



Geochemical assessment of thermal water in Bouhanifia aquifer system: suitability for touristic therapeutic treatment

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Received: 3 June 2020 / Accepted: 24 June 2022 / Published online: 15 July 2022
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Abstract

The touristic balneology is an essential source to promote the economy of the region. Our study aims to identify the geochemistry, the typology and the nature of the thermal waters of Hammam Bouhanifia, a geochemical and bacteriological study was carried out in the region, 13 sources were studied. The geochemical analysis results show a high mineralization of the waters (EC varies between 1.28 and 3.26 mS/cm); high-temperature variation (26 to 65 °C) indicates a high depth emergence. The geochemical classification of waters by the piper diagram shows typical Ca–Mg waters with a dominance of sulphates. All the water points have good bacteriological quality with the exception of source No. 6, which may indicate an infiltration of domestic discharges. The thermal reservoir of Hammam Bouhanifia may represent an important source of geothermal energy in Algeria in addition to its role in the development of thermal tourism in the western region of the country.

Keywords Spring sources · Hammam Bouhanifia · Touristic balneology · Geochemical · Economy

Introduction

Thermal water can be defined as gushed fluids with a temperature relatively high than air. Several studies have carried out in the last ten years to characterize the geothermal systems worldwide (Dib 1985; Rezig 1991; Bouchareb-Haouchin 1993; Kedaid and Mesbah 1996; Thomas and Tellam 2006; Coetsiers et al. 2008; Abdelkader et al. 2012; Bouchareb-Haouchine et al. 2012; Makni et al. 2013; Kemboi 2015; Mokadem et al. 2015; Belhai et al. 2016; Hamed et al., 2017; Besser et al. 2018; Bagheri et al. 2020; Benmarce et al. 2021; Khiati et al. 2021); the importance of works about geothermal systems show its importance in economic (Therapy, Holidays, touristic activities) and also

it can be used to generate geothermal energy (Dincer and Ezzat 2018).

Chemical parameters of groundwater are influenced by geological formations, atmospheric precipitation, inland surface water, and geochemical processes as they are in contact with the rock and the various anthropogenic activities (Burger and Čelková 2003; Yangui et al. 2011; Saravanan et al. 2015). Groundwater geochemistry provides valuable information to determine the origin, transit time, flow patterns and water regimes (Li et al. 2010; Hoque and Burgess 2012; Peterman et al. 2016), geological structure, and mineralogy of aquifers, as well as hydrogeochemical processes. Their monitoring is essential to design preventive measures for human health (Salcedo et al. 2017).

Algeria counts 282 thermal sites according to Statistics conducted in 2015; 61% of them are in the north of the country and 39% of them are in the south of the country. More than 282 hot Springs sources are identified in Algeria, Principally located in 24 districts: Setif, Guelma, Khenchla, Mila, Biskra, Ain Timouchent, Blida and Ain Defla, Saida, Tissemsilt, Djelfa, El Oued, Mascara, Tlemcen and Oran.

The Mascara region was characterized by the existence of many thermal sources. The majority of them has a geothermal signature with variable temperature at surface; achieve in some site 70 °C. our study focused on the Hammam

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Bouhanifia located in the West part of district of Mascara in the west of Algeria.

The aim of this study is the characterization, classification thermal waters existing in the region of Bouhanifia and its suitability for therapeutic purposes which promote tourism activity and economy in Bouhanifia.

Materials and methods

Study area

Bou Hanifia is located in southeast of Mascara (West of Algeria). It houses a very famous hydrothermal touristic complex “Hamam Bouhanifia” whose origin dates from Roman Civilization. The region is located in the west of Algeria at $35^{\circ} 18' 58''$ North and $0^{\circ} 02' 54''$ west. The region was characterized by an annual average temperature of 18°C and an average annual precipitation of

408 mm in the period 2006–2015 (ONM 2015). The study site region was showed in the map of Fig. 1

Geology

The Bouhanifia region has a verity of geological sedimentary deposits (Fig. 2); The Lower marine Miocene around Bouhanifia, the outcrops of the Lower Miocene are limited to the North by a substantially East–West fault passing north of the village, marked out by the northern slope of Rkhamoun el Kebir and Ain Tizi. To the south of this accident, the lower marls outcrop widely. The Continental Miocene it is An important continental series follows the lower marine Miocene.

