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Impact of thermal water on environment: case study of Mila and Guelma region, Algeria

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ABSTRACT

A hydrochemical characterization of the waters of the study region (North-East Algeria) was carried out following samples taken at 36 thermal springs and their effluents during May 2022. The analysis of the waters allowed to establish the chemical facies and their classification according to the Stuyfzand's method and to deduce the aptitude of these waters for irrigation and the risks of salinity. The results revealed physico-chemical characteristics, relatively, variable. Q-mode cluster analysis was applied to the thermal water, generated four (4) groups clusters. Group1 represent a group of waters with low salinity dominated by Na-HCO_3; Stuyfzand's classification indicated that the waters are fresh-brackish with moderate to moderately high alkalinity. Taking into account the classification of Richards; we were able to identify the presence of the C3S1 class for the majority of the stations. The C3S1 class designates waters that can be used without any particular control for the irrigation of crops that are moderately tolerant to salts. These waters have average EC values of 3,616.3 µS/cm allowing their use in a less restrictive way for irrigation. Potential environmental effluents from the thermal spas could pollute both irrigation and drinking water, which represents a danger to the health of the region's inhabitants.

1. Introduction

In Algeria, more than 282 springs have been identified in the North, of which more than 50% are located in NE Algeria. The emergence temperature varies between 30°C and 96°C. The highest temperature is located in Guelma (Hammam Debagh). These resources would generally come from geothermal reservoirs of Mesozoic age of limestone and sandstone type. At depths between 1,500 and 2,500 m (Kedaid, 2006), their temperatures at depth can reach 120°C, and a relatively high geothermal gradient occurs in the north-east of Algeria (about 50°C) (Kedaid, 2006). The so-called high-energy geothermal resources are characterized by a temperature higher than 150°C and are mainly used for electricity production. The medium and low energy geothermal resources are characterized by a temperature between 30°C and 150°C and are intended for housing heating (60°C to 80°C), heating of greenhouses, fish farming, etc. The geothermal resources in Algeria are of low energy type.

The geothermal exploitation program in Algeria saw its beginnings with Ville (1852) and his research on rocks, waters, and mineral deposits in the provinces of Oran and Algiers. Bails (1888) followed with a notice on thermal and mineral springs in the department of Oran. Hanriot (1911) collaborated with Dr. Trolard on "The mineral waters of Algeria." Pouget and

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Chouchak (1923, 1926) conducted a detailed study on the radioactivity of Algerian waters in the provinces of Oran, Algiers, and Constantine. Guigue (1940, 1947) published works on the main thermal springs of Algeria, focusing on geochemistry within the geological map of Algeria. Other notable contributions include the works of Cornet (1964), EURAFREP (1966) with the participation of Cormy and Demians d'Archimbaud (1970), Jacqmin, Facca (1966), Marinelli, and Tonani under the direction of SONATRACH. In 1974, Dr. B. Laissoub (1974) explored thermalism in Oranie, while in 1982, the Italian company ENEL collaborated with SONALGAZ to assess geothermal energy potential in the northern and eastern regions. The geothermal studies in the initial phase mostly focused on Algeria's northeast. The Center for Renewable Energies of Algeria (CDER) continued the geothermal work beginning in 1983, and the program was expanded to include the entire northern region of the country (Dib, 1985; Rezig, 1991; Bouchareb, 1994; 2012; Issaadi, 1992; Kedaid, 2006; Dib, 2008; Fekraoui, 2010; Saibi, 2009; Belhai et al., 2016; Belhai et al., 2017; Foued et al., 2017; Djemmal, 2018; Kouadra et al., 2018).

The exploitation of geothermal energy remains very limited in view of the existing geothermal potential. Balneology is the main use, except some cases in the south of the country. The physico-chemical characterization is very important to study the suitability of thermal waters for consumption and irrigation. In the thermal spas, thousands of visitors bathe, some people drink the thermal water without any pre-established restrictions during the therapeutic period. However, regarding the drinkability and physico-chemical quality of the water, the thermal waters of the study area according to the WHO guidelines (2006) are not safe for consumption because the samples are hard and the cations and anions exceed the WHO standards. The wastewater discharged from spas directly to environment may have a negative impact on land and groundwater. In this case, the health of the local inhabitants may be endangered.

By this time, no study has mentioned the subject of pollution by hydrothermal effluents. Due to this situation, we were compelled to initiate this study in order to evaluate the health condition of the streams subsequent to engaging in such activities, to understand the hydrochemistry of thermal waters in particular the management of these water resources in a sub-humid environment with semi-arid influences. The impact of these discharges on surface water was evaluated by taking water samples from the thermal spring itself, upstream and downstream of these discharges. Several approaches are used to assess the degree of water contamination in this study. Two of these studies are field survey and laboratory analysis done for the assessment of the degree of contamination.

2. Geological and Hydrogeological Settings

Our study region concerns the North-Eastern part of Algeria. It includes the wilayas of Mila and Guelma. The northern part of Algeria presents a very complex geological framework. The study area is located within the Tellian domain, which is a part of the Maghrebide chain. This chain spans over 2000 km, extending from Calabria (Italy) in the east to the Strait of Gibraltar in the west. It forms a segment of the Alpine peri-Mediterranean orogen, dating back to the Tertiary period, as described by Delga in 1969. The geological formations in this region are diverse, ranging in age from the Triassic to the Quaternary. These geological formations have undergone various tectonic phases, notably neotectonics, which have shaped the current geological structures and contributed to the presence of thermal springs. The Guelma Basin is qualified as a pull-apart basin created between two overlapping east-west dextral strike-slip faults. On the margins of this basin in pull-apart (Maouche et al., 2013), there is a series of N-S to NNW-SSE trending normal faults that intersect the subparallel shear faults (Delga, 1969; Meghraoui, 1988; Vila, 1980). The study area is a depression filled with Miocene (clays and gypsum marls) and the Quaternary (heterogeneous alluvium in the form of a terrace) deposits. These alluvial deposits, often very permeable and above all very thick, constitute an important source of water supplied by the infiltration of rainwater and by the lateral contributions of the Seybouse watershed. The infiltrations lead the surface waters to the deeper levels, which form the base of the watershed of a very important thermal reservoir in the study area and the neighboring areas (Bouaicha et al., 2019). The Mila basin lithostratigraphically reveals water deposits with great hydraulic potential constituted essentially by the fissured and/or karstified carbonate formations of the Néritique Constantinois, formed by massive limestones of the Jurassic and limestones and marlstones of the Cretaceous, the pénitellienne series and the nappe de Djemila geological formation. The Constantine Neogene Basin is represented in the Mila area mainly by Neogene detrital and evaporitic deposits. The Triassic deposits injected along the tectonic faults or outcropping in the form of diapirs have a direct influence on the geochemical facies of warm waters (Figure 1).

