Water chemistry, Geothermometry of the northern Algerian Sahara in geothermal system, case study Ghardaia, Algeria

Mihoub Redouane (1), Amroune Abdelouhab (2), Bekkouche SMA(3) and Rabahi Noureddine (4)

(1) Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Energies Renouvelables, CDER, 47133, Ghardaïa, Algeria
(2) Département des sciences agronomiques, Faculté des sciences, Universitaire Mouhamed Boudiaf M'Sila.
(3) Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Energies Renouvelables, CDER, 47133, Ghardaïa, Algeria
(4) Département de geologie, Faculté des sciences, Université de Batna -2.
E-Mails redmihoub@yahoo.fr

Abstract—Ghardaia, located in the north of the Sahara in Algeria, and extends over an area of 86105 km ^{2}. The water Wells inventory in the study area has reported to 565 Wells which exploit the intercalary continental and offering a flow of 387.86 hm^3/year. A chemical study counting data base reveals in this study, that we describe the physic-chemical characteristics .The isotopic indicate a meteoric origin of the thermal water results the estimated temperature ranges between 22°C to 45°C, while the cationic geothermometers where estimated between 100-500°C. Geothermal represented by several interesting clues and corresponding to the northan and north - east of the study area. The south marks the areas of geothermal high heat flux. **:** the main characteristics of groundwater in the region in a regional geological setting and data collected of oil Wells contribute that there are an internal movement of warm waters through the existing fault network and by contact with rocks create a convection process. The Ghardaia's geothermal system is a non-volcanogenetic system. The water has gained depth.

Key-Words— Algeria, Ghardaia, geothermal water, mixing, deep circulation.

I. INTRODUCTION

Algerian platform, is the most important basins, it includes those of Illizi-Berkine , Hassi Messaoud, Hassi R'mel and Oued Mya (Ghardaia) in the center, and Tindouf, Bechar, Reggane, Ahnet, Sbaâ, and Timimoun to the West . The Northern Sahara Aquifer System "SASS" covers an area exceeding [1 million (square kilometers)], 60 % in Algeria, 10 % in Tunisia and 30 % in Libya. With a capacity of up to 1600 m , there are two main reservoirs:

- Intercalary Continental midsole combining land Lower Jurassic and Lower Cretaceous.
- Terminal Complex with carbonate formations from the Upper Cretaceous to Paleocene and Eocene and Miocene series.

The geological science is a part of renewable energy it consists in extracting the heat stored in the soil for the production of electricity , geothermal science in high temperature [39] or the heating , geothermal science in low-temperature [48]. The magmatic activity has led, as soon as the superior Eocene, to the effusion, at its summit in basaltic traps to tholïtics affinities. The Hoggar in the south of Algeria is a bulge of lithospheric scale [33]associated with a hot point . The Paleozoic series, discordant on the base which form the filling of these basins, have significant thicknesses, often exceeding the *8000* m. The Hoggar is located within the African plate far from the recent East African rift system. Associated with a swell 1,000 km in diameter, Hoggar Cenozoic volcanism is classically considered to be a mantle plume product even though no thermal anomaly has been observed [16] ;[23].on average. The advantage and disadvantage of methods applied in this study is the Treatment of all existing data enabled us to identify geothermal area and especially to define the relationships with characteristics hydro-chemical that may be offered, and to build the areas of internal energy stored?