The Upper marine Miocene (Tortonian-Sahelian) the facies is less clayey-marly than in the lower Miocene it includes: conglomerate and basic sandstone; blues Marl are mainly developed in the North in the downstream part of the basin. In the south, the sandy facies becomes predominant. Also Sand of 'EL BORDJ in north of Mascara. The sandy facies is superimposed on the blue marls in the

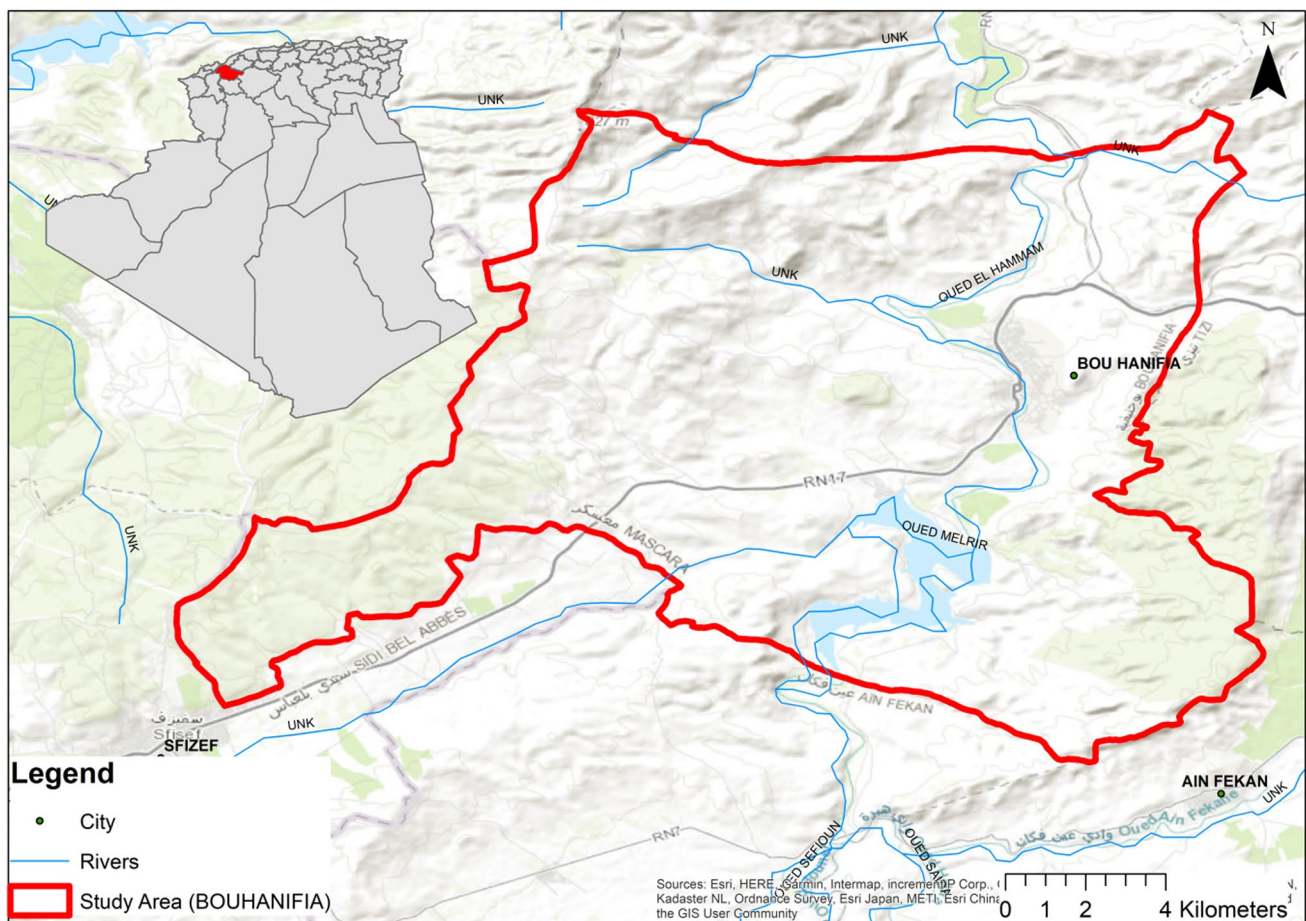


Fig. 1 Study area

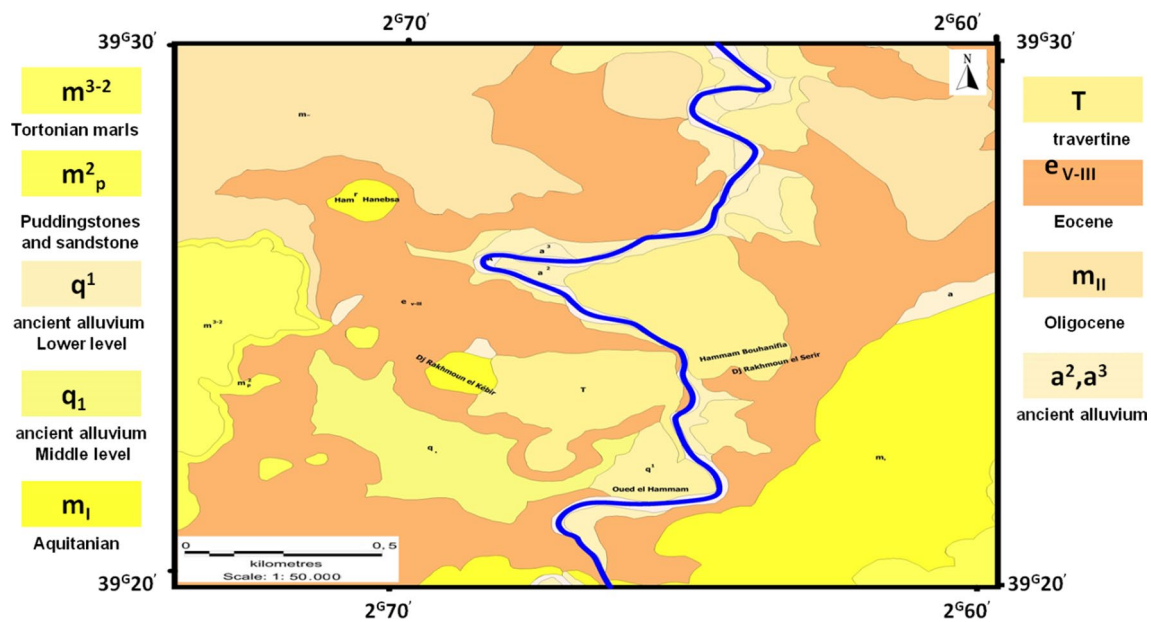


Fig. 2 Geology of study area

form of fine yellowish sands, with past marls and intercalations of Lithothamnium limestones. The Pliocene Shreds of coarse Pliocene sandstone are found to the south or southwest of Bouhanifia, while lacustrine limestone outcrops to the east on the edge of the plain of Ghris. The Quaternary alluviums include old alluviums which occupy large areas, 5–60 m above the current bed of Oued el Hammam: sands and clays with pebbles, silts and lenses of gravel, coarse sandstone tuffs and puddings, a 20-m of terrace constitutes the old alluvium (high terrace); a low terrace formed of silts. Large deposits of travertine ("limestone onyx") form two massifs on either side of the village of Bouhanifia they were deposited by the thermal springs in connection with the fractures affecting the region, and obstruct more or less ancient griffins.

Sampling and analysis methods

Thirteen (13) spring source samples were collected, for geochemical and bacteriological water analysis. Samples were filtered using filter membrane of 0.42 µm and have been acidified using polyethylene sterile bottles of 500 ml. samples were tacked in the period of May 2016.