The study area is defined by sub-humid climate with a semi-arid influence to the south, with variable precipitation in time and space. Guelma is characterized by an average annual precipitation of 675 mm/year. The annual temperature varies between 2.5°C (in January and February) and 34°C (in July and August). Hydrographically, the study area is characterized by a relatively dense hydrographic network composed essentially by Oued Seybouse and its main effluents Bouhamdane, Oued Chenior and Oued El Hammame. But Mila, the average annual precipitation of 600 mm and temperatures that are close to 40°C in summer and that fall below zero in winter. A significant hydrographic network characterizes the region, with Oued Rhumel merging with Oued Endja to create Oued El Kebir. Other notable watercourses include Oued Cotton, Oued Seguen, Oued Bouslah, and Oued Smendou, along with dams such as Hammam Grouz and Beni Haroun Dam. These dams have a combined capacity of 960 million m^3 and provide water supply to the neighboring cities, namely Constantine, Batna, Khenchela, Jijel, Mila, and Oum El Bouaghi.

3. Materials and Methods

3.1. Sampling and Analysis

The prospecting of grounds led us to choose 36 stations (Figure 2) distributed in a way to cover the

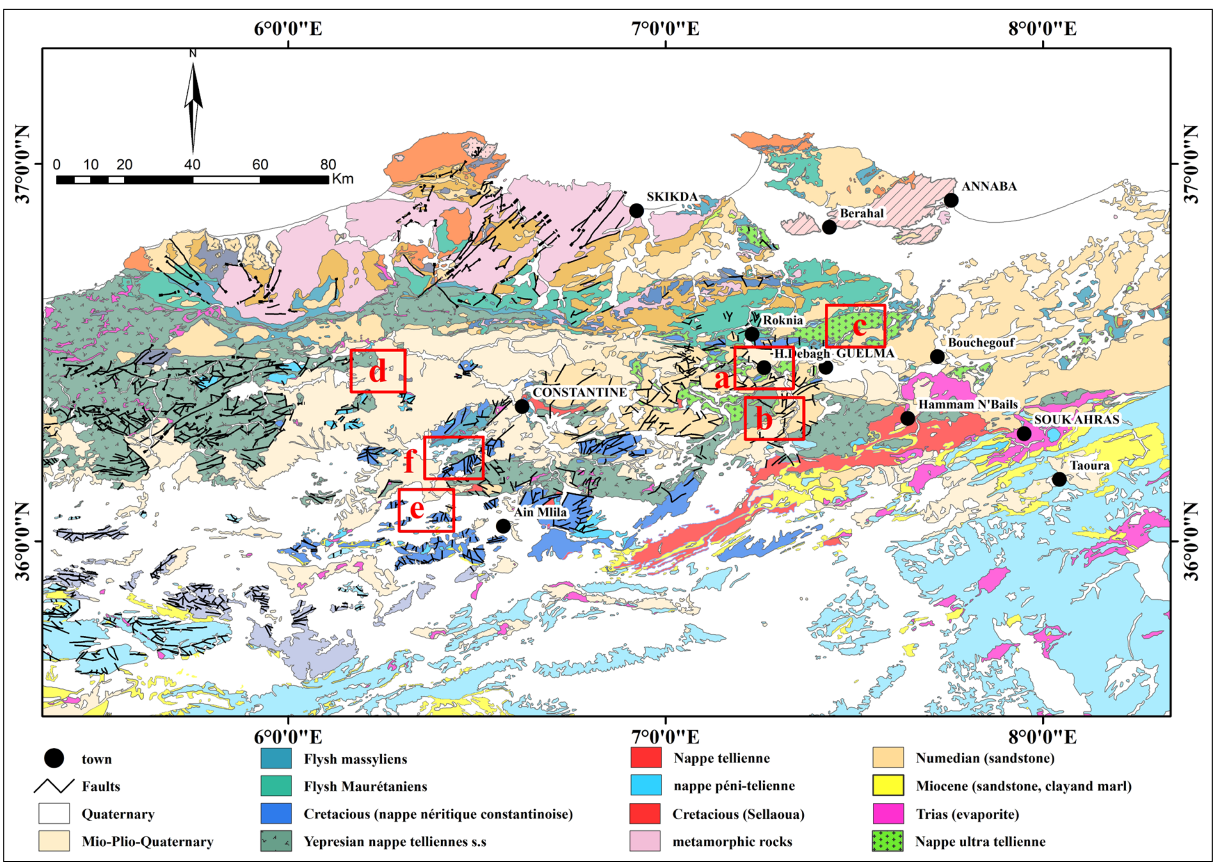

Figure 1- Geological maps of northeastern Algeria, with sampling sites; a) Chellelacomplexe, b) Guerfa, c) Ouled Ali, d) Beni Guechat, e) Teleghma, f) Hammam Grouz (Vila, 1978).

