parcels for irrigation; an amount of water is taken off for washing. In the Kebili region, 55 places for washing were counted in 17 localities (Ben Mohamed, 2002). The use of hot water in washing is very practical and developed for many reasons: washing easy, warm water in winter time, with no cost (water saving), large space and washing together (spending time). This activity is spread in the southern part of the country generally near the boreholes or close to the open canalization used to irrigate oasis.

4. CONCLUSION

The big amount of geothermal water is used for oasis irrigation after being cooled in atmospheric cooling towers and heating of greenhouses. The energy consumption in greenhouses is increasing by every year due to the new greenhouses projects in the southern part of the country. Sometimes there are some unresolved conflicts between users. Thus, for water saving purposes, cascaded use should continue in the country. For some projects, especially the new ones, the outlet water from the greenhouses is used directly for oasis irrigation. The need for irrigating a greenhouse is only 0.1 times the heating. The return water should supply the oases surrounding the area, but this is often difficult to achieve. The location of a greenhouse project near the oasis is preferred and a combination greenhouse-oasis must be considered in the future. That's why, the attribution of an open field oasis project to the greenhouse's farmers could be a good idea and a very practical thing to consume, valorize and save all the geothermal return water. Bathing activity in Tunisia is very ancient and it has been practiced all over the country since long ago but not well developed. We can promote the use of thermal water in the country by looking for a better conception to thermal stations and hammams, which should play the role of attractive points, especially on the edge of the desert. This can be promoted with foreign investors.

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