Temperature, electrical conductivity (EC), and pH measurements were conducted on-site using portable PCE instrument of type PEHD-multi-parameters (Fig. 3). Major



Fig. 3 PCE instrument of type PEHD-multi-parameters

ion analyses (for Na⁺, K⁺, Ca²⁺, Mg²⁺) were measured by atomic absorption spectrophotometry, while SO₄²⁻ concentrations were determined by spectrophotometry and alkalinity was determined using standard titration techniques. Cl⁻ was analyzed using the AgNO₃ titration method. The bacteriological analysis is based on the determination of Aerobic germs, coliforms, fecal coliforms and fecal streptococci using microbiological procedures. Analysis of samples

Table 1 Field measured parameters

ID	Source name	T °C	PH	EC (ms)	Longitude	Latitude
1	Source De L'abattoir	41.3	6.98	2.32	35.314956	-0.050915
2	Ain Baraka	49.6	6.58	2.42	35.315551	-0.050848
3	Ain Hamia	53.7	6.50	2.48	35.317514	-0.050819
4	Ain Oued	52.4	6.46	2.35	35.318046	-0.0509
5	Ain Sakhra	45.8	6.17	2.50	35.318564	-0.051164
6	Ain Karma	47.1	6.50	2.41	35.318758	-0.051431
7	Ain Sid Moussa	26.9	7.32	2.37	35.322227	-0.056304
8	Ain Hammat	52.8	6.19	3.26	35.340766	-0.105562
9	Source N:06	42.4	6.76	2.52	35.314375	-0.05012
10	Source Du Pont	51.6	6.65	1.88	35.314886	-0.050912
11	Source N:03	65.6	6.44	2.44	35.316577	-0.048389
12	Ain Boukhanfour	49.2	6.60	2.34	35.316168	-0.050741
13	Source Du Palmier	64.5	6.40	2.35	35.316152	-0.049161

Table 2 The statistic summary of in-situ parameters

Parameters	CD (mS/cm)	T °C	PH
Max	3.26	65.60	7.32
Min	1.88	26.90	6.17
Mean	2.43	49.45	6.58
Sdv	0.28	9.50	0.30
CV	0.12	0.19	0.05

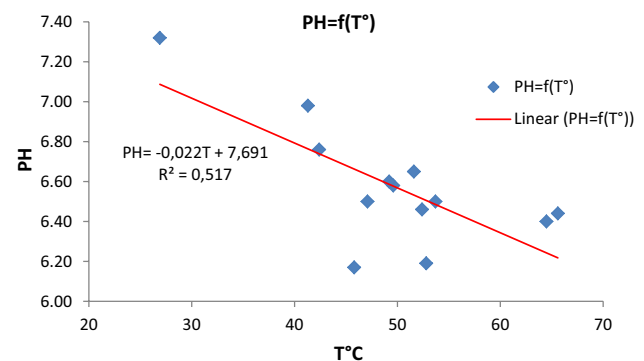
was conducted in the laboratory of FERTIAL Company of Annaba (Algeria).

Results and discussion

Field measurements such as Temperatures (in °C), pH and electrical conductivity (EC, in mS/cm), are listed in Table 1.

The Table 2 show the statistic summary of the principle field measured parameters.

The water samples show heterogeneity in their chemical and physical features. Temperature range from 26.90 °C measured in Ain Sidi Moussa to 65.60 measured in Source N°03. Variation coefficient is about 19%. Based on the nature of the hydraulic head in the underlying aquifer at the point of discharge, Bouhanifia sources have a Gravity springs type because it emerges under unconfined conditions where water table intersects land surface. The descending

**Fig. 4** Relation between Ph and temperature of Hammam Bouhanifia Spring sources

sources can also identified by function of the temperature (Kresic and Stevanovic 2010). The air temperature of the region is about 18 °C. The temperature of spring sources is great than 18 °C, this indicates a hot spring source type.

PH is expressed by the equation $pH = -\log [H_3O^+]$; values range from 6.17 to 7.32, lower values correspond to the source of Ain Sakhra, higher value is correspond to the source of Ain Sidi Moussa.