The aim of this study is to find out the origin of the thermal water and possible relationship with the geological and tectonic set of the study area. The studies on the deep aquifers since the beginning of the twentieth century have demonstrated that the underground circuit of thermal waters integrates into the overall movement of groundwater. The Temperature gradient is by definition related to the depth and nature of the rock and hence an average gradient may not represent the thermal condition 4° C / 100 m. The use of thermal waters in Algeria goes back to antiquity. In effect, the remnants such as wells and remnants of public baths were found near hot springs as early as *3000* front. J.-C. Subsequently, the Roman civilization has made a systematic use of thermal waters and mineral resources for various uses. The temperature of the soil depends on the depth in which is measured, Such as the sun rays [38], the ambient temperature and the wind speed. In geothermal resource, the mode of transfer of the heat offering exchange surfaces between sufficient this fluid and the rock and the possibilities of movement for the heat transfer fluid. The water with its physic-chemical and thermal characteristics constitutes the most effective vector. The thermal waters acquire a new interest for the man and their hydrothermal systems represent an energy resource which has the advantage of having a low impact on the environment. Algeria with its solar deposit is very important to large opportunities for the development of the chain [41]. An optimal use of solar energy [39] needs an accurate knowledge of solar radiation at a particular geological location. Accurate measurement of soil temperature is a difficult task. Heat flux plates can be used to make direct measurements of soil temperature [38] .This work is a general summary of data collected which constitutes a state of places of the potentialities of geothermal energy in the Ghardaia's area which future strategies to recovery of this resource can be developed. The rest of this paper is organized as follows: Section (*2*) presents site location and data collection. In section (*3*) we describe water chemistry in section (*5*) geothemometry, in section (6) concludes the end suggest a future work.

II. Site Location and Data Collection

Ghardaïa , located in the center of the Northern Sahara ,*600* km, south of the capital Algiers .It is one of the great oasis in Algeria , it is characterized by a vast expanse where rocky outcrops of bare of rock witch blackish brown color. This tray is masked by the strong river erosion early Quaternary who cut in its southern part of the flat-topped buttes and shaped valleys. It is located between (3*° 40' 38''* longitude E - *32° 29' 14''* N latitude), him surface area is *86 105* km^2. The collected data used in this work (Geothermal data, physic-chemical data, data of water well, of oil well , temperature, etc.), have been collected at the Applied Research Unit for Renewable Energies (URAER) , Agency of water (ADE) ,and Agency hydraulics resources (ANRH), and SONATRACH, situated in the south of Algeria (Ghardaia) . The relief (Fig.*1*) of Ghardaïa is characterized in to the north by the chain of rocky (the chabka) and in to the south by (Hamada)[12]. The altitudes are relatively low; they gradually declined from up-stream to down-stream, especially in the northern part of the area, leads to the formation of many valleys called dayates, very fertile or sink and join a multitude of Valley. Rock cliffs and the Oasis determine the landscape in which are located the cities of M'Zab and around which revolve other oasis: Berriane, El Guerrara, Zelfana, Metlili and much more remote in the south ,the oasis of Hassi El Fhel and El Golea [9]. The climate of Ghardaia's area is arid with a minimum and maximum air temperature ranging from (*14* - *47* °C) and from (*2* - *37* °C) during summer and winter months respectively. The daily Global Solar Radiation (GSR) varies between a minimum of (*607* Wh/m^2/day) to a maximum of (*7574* Wh/m^2/day) and the annual mean-daily GSR is about (*5656* Wh/ m^2/day) [18]. Exceptionally, when the rains are important, especially in the northwest of Ghardaïa, These Valleys (O. Mzab) drain enormous quantities of water which has estimated between(*205* -*722* m^3/s) .The winds are violent and frequent in the month of February, in June it causes a sand storms. The month of June to September, is the sirocco how predominate

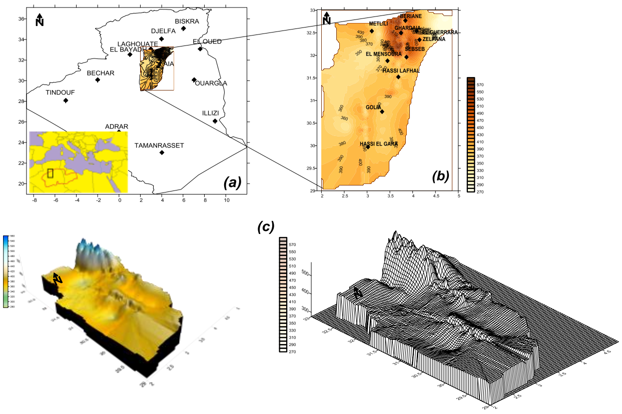

Figure . ***1***. Site location of Ghardaia city*;*
(a)Algeria area, b) Ghardaia area, c) relief (3D) of Ghardaia area).