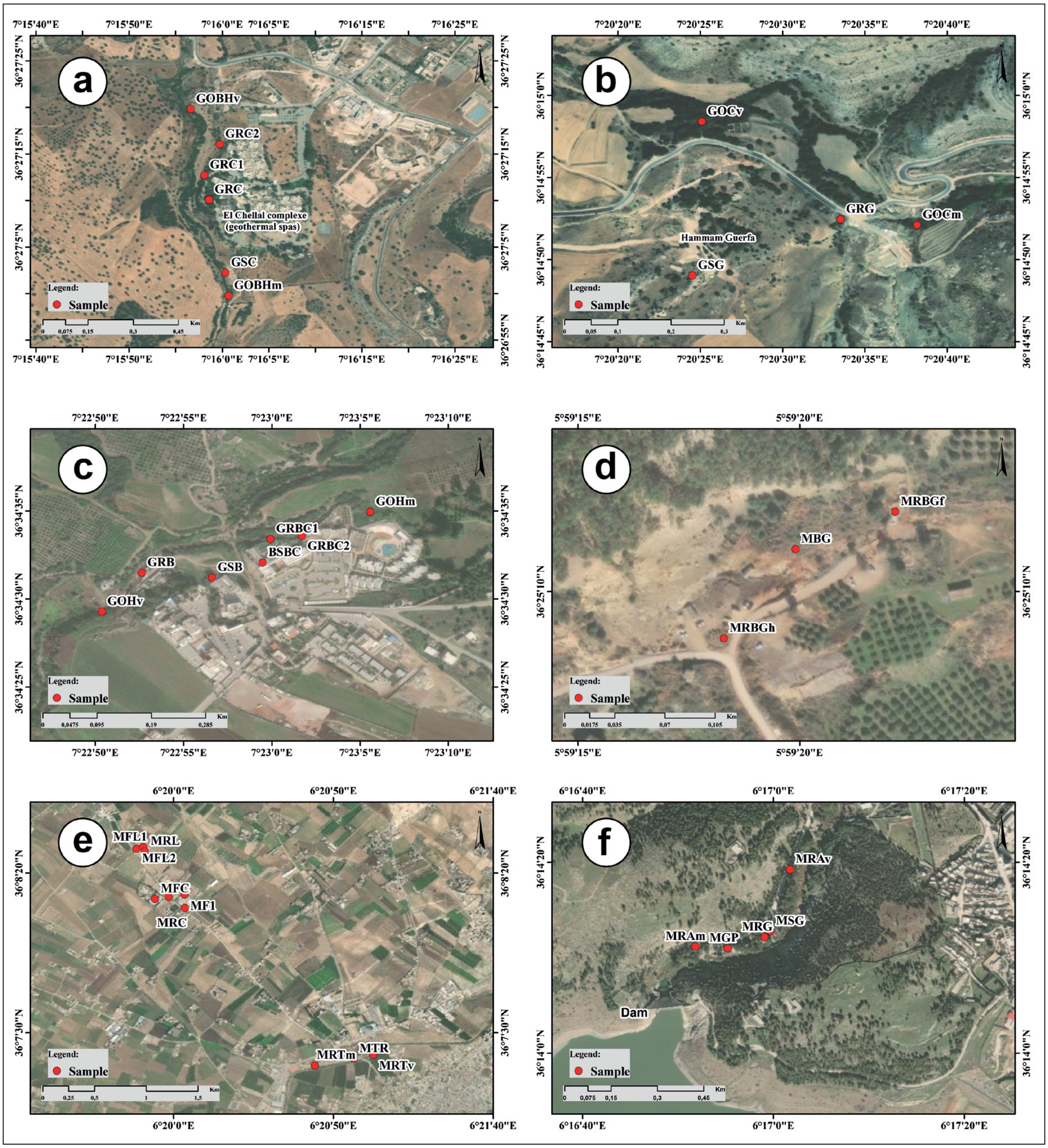

Figure 2- Map shows sampling sites; a) Chellela complexe, b) Guerfa, c) Ouled Ali, d) Beni Guechat, e) Teleghma, f) Hammam Grouz.

thermal areas characterized by a strong recrudescence of curists or tourists during the year (especially the period September - May). This generates important quantities of waste water (effluents of the hydrothermal stations or Hammam). These effluents are wasted without preliminary treatment.

The sampling was carried out during the month of May 2022. We have four types of water to analyze (thermal source, discharges of thermal complexes and upstream and downstream of wadis). It was carried out after rinsing the bottles with distilled water three times and placed in polyethylene bottles and stored in a cooler at a temperature of 4°C (APHA, 2005). Hydrogen potential (pH), electrical conductivity (EC), temperature (T°C), and dissolved oxygen (DO) were measured in situ using a multiparameter apparatus type AZ 86031 Combo Water Meter-T°/pH/EC/DO (Taiwan). Thereafter the samples were transported to the laboratory for the analysis of chemical parameters such us: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), carbonate (CO_3^{2}), bicarbonate (HCO_3^{-}), nitrate (NO_3^{-}), nitrite (NO_2^{-}), total hardness (TH) and biochemical oxygen demand for 5 days (BOD_5). Ca^{2+}, Mg^{2+} and TH are based on complexometric titration. There concentrations are measured by a standard solution of Ethylene-Diamine-Tetracetic-Acid (EDTA), which is a complexing agent. For CO_3^{2-} and HCO_3^{-} the volumetric method was also used but with the help of a 0.1N hydrochloric acid solution. Chlorides are determined by a titrated solution of silver nitrate in the presence of potassium chromate. Sulfates and nitrites were determined by a spectrophotometric method (spectrophotometer DR/2000) and Na^{+} by a flame photometer. The BOD_5 is measured with a BOD meter type BSB-Controller Modell 1020T, for 164ml of sample we add 3 capsules of NaOH, incubation for 5 days in the dark, the result is multiplied by the factor 10 in mg/l.

3.2. Statistical Analysis

3.2.1. Cluster Analysis

Hierarchical Cluster Analysis (HCA) is a strong classification tool based on dissimilarities between the objects desired for classification. This unsupervised statistical technique is largely used by scientists on hydrogeochemistry to classify water samples according to their similarity to each other (Alther, 1979; Williams, 1982; Farnham et al., 2000; Meng and Maynard, 2001; Alberto et al., 2001; Belkhiri et al., 2010; 2011; Foued et al., 2017; Bouaicha et al., 2019; Boutreraa, 2019 and Barkat et al., 2021). Q-mode HCA was used to distinct hydrochemical groups by classify water sample involving Ward's method (Ward, 1963) with Euclidean distance as a measure of similarity. All 15 hydrochemical parameters measured (pH, T°, EC, OD, DHT, Mg^{2+}, Ca^{2+}, Na^{+}, HCO_3^{-} , CO_3^{2-} , SO_4^{2-}, Cl^{-}, BOD_5, NO_3^{-} and NO_2^{-}) were utilized on the normalized data set to carry out the HCA.