A good correlation was founded between the PH and the temperature of spring sources samples ($R^2 = 0.547$); it seems depend to the mineralization process occurred at the depth

Table 3 Geochemistry of Bouhanifia spring sources

No.	Nom	HCO ₃ ⁻ mg/l	NO ₃ ⁻ mg/l	Cl ⁻ mg/l	Na ⁺ mg/l	K ⁺ mg/l	Mg ⁺⁺ mg/l	Ca ⁺⁺ mg/l	SO ₄ ²⁻ mg/l
1	De l'abattoir	8.20	0.58	344.00	229.40	25.21	48.95	154.80	141.00
2	Ain baraka	8.40	0.69	324.00	226.70	24.20	47.61	151.80	133.00
3	Ain hamia	8.80	0.48	318.00	223.70	24.00	45.65	159.00	182.00
4	Ain oued	8.40	0.62	262.00	224.20	23.93	45.42	159.50	191.00
5	Ain sakhra	8.40	0.47	280.00	228.20	24.20	47.12	164.70	188.00
6	Ain karma	8.80	0.55	276.00	225.60	23.84	46.99	165.10	162.00
7	Ain sid moussa	8.40	0.80	294.00	234.30	22.31	54.44	177.90	152.00
8	Ain hammat	12.00	0.96	322.00	333.30	44.22	60.91	213.80	322.00
9	Source N:06	6.80	0.54	290.00	237.70	23.69	64.03	166.10	241.00
10	Source du pont	7.20	0.63	270.00	224.80	23.54	44.86	154.50	136.00
11	Source N:03	8.40	0.65	268.00	218.90	22.84	43.78	166.30	228.00
12	Ain boukhanfour	8.20	0.65	262.00	225.60	23.84	46.67	152.30	187.00
13	Du palmier	8.40	0.64	258.00	218.50	23.08	44.16	160.20	134.00
Statistic summary	Max	12.00	0.47	344.00	333.30	44.22	64.03	213.80	322.00
	Min	6.80	0.96	258.00	218.50	22.31	43.78	151.80	133.00
	Mean	8.49	0.64	289.85	234.68	25.30	49.28	165.08	184.38
	SDV	1.15	0.13	27.27	28.92	5.50	6.22	15.66	51.94
	CV	0.14	0.20	0.09	0.12	0.22	0.13	0.09	0.28

In bold is the maximum values measured

of aquifer. The Fig. 4 shows correlation between temperature and pH.

pH has a great importance in the precipitation of CaCO₃ (Kimblin 1995; Ali Rahmani and Chibane 2022). The PH describes the physical condition of mineralization processes occurred in the aquifer, its value depends on many factors like temperature, Concentration of dioxide of Carbone.

Water samples conductivity expresses a high mineralization of the water which indicates an important hardness of spring sources. The summary statistic of measurement shows that the high electric conductivity is about 3.26 mS/cm corresponding to the sources of Ain Hammat, low value was observed in Source du Pont with 1.88 mS/cm.

The geochemical analysis results are shown in the Table 3. The results show homogeneity of the chemical composition of all spring sources; this means the same course during the recharging process. According to previous geological work, show that none of the different geological units studied feeds the thermal springs of BOU-HANIFIA. Indeed spring sources have a deep origin and

must be fed by the Jurassic or the Cretaceous, the rise of thermal waters being facilitated by the large faults which limit the Eocene in the South.

Piper plot (Fig. 5) shows that spring sources have a Ca–Mg type with sulfate dominance which indicates a contact with calcite and dolomite rocks. The variation coefficient of geochemical parameters (CV < 28%) of these waters illustrates the same domain of spring sources or the same origin.

Figure 6 illustrates the plot of Wilcox (2d plot in function Na% in function of electric conductivity).

According to Wilcox plot (Fig. 6), all water samples are of good quality except the sample (Ain hammat) is situated in poor water quality area.

Figure 7 shows a spatial variation of electric conductivity (EC).

Values of EC are high in the North-west; values are low in the southeast. This variation is controlled by the geologic settings of the area.