III. Water Chemistry

1) **Potentiel hydrogen (PH)** Variations are 7.5 to 8.8 the water is between neutrality and basicity northernmost water is more basic 8.8 "northern Beriane", 7.8 to 8.4 in "the center" , the waters have "pH "value 8.3 has higher northernmost so it's off containing bicarbonates while those with lower values of 8.3 are less responsible, characterize the center and south of the study area .

2) **Electrical conductivity** the concentration and nature of the state of ionization of the dissolved compounds. values are meaningful variations north reach up to 3.5 ms / cm decreases from the center to the south of the area of study lower 1ms / cm .

3) **The dry residue** Represents the total mineralization of water "total dissolved salts and organic matter content in water" .the variations in south of the study area (El Menia are not overloaded 1 - 0.5 g /l the increase from the center to the north " charged water " 1-2.5 g / l.

Table1: water chemical ions data (mg/l) from the northern part of Algerian sahara (Ghardaia).

Locality	Depth (m)	T (°C)	Na	K	Ca	Mg	HCO3	SO4	Cl	NO3	NH4	Si
Bouheraoua	390	34,2	242	9	180	78	137	580	379	5,7	Inf 0,01	6,1
bensmara 1	371	33, 4	198	10	163	75	155	483	334	5,3	Inf 0,01	6
Daya ben dahou	467	34,8	229	8,2	160	70	139	593	320	7,6	Inf 0,01	5,7
berriane 2	545	34 ,2	137	12,5	97,2	41	184	294	189	2,2	Inf 0,01	5,5
Laroui	650	46,2	155	17,7	133	61	198	384	256	1,8	Inf 0,01	5,6
Guerrara Laa	1000	46,4	232	19,1	164	69	166	476	411	3	Inf 0,01	7,2
Zelfana 1	1000	46,2	315	11,5	163	64	152	430	482	4,4	/	7,6
Zelfana 8 fedjenaam	950	33.6	252	10,8	133	55	166	425	360	4,7	/	7,2

4)**Reservoir temperature estimation**

The temperature of the groundwater increases by (1° C per *30* m) when the thermal gradient is normal. The temperatures used (Fig.4.) are those measured at the level (0) in diverse points in the study area . We note through that the temperature varies with depth, the waters temperature value is influenced by the thermal gradient. The temperatures are increasing from the south (El Golia) to the north of study area (north of Berriane) . The maximum value measured is *45*°C more in the North, the minimum value measured is *24*°C in the south and the average temperature is *40*°C characterizes the Center of study area. The temperatures measured are classified as follows:

- 90% boreholes whose waters are mesothermal *24*°C ≤ T ≤*37*°C.
- 10% drill whose waters are orthothermal *37*°C ≤ T ≤ *45*°C.

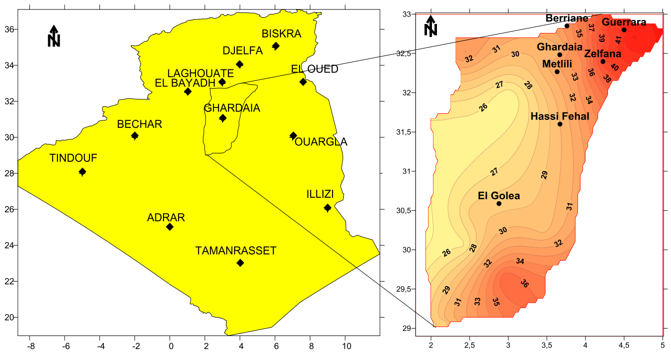

Figure. 2. Measured Water temperature of the Intercalary Continental.

5)Application of Chemical Geothermometry

The water in the thermal reservoir must be in balance5[1]:

The mineral species used as indicator of the temperature; regardless of the chemical geothermometry used to determine the temperature of the tank, the validity of the outcome under-intends that a certain number of criteria are checked (Fournier, 1977).

a)Silica geothermometry

The equations used are:

Quartz p v: $$T1 = \frac{1309}{5.19 - \log SiO2} - 273.15 \quad (1)$$

Quartz p v m in 100 ° C:

$$T2 = \frac{1522}{5.75 - \log SiO2} - 273.15 \quad (2)$$

Chalcedony:

$$T3 = \frac{1032}{4.69 - \log SiO2} - 273.15 \quad (3)$$

A-cristobalite:

$$T4 = \frac{1000}{4.78 - \log SiO2} - 273.15 \quad (4)$$

B-Cristobalite: $$T5 = \frac{781}{4.51 - \log SiO2} - 273.15 \quad (5)$$

Amorphous silica: $$T6 = \frac{731}{4.52 - \log SiO2} - 273.15 \quad (6)$$

Where: SiO2 is expressed in mg/L; T is expressed in °C.