3.2.2 Factor Analysis

As a multivariate analysis technique, factor analysis is used to reveal the latent structure of a data set of variables, which may explain observed variance in uncorrelated variables called factors (Brown, 1998). Factor analysis shows the common variance of variables and allows searching inter correlation among the variables. Factor analysis can be applied to any type of scientific data in order to establish a model of variation by reducing large sets of variables into factors allowing easy manipulation and interpretation. The extraction of latent factors can be done by several methods and the most commonly used is the principal components PC. The total number of PCs extracted and ranked in order of merit using this multivariate technique, denotes the total number alternative source of variation in the data. The first PC or factor present the highest Eigen value (Eigen vector sum) and explains essential variance of data set, whereas the last PC or factor contributes with least important variance. Factor loadings represent correlation coefficients between the variables and the factors, and terms high, moderate, and weak are used to factor loadings with absolute loading values: > 0.75, 0.75-0.50, and 0.50-0.30 respectively (Liu et al., 2003).

3.3. Hydrochemistry Process

The hydrochemical methods of characterization and classification of water used in this study are based primarily on the Piper diagram (Piper, 1944) and the Stuyfzand classification (Stuyfzand, 1989). The Piper diagram is used to represent the cationic, anionic and global facies. The Stuyfzand classification is used to determine the main type, type, sub-type and class of chemicals. Each of the four levels of subdivision contributes to the total code of the water sample. The main type is determined based on chloride. Water are classified as oligohaline (G), oligohaline-fresh (g), fresh (F), fresh-brackish (f), brackish (B), brackish-salt (b), salt (S) and Hypersaline (H). The type is determined by alkalinity index (HCO_3^{-} concentration). The classification of sub-types is determined by the prevailing cations and anions. The class is determined from the sum of Na^{+}, K^{+} and Mg^{2+} based on Stuyfzand's Equation (1) which calculates the Basic Exchange Index (BEI).

$$BEI = Na^{+} + K^{+} – 0.8768\ Cl^{-} \qquad \text{(Equation 1)}$$

3.4. Water Salinity

The qualitative parameters used, in addition to electrical conductivity (EC), to assess groundwater

Table 1- Evaluation equation of quantitative parameters.

Parameter	Equations
$Na^+\%$	$Na^+\% = Na^+ + K^+ / (Na^+ + K^+ + Ca^{2+} + Mg^{2+}) *100$ Equation 2
SAR	$SAR = Na^+ / \sqrt{} (Ca^{2+} + Mg^{2+})/2)$ Equation 3
MAR	$MAR = Mg^{2+} / (Ca^{2+} + Mg^{2+})$ Equation 4
PI	$PI = Na^+ + \sqrt{}HCO_3^- / (Ca^{2+} + Mg^{2+} + Na^+)*100$ Equation 5
RSC	$RSC = [(HCO_3^- + CO_3^{2-}) – (Ca^{2+} + Mg^{2+})]$ Equation 6

quality for irrigation purposes are outlined in Table 1. These are sodium percentage (Na^+ %), Sodium Adsorption Rate (SAR), Magnesium Adsorption Rate (MAR), Permeability Index (PI), and Residual Sodium Carbonate (RSC). The total soluble salt concentration determined by EC affects the choice of irrigation water. Plant growth can be negatively affected by high salinity. The Na^+% was evaluated by equation 2 (Raghaunth, 1989). The calculation of this percentage allows evaluating the potential degradation of the soil structure and the alteration of its properties (Eaton, 1950). An excess of sodium (Na^+ % > 80) can also cause toxicity in some plants. The SAR was determined by equation 3 (Wilcox, 1953). The MAR ratio (equation 4) highlights the importance of magnesium for the soil and the plant. It is considered an indispensable element when the MAR is less than 50. Otherwise, this chemical element becomes harmful (Raghaunth, 1989). The PI was calculated by equation 5 (Doneen, 1964). Three classes were obtained. The first two classes with a maximum of 75% deduce a good suitability of water for irrigation. The third class below 25% where the water is unsuitable for irrigation. The CSR highlights the abundance of carbonates and bicarbonates. In case it exceeds 1.5meq/l can harm the soil fertility.

4. Discussions

4.1. Hydrogeochemical Characteristics

The distribution of thermal springs in north-eastern Algeria is strongly influenced by the geological and hydrogeological characteristics of the region. In particular, this distribution coincides with the main structural features and reservoirs represented by the region’s Jurassic and Cretaceous carbonate and Triassic formations.

The hydrochemical evaluation of the spring waters shows that the temperatures measured at the emergence are not representative of the real temperature of the reservoir. A possible cooling of the thermal waters may occur in several ways such as the movements of deeply-circulated hot waters, Joule-Thomson effect during degassing, heat exchange between water and surrounding rocks, and mixing with cold waters (Bouaicha, 2018). The conductivity of waters depends on the amount of ions. The values of conductivity are high in places. This is related to the easy solubility of evaporite-rich Triassic formations. For the main elements, calcium may have two main origins. They are dissolution of carbonates or gypsum. Magnesium comes from the dissolution of magnesium-rich carbonate rocks. Sodium is related to the rapid dissolution of evaporitic formations. For bicarbonates, they result from the dissolution of limestone rocks, which are the main geothermal reservoirs in the study area. Chlorides are generally related to the lithological nature of the different geological formations. So that evaporates remain the main source. In general, the waters rich in chlorides are rich in sodium as well. Sulfates are the predominant element in the thermal waters of the study area and may have different origins. They are geological (dissolution of gypsum), biological (degradation of organic matter) or anthropic (discharges from thermal baths or use of pesticides).

The summary of all the physico-chemical analyses are shown in Table 2. The analysis of the different physico-chemical parameters of the thermal waters showed a relative heterogeneity. The temperature varies between 16.6-65°C (effluent and thermal waters). Water is said to be thermal when its temperature at emergence exceeds the average annual air temperature (i.e. 4°C).

The temperatures of the thermal waters vary according to the geological conditions and the geographical situation. In Algeria, the hottest waters are those of Hammam Debagh with 96°C.

Table 2- Statistical Parameter values of the four principal water groups.