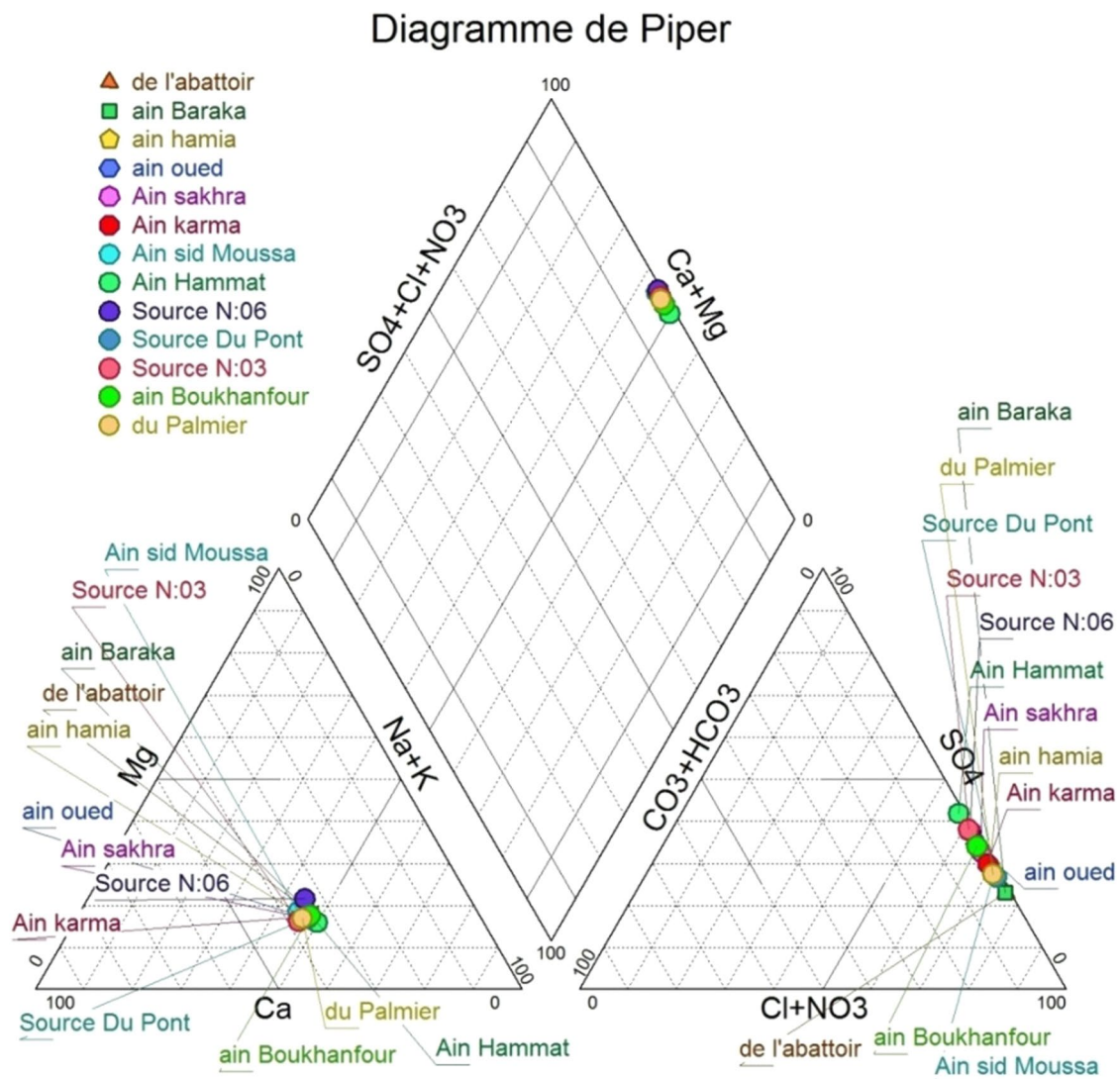


Fig. 5 Piper plot show the geochemical classification of water samples

Figure 8 shows the spatial variation of temperature of the spring sources.

The high temperature is observed in the extreme North-West, and in the southeast; this explained by the existence of fault in emergence of spring sources from high depth.

The Bacteriological quality of spring sources is shown in Table 4.

The results confirm the bacteriological safety of all water samples except one sample (Source N°6). This spring source may be influenced by the return flux of domestic water in the river; also we can explain this by the existence of septic tanks in the region.