Table 2: Water Temperature estimated and measured from the northern part of Algerian sahara (Ghardaia).

Locality	si	sio_2 (mg/L)	T1	T2	T3	T4	T5	T6	T Measured
Bouheraoua	6,1	13,054	609,175	471,621	776,078	658,312	698,750	625,348	34,2
Bensmara 1	6	12,84	595,217	463,030	751,242	638,072	670,740	599,7622	33 ,4
daia Ben Dahoua	5,7	12,198	554,583	437,590	681,144	580,509	593,253	528,888	34,8
Berriane 2	5,5	11,77	528,462	420,889	637,740	544,539	546,403	485,969	34 ,2
Laroui	5,6	11,984	541,430	429,215	659,131	562,298	569,386	507,030	46,2
Guerrara :Laameyed	7,2	15,408	778,769	570,347	1113,215	925,327	1110,639	999,499	46,4
Zelfana 1	7,6	16,264	849,116	608,458	1275,493	1048,919	1332,558	1199,483	46,2
Zelfana 8 fedj Enaam	7,2	15,408	778,769	570,347	1113,215	925,327	1110,639	999,499	33.6

The results thus obtained, leads us to suggest two assumptions:

- Either these temperatures are representative of those of a very deep tank;
- Either these temperatures are underestimated.

2) Na/K Geothermometry

$$K(T) = \frac{/Na^+/}{/K^+/}$$

- A.J.Elis : $T7 = \frac{908}{0.700 + \log\frac{Na}{K}} - 273.15$ (7)

-R.O.Fournier: $T8 = \frac{1217}{1.483 + \log\frac{Na}{K}} - 273.15$ (8)

- A.H.Trusdell: $T9 = \frac{856}{0.857 + \log\frac{Na}{K}} - 273.15$ (9)

-Arnorson : $T10 = \frac{933}{0.993 - \log\frac{Na}{K}} - 273.15$ (10)

Where: Na and K are expressed in mg/l; T is expressed in °C.

Table 3: Water Temperature estimated and measured from the northern part of Algerian sahara (Ghardaia).

Locality	Na	K	T7	T8	T9	T10	T Measured
Bouheraoua	242	9	-106,512	-77,865	-120,454	-521,556	34,2
Bensmara 1	198	10	-91,819	-62,975	-107,400	-554,646	33 ,4
daia Ben Dahoua	229	8,2	-108,166	-79,563	-121,928	-517,994	34,8
Berriane 2	137	12,5	-54,574	-26,652	-74,596	-652,237	34 ,2
Laroui	155	17,7	-36,101	-9,355	-58,476	-709,652	46,2
Guerrara :Laameyed	232	19,1	-62,108	-33,841	-81,199	-630,692	46,4
Zelfana 1	315	11,5	-107,324	-78,698	-121,178	-519,802	46,2
Zelfana 8 fedj Enaam	252	10,8	-100,010	-71,236	-114,670	-535,869	33.6

This geothermometry is generally used to estimate the high temperatures at great depths. After the application of the four geothermometer Na/K on the whole, it notes that these geothermometer give temperatures clearly superior to those calculated by the geothermometer silica where sometimes they exceed 100°C.

3) Na-K-Ca Geothermometry

This geothermometry is applicable for the waters rich in calcium and whose temperatures calculated by the geothermometry Na/K , The equation is used:

- Fournier et Trusdell

$$T11 = \frac{1647}{\log\frac{Na}{k} + \beta\left(\log\frac{\sqrt{Ca}}{Na} + 2.06\right) + 2.47} - 273.15 \qquad (11).$$

Where Na, K, and Ca are expressed in mg/L, T is expressed in °C. We try β = 4/3; if the temperature found is greater than 100°C, it resumed the calculation with β = 1/3.