		T°	pH	EC	DO	TH	CO_3^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	Na^+	Cl^-	SO_4^{2-}	NO_2^-	NO_3^-	DBO_5
Group 1	**Mean**	33.9	7.82	1165	4.1	8.8	18.3	237.9	72.14	58.99	98.9	156.2	200	0.022	0.7	10
	Min	16.6	7.28	578	0.3	3.36	0	183	44.09	13.87	14.26	21.3	118	0.007	0.1	5
	Max	40.6	7.95	1835	20.1	14.32	36.3	469.7	144.29	91.11	199.14	276.9	480	2.68	4.6	29
	SD	10.02	0.24	462.13	8.31	3.40	13.29	95.97	34.87	26.54	73.62	123.77	132.56	1.00	1.60	8.79
Group 2	**Mean**	38.80	7.48	1214	4.40	8.30	0.00	255.59	78.16	56.32	116.18	157.98	278.00	0.02	0.55	14.50
	Min	29.70	6.50	1020	0.60	5.68	0.00	164.70	40.08	22.47	5.33	14.20	80.00	0.00	0.20	5.00
	Max	65.00	8.00	2300	21.00	13.20	12.20	318.42	176.35	110.30	363.40	351.45	462.00	0.20	1.40	25.00
	SD	8.45	0.36	384.29	4.21	2.11	2.49	48.32	33.06	20.90	83.08	101.52	102.49	0.07	0.44	5.47
Group 3	**Mean**	51.05	7.06	2315	1.05	19.94	0	278.77	109.02	173.87	84.285	214.775	671.25	0.008	0.3	12.5
	Min	41	6.45	2310	0.8	17.08	0	230.58	49.7	172.6	44.51	177.5	652.5	0.005	0.3	10
	Max	61.1	7.67	2320	1.3	22.8	0	326.96	168.34	175.14	124.06	252.05	690	0.011	0.3	15
	SD	14.21	0.86	7.07	0.35	4.04	0.00	68.15	83.89	1.80	56.25	52.71	26.52	0.00	0.00	3.54
Group 4	**Mean**	42.3	6.9	22,700	3	38.4	0	644.16	673.34	56.79	1,906.47	3,271.325	840	0.036	1.2	19
	Min	38	6.19	22,500	2	35.2	0	606.34	641.28	37.63	1,753.33	3,237.6	710	0.022	1.2	5
	Max	55.6	7	24,000	7	41.6	0	710.04	705.41	75.96	1,971.71	3,305.05	920	0.049	1.4	20
	SD	9.18	0.44	814.45	2.65	3.20	0.00	52.48	32.07	19.17	112.10	33.72	105.99	0.01	0.12	8.39

* All values are in mg/l except pH, T (°C), EC (µS/cm) and TH (meq/l).

*EC (electrical conductivity), DO (dissolved oxygen), TH (total hardness), carbonate (CO_3^{2-}) and biochemical oxygen demand for 5 days (BOD_5).

In Mila region, the Beni Guechat spring stands out as the hottest, reaching 56.1°C (Figure 2d). On the other hand, the Ain Tinn spring exhibits the lowest temperature, measuring at 32°C. The classification of waters according to Verdeil (1982) is given as follows, hyperthermal waters (T > 45°C), orthothermal waters (37°C< T < 45°C), mesothermal waters (22°C < 37°C) and cold waters (T <22°C).

55% of the springs (11 out of 36) are classified as hyperthermal and 45% of them are classified as orthothermal (Issaâdi, 1992). pH values vary between 6.19 and 8. This indicates a slightly alkaline character. Generally, the values of EC are high ranging between 758-24,000 µS/cm. According to Issaâdi (1992), the thermomineral springs of Algeria are grouped into four based on the electrical conductivity (EC) values as follows: class 1 (EC < 2,000 µS/cm), class 2 (2,000 < EC < 7,500 µS/cm), class 3 (7,500 < EC < 15,000 µS/cm), class 4 (EC > 15,000 µS/cm).

78% of the sampled waters have conductivities lower than 2,000 µS/cm. These waters are weakly mineralized. They are linked to carbonate reservoirs. While 13% have conductivities ranging between 2,000-7,000 µS/cm. These are generally mesothermal waters. Finally, 8% of the waters have conductivities higher than 15,000 µS/cm. These waters are strongly mineralized and are affected by evaporate formations and hydrothermal effluents.

Concentrations of the major elements vary from one element to another. The order of abundance of anions in the majority of samples is as follows: Na^+> Ca^{2+}> Mg^{2+}; and the order of abundance of cations is: SO_4^{2-}> HCO_3^-> Cl^-. The maximum concentrations of Ca and Na are 705.41 and 1971.71 mg/l. However, they are higher than their standards of the WHO (2006) which is 100 and 200 mg/l, respectively. The source of Ca may be related to the dissolution of gypsum formations ($CaSO_4.2H_2O$) or the dissolution of carbonate formations ($CaCO_3$). The average concentrations of sodium in the waters is 302.42 mg/l. The presence of bicarbonates in the waters is due to the geological nature of the reservoir (neritic limestone). Therefore, the dissolution of carbonates releases Ca^{2+} and HCO_3^- when the waters are enriched in CO_2 after being in contact with the atmosphere and the average content is 298.71 mg/l. The concentrations of anions such as Cl^-, SO_4^{2-} range between 14.2-3305.05 mg/l and 80-920 mg/l, respectively. 30% of Cl^- (250 mg/l) and 62% of SO_4^{2-} (250 mg/l) exceed the desirable limits (WHO 2006). The increase of SO_4^{2-} and Cl^- concentrations is the consequence of the dissolution of gypsum and halite minerals of the Triassic formations (diapirs area).

4.2. Cluster Analysis

The main ion concentrations were taken as normalized data. Hydrochemical groups were determined applying Q-mode clustering analysis (HCA), which is given as a dendrogram. HCA is performed by applying Ward's method of coupling with Euclidean distance for evaluating similarity of sample data. Four preliminary groups are chosen based on visual review of the dendrogram using pennon line (an imaginary horizontal line), each account for a hydrochemical facies.

- Group 1 represents a group of waters with low salinity (medium EC = 1,165 µS/cm) and surrender orders (mg/l) $Na^+ > Ca^{2+} > Mg^{2+}$ and $HCO_3^- > SO_4^{2-} > Cl^-$ (Figure 3). The dominance of HCO_3^- and Na^+ (Figure 4**)** is closely tied to the aquifer's lithologic nature and also untreated effluents of hydrothermal complexes (Chellela, Bouchahrine and Teleghma) (Figure 2a, c and e).