Conclusion

The hot spring of the area of study forms a good thermal potential in the region. The geochemistry and bacteriological quality of Bouhanifia thermal sources have been carried out in this study. All measured sources show water of Ca-Mg type with dominance of sulfate species. The existence of sulfate is suitable in the thermal sources in case of touristic balneology. Bacteriological analysis shows the safety of spring sources, except the spring source N°06 which is marked by the presence of 93 coliforms. It is due to the infiltration of some urban and domestic water. The spring sources of the region are good for therapeutic uses. For a future prospection and amelioration

Fig. 6 Wilcox plot show water quality in function of conductivity and sodium %

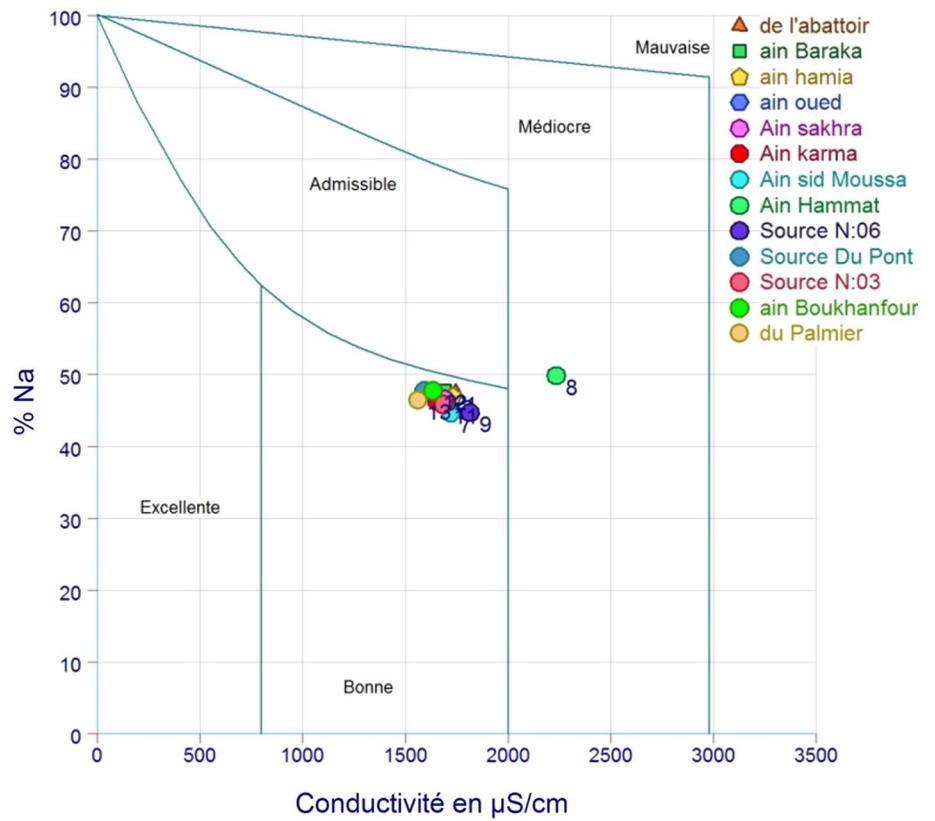


Fig. 7 Spatial variation of electrical conductivity in spring sources

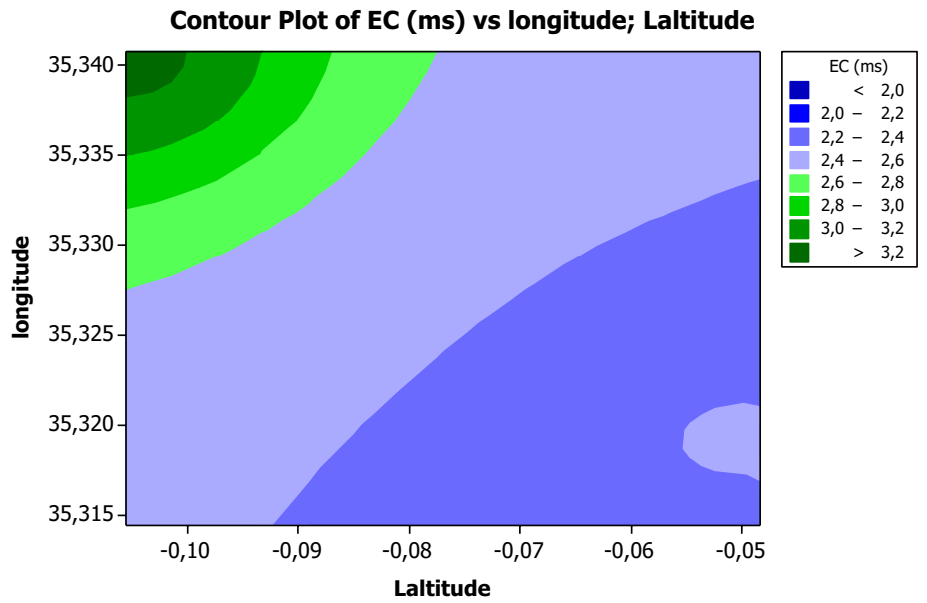
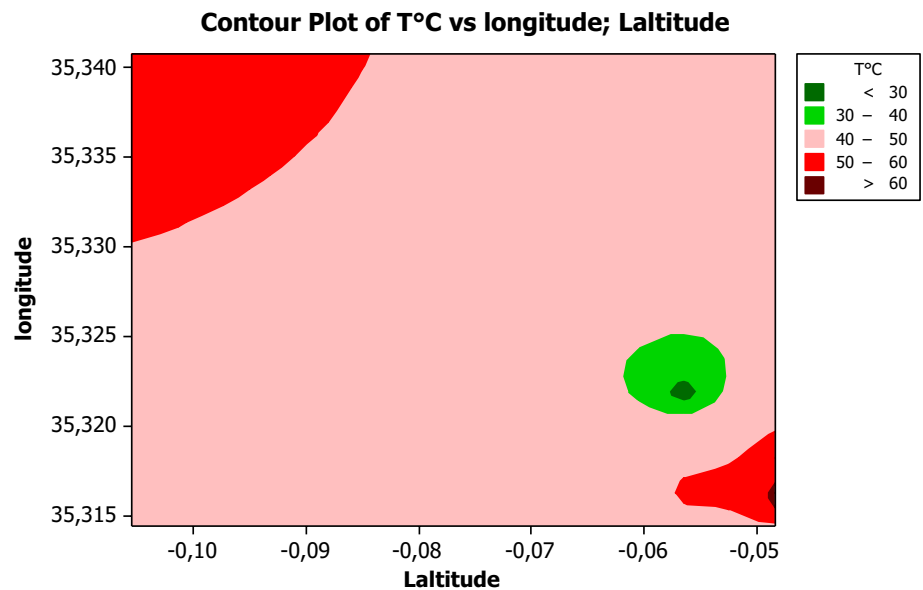


Fig. 8 Spatial variation of temperature**Table 4** The results of bacteriological analysis of spring sources samples

Sources name	Temperature	Aerobic germs	Coliforms	Fecal coliform	Fecal streptococci	Clostridium sulphito reducers
Standards	25 °C	20	< 10	Absence	Absence	Absence
Les palmiers	60.1 °C	11	Absence	Absence	Absence	Absence
El.amel	64.9 °C	10	Absence	Absence	Absence	Absence
Source N°3	66.9 °C	3	Absence	Absence	Absence	Absence
Source N°6	44.3 °C	25	93	Absence	Absence	Absence
Source du pont	51.2 °C	10	Absence	Absence	Absence	Absence
Boukhanfour	–	0	Absence	Absence	Absence	Absence
Source N°2	–	0	Absence	Absence	Absence	Absence

of our knowledge about the thermal reservoir of Bouhanifia, we propose an isotopic study (^{18}O , ^2H , ^3H and ^{14}C) to determine the origin of this water and evaluate their relative age. This thermal potential can also serve to be a very important source of geothermal energy to be explored and developed for clean energy.

Funding Not applicable in our paper.

Availability of data and material Data are provided on paper.

Code availability Not applicable in our paper.

Declarations

Conflict of interest The authors declare no conflict of interest.

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