Table 4: Water Temperature estimated and measured from the northern part of Algerian sahara (Ghardaia).

Locality	Na	K	Ca	T11	T measured
Bouheraoua	242	9	180	101,024	34,2
Bensmara 1	198	10	163	114,309	33 ,4
daia Ben Dahoua	229	8,2	160	97,023	34,8
Berriane 2	137	12,5	97,2	183,244	34 ,2
Laroui	155	17,7	133	218,618	46,2
Guerrara :Laameyed	232	19,1	164	234,107	46,4
Zelfana 1	315	11,5	163	157,342	46,2
Zelfana 8 fedj Enaam	252	10,8	133	157,085	33.6

<u>β = 4/3</u>

Table 5: Water Temperature estimated and measured from the northern part of Algerian sahara (Ghardaia).

Locality	Na	K	Ca	T11	T measured
Bouheraoua	242	9	180	-20,334	34,2
Bensmara 1	198	10	163	-5,1605	33 ,4
daia Ben Dahoua	229	8,2	160	-22,369	34,8
Berriane 2	137	12,5	97,2	34,970	34 ,2
Laroui	155	17,7	133	53,790	46,2
Guerrara :Laameyed	232	19,1	164	33,778	46,4
Zelfana 1	315	11,5	163	-15,431	46,2
Zelfana 8 fedj Enaam	252	10,8	133	-8,264	33.6

<u>β = 1/3.</u>

This geothermometer effectively corrected often the extremely high temperatures characterized waters that are much diluted. The application of this geothermometer whole of the points (β = 4/3) in the study area; has given temperatures clearly superior to those measured but with β = 1/3 the values become closer.

IV. Conclusion

Now that we have all the information regarding , heat flux , thermal gradient ,depths of reservoirs and temperature thermal water , we confirm that thermal reservoirs of Intercalary Continental , in study area (Ghardaia), has relationship with principally depth of aquifers and thermal gradient , not with heat flux . The obtained results of measured thermal water are very satisfactory. In the south of Ghardaia (EL Golia) this due to the high correlation .In spite the high values of the heat Flux, Water temperatures measured remains low as well as the thermal gradient, however, that the depth of the reservoir of IC are also low, Against the NE in the study area , the depths are large match perfectly with the measured water temperatures deemed high, however, that the values of the heat flux remains low values but those obtained of thermal gradient are high . The soil temperature and heat flux, clearly shows that the geothermal energy potential is very important (batholiths, or a rock eruptive).
The origin of thermals is related to the geothermic gradient and depth of aquifers. Higher in the north, despite the values decreased at depths less than [2000] (m), however, to the east the reduced gradient and depths increase over [4000] (m). Why we think has an internal movement of warm waters through the existing of faults. It is necessary to develop a program for the development and optimization of the geothermal energy to the cantonal scale regional and in planning the operating techniques implemented in function of each context. This planning territorial energy is to coordinate with the other schedules

aimed guidelines the Sub-soil, including one concerning . Elevations values of conductivities, PH, dry residues, and mineralization in the north of study area perfectly match those of water quality in this part "central and northern study area, it indicate probably the arrivals of saturate water in chemical parameters (high mineralization) , define that (unstable area)" . can be explained only by brittle tectonics and the dense network of fractures promoting circulation of deep water., in the south against all parameters have low values and decrease with the flow direction of NW-S waters "(stable area)"

At the level of the basin of the Grand Erg Oriental, these tools have allowed in addition, to highlight globally and locally the following information:

The waters homogeneous and fossils of the intercalary Continental, dating back to the Pleistocene lower.

We think finally that geothermal potential characterize the north of area study and heat transfer is by convection process, also that probably the heat biathlete is not far from the surface and very related with instable tectonics (Trias and farm) that we will profoundly presented in another study.

Finally, taking into account the challenges and opportunities offered by the exploitation of the deep geothermal, it appears as a priority to begin at the faster geological and geophysical studies of the deep sub-soil, drilling of exploration including, in order to integrate as soon as possible the exploitation of geothermal resources of great depth in the cantonal planning.

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