- Group 2 is dominated by sulfate, bicarbonate and sodium. Chloride is also present with an important concentration (medium Cl^-=157.975 mg/l). This group has an electrical conductivity about 1,214 µS/cm and can be observed in south, west and north of Guelma (Chellala and Ouled Ali) (Figure 2a, c) and in southeast of Mila (Hammam Grouz and Teleghma) (Figure 2f, e). All the thermal sources come out along the lines of the fractures of the carbonate formations.

- The water type group 3 has an EC of 2,315 µS/cm and is dominated by sulfates and magnesium but also contains a significant concentration of chloride. This group characterizes the thermal spring of Guerfa. Guerfa thermal spring comes out through cracks in limestone massifs owing to fault or fold marked of presence of black marl and gray clays with occasionally reddish gypsum with conglomerates. During the last earthquake, the water gushed out with a red color (clay particles) for a few days, which indicates that the emergence is through an active zone on soft formations (gypsum to conglomerates).

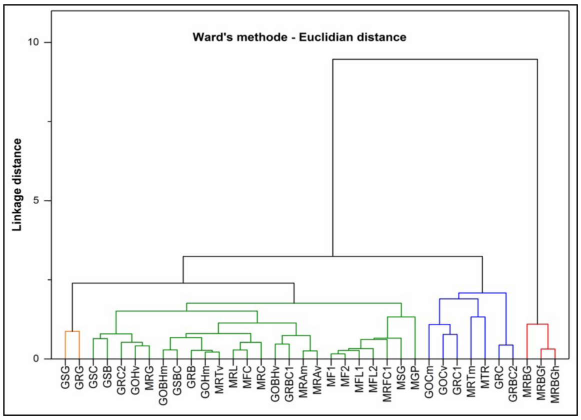

Figure 3- Dendrogram of cluster analysis.

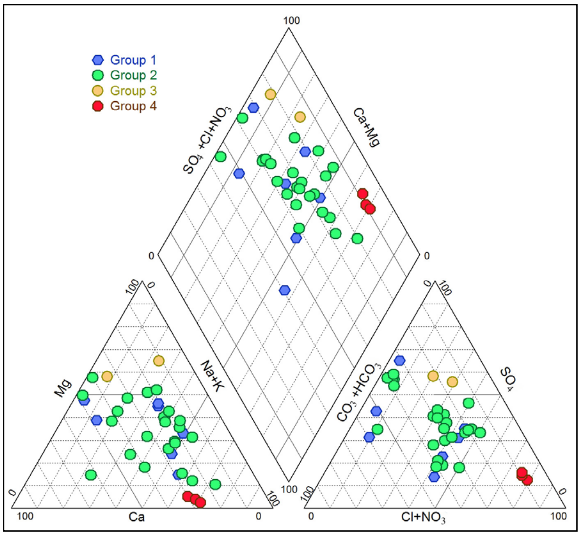

Figure 4- Piper diagram.

- The group 4 water type characterizes thermal source of Beni Guechat (Figure 2d) in the northern sector of Mila. Water of this group is very highly mineralized (22,700 µS/cm). Cl^-, Na^{2+} and SO_4^{2-} are the most dominant ions (Figure 4), which indicate that water spring facies is very strongly influenced by water-rock interaction by leaching of the evaporate formations. The high Na and Cl^- contents insinuate the dissolution of chloride salts. During hot weather, crystals of salts (NaCl) (Figure 5) precipitate around the emergence after evaporation of these waters.

4.3. Factor Analysis

Pertinence of the data for FA was monitored using Kaisere-Meyere-Olkin (KMO) and Cronbach's alpha tests. The value of KMO and Cronbach's alpha were

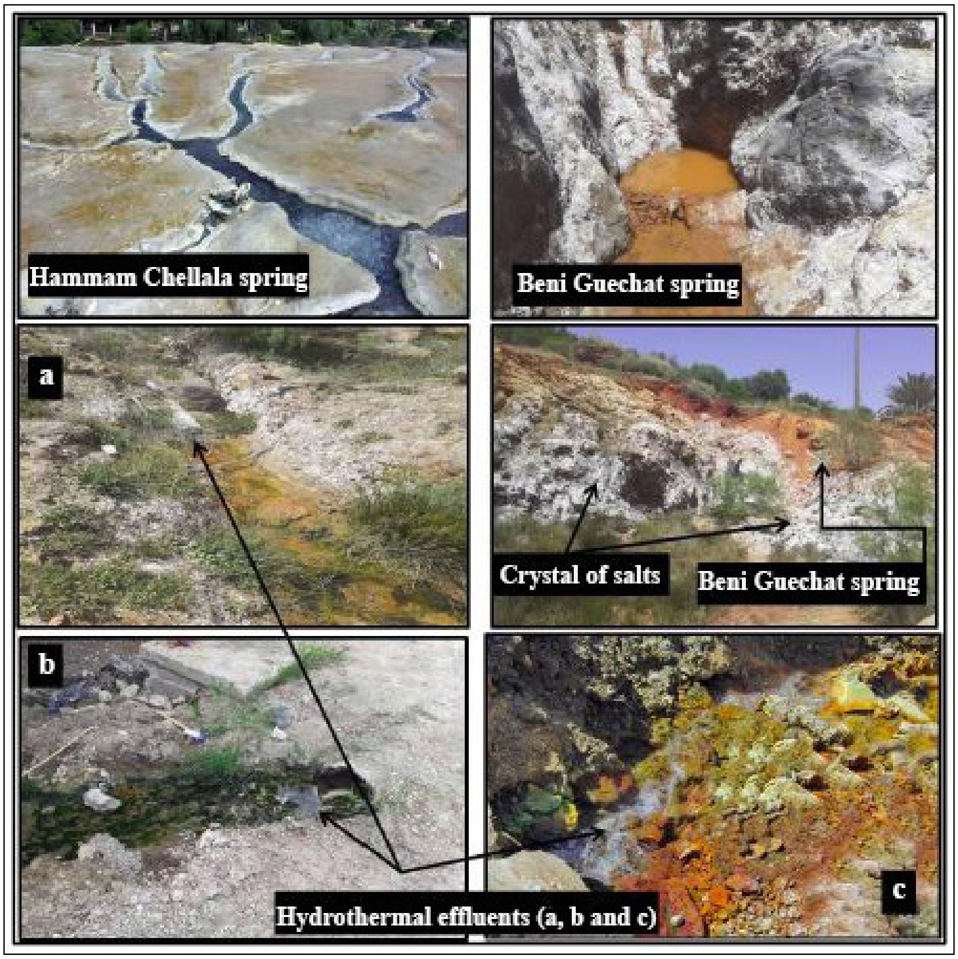

Figure 5- Hot springs and their effluents.

0.61 and 0.7 respectively. Therefore, these tests show that the sampling is appropriate for factor analysis. Based on the Kaiser criterion (Kaiser, 1960), four factors were extracted and rotated using the varimax normalization. These factors explain 76.91 % of the total variance (Table 3) is quite good and enough to explain sources of variation in the hydrochemistry. On the other hand, the communality, which is the portion of variance well explained by the factors for each variable, was > 0.5 for all variables. This indicates that all variables can be used for the FA.

Factor 1 explains about 45.26 % of the total variance, had high positive loadings for EC, TH, HCO_3, Ca^{2+}, Na^+, Cl^- and SO_4^{2-}. These loadings suggest that the observed pattern is likely a consequence of interactions between minerals and water.

Factor 2 accounts for 14.37% of the total variance and have high positive loadings for Mg^{2+} and moderately negative loading for BOD_5. These can be related to the anthropogenic activities.

Factor 3 represents about 10.58 % of the total variance. This shows high positive loadings for CO_3^{2-} and moderately absolute loading for DO, pH and T°. This indicates that the temperature has no influence on dissolution of carbonate minerals. The variables of NO_2^- and NO_3^- contribute strongly to the factor 4. This explains 6.69 % of the total variance and is probably related to anthropogenic activities such as sanitation activities and the agricultural practice.

4.4. Hydrochemical Classification

According to the chloride contents, 7 samples (19.44%) present a main type of oligohaline-fresh (low salinity; code g, Cl^- <0.141 meq/l), 5 samples present a fresh type, 2 samples present a brackish type, 3 samples brackish salty and the majority

Table 3- Scores of factor analysis of the physico-chemical parameters.

Parameter	F1	F2	F3	F4
T°	0.1862	0.5513	**-0.5565**	-0.2485
pH	-0.5015	-0.2236	**0.5969**	-0.0931
EC	**0.9828**	-0.0244	-0.1023	0.0181
DO	0.0206	0.0304	**0.6537**	-0.1118
TH	**0.9430**	0.2701	-0.1039	-0.0469
CO_3^{2-}	-0.0888	0.0113	**0.7788**	0.0244
HCO_3^-	**0.9046**	-0.1137	-0.1600	0.1060
Ca^{2+}	**0.9852**	0.0045	-0.0734	-0.0289
Mg^{2+}	0.0064	**0.8272**	-0.1052	-0.0601
Na^+	**0.9740**	-0.1161	-0.0640	0.0279
Cl^-	**0.9760**	-0.0542	-0.0872	0.0381
SO_4^{2-}	**0.8126**	0.3371	0.0207	-0.2183
NO_2^-	-0.1125	0.1003	-0.0350	**0.8316**
NO_3^-	0.1513	-0.3101	-0.0580	**0.7642**
BOD_5	0.0042	**-0.6552**	-0.0573	0.0093
Eigen value	6.7891	2.1563	1.5880	1.0041
Variance (%)	45.2606	14.3753	10.5866	6.6943
Cumulative variance (%)	45.2606	59.6359	70.2225	76.9168

presents (19 samples) 52.78% a main type of fresh brackish water of code f (Table 4). Based on the average chemical elements, the water subtypes are characterized by a dominance of Cl^-, SO_4^{2-} and Na^+. The concentrations of HCO_3^- of 16 samples range between 2-4 meq/l (44.44%), of 3 samples range between 8-16 meq/l and of 17 samples (47.22%) range between 4-8 meq/l. The alkalinity of all these samples are moderate to moderately high ranging between 2-16 meq/l (code 2, 3 and 4). This is originated from the dissolution of gypsum and/or limestone. According to the Stuyfzand classification, waters revealed a class in surplus of code (+) (high concentrations of K, Na and Mg), these concentrations are thought to originate from the processes of dissolution of the evaporates (Triassic undergrounds surrounding).

4.5. Suitability of Thermal Waters for Irrigation

The evaluation indices of the suitability of thermal waters in the study area for irrigation are reported in Table 5. The results of Na^+% showed that 7 sampling locations have excellent water quality, 13 sampling locations represent Good quality; 11 sampling locations represent Permissible quality and 5 sampling points report Doubtful quality (Figure 6).

The calculation of MAR shows that all the sampling locations have concentrations lower than 50 (i.e. acceptable class). Therefore, the water samples are classified as usable for irrigation.

The PI values show 3 classes, of which the majority 30 (83.33%) of the 36 water points have good water quality, the RSC values are low, not reaching 1.25 meq/l for all of the examined water samples.

EC reflect that the thermal waters of our study area, the majority (72.22%) have a permissible class, except for the region of Guerfa, Grouz and Oued Bouhamdane (Figure 2a, b and f) have a Doubtful quality. Additionally, Hammam Beni Guechat (Figure 2d) demonstrates unsuitable water quality due to its high salinity levels, which are likely to have a detrimental impact on the soil and plants.

Regarding the risk related to sodium, the waters are characterized by a SAR below 10 presenting a minimal risk of Na^+ accumulation. 3 samples present a high risk of alkalization. This shows that the waters may affect the permeability and cause infiltration problems.

Based on the US Salinity diagram (Figure 7) by Richards in 1954, we classified the thermal waters

Table 4- Stuyfzand classification.

	Classification level	Code	Number of samples	In %
Principal type	**[Cl^-] (meq/l)**			
Oligohaline	<0.141	G	-	-
Oligohaline-fresh	0.141 - 0.846	g	7	19.44
Fresh water	0.846 - 4.231	F	5	13.89
Brackish fresh water	4.231 - 8.462	f	19	52.78
Brackish water	8.462 - 28.206	B	2	5.56
Brackish salt	28.206 - 282.064	b	3	8.33
Saltwater	282.064 - 564.127	S	-	-
Hyperhaline	>564.127	H	-	-
Type	**[HCO_3^-] (meq/l)**			
Very low	<0.5	*	-	-
Low	0.5-1	0	-	-
Moderately low	1-2	1	-	-
Moderate	2-4	2	16	44.44
Moderately high	4-8	3	17	47.22
High	8-16	4	3	8.33
Very High	16-32	5	-	-
Rather extreme	32-64	6	-	-
Extreme	>64	7	-	-
Classes	**IEB= $Na^+ + K^+ - 0.8768 * Cl^-$**			
Deficit of ($Na^+ + K^+ + Mg^{2+}$)	< 0	-	12	33.33
Equilibrate of ($Na^+ + K^+ + Mg^{2+}$)	= 0	0	-	-
Surplus of ($Na^+ + K^+ + Mg^{2+}$)	> 0	+	24	66.67

in the study area based on salinity and SAR. Most of the waters (group 2 and majority of group 1) are of acceptable quality (C3-S1). However, some water points in Guerfa (group 3) (Figure 2b) and Oued Bouhamdane (Figure 2a) are classified as doubtful quality (C4S2). Beni Guechat (group 4) (Figure 2d) has unsuitable water quality. Overall, the waters have relatively low SAR, making them suitable for irrigating salt-tolerant crops on well-drained soils. Salinity levels need to be monitored.

Figure 6- Direct discharge of effluents heavily loaded with minerals and surfactants into the valley without pre-treatment.

The Wilcox (1955) diagram based on Na^+% and conductivity shows that most of the samples fall into the category of good to permissible water except for group 4 (unsuitable for irrigation) and group 3 (doubtful quality) (Figure 8). According Bremond and Vuichard (1973), water is difficult to use for irrigation as soon as it exceeds 1,500µS/cm. The level of irrigation water quality always depends on the soil type and the crops grown (Rodier, 2005).

5. Results

Physico-chemical parameters and hydrochemical techniques were used to describe the quality of the thermal waters used for irrigation in the study area. The study was based on 36 water samples (springs, discharges and wadi). Q-mode cluster analysis was applied to the thermal water quality datasets and generated four groups of clusters (groups 1, 2, 3 and 4). Group 1 represents low salinity and Na^+-HCO_3^- partition orders. Group 2 is dominated by sulphate, bicarbonate and sodium. Chloride is also present in significant concentrations. Group 3 is dominated by sulphates and magnesium. However, they also contain significant concentrations of chloride. Group 4 is characterized by the thermal spring of Beni Guechat.

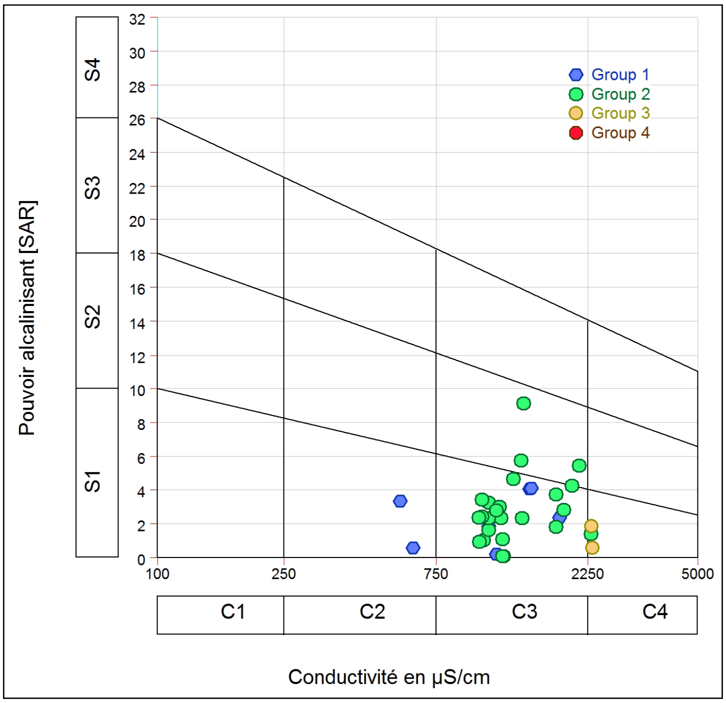

Figure 7- Classification of irrigation water using the Richards SAR method.

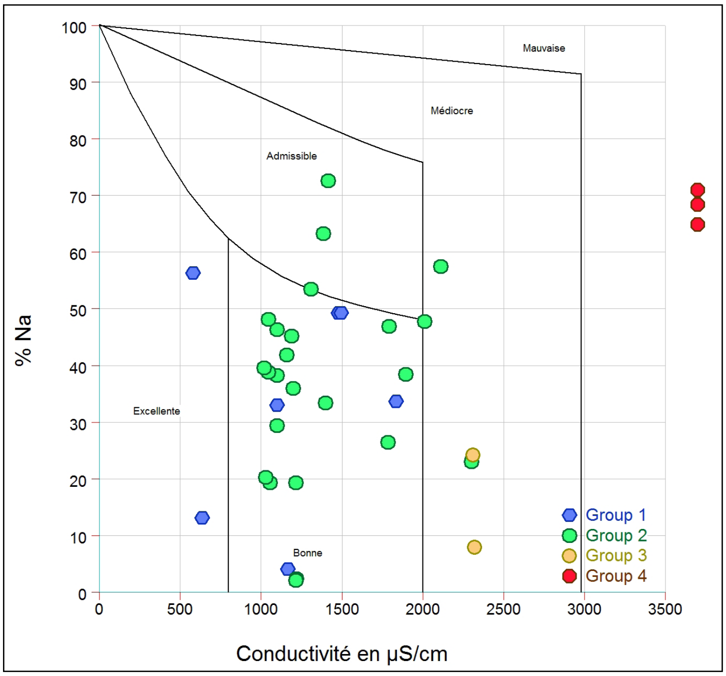

Figure 8- Wilcox Diagram for thermal waters.

Table 5- Suitability of thermal waters for irrigation according to the different classification indices.

Na^+ % (meq/l)	Class	Number of samples	In %
<20	Excellent	7	19.44
20-40	Good	13	36.11
40-60	Permissible	11	30.56
60-80	Doubtful	5	13.89
>80	Unsuitable	-	-
EC (Ds/m)			
<0.25	Excellent	-	-
0.25-0.75	Good	2	5.56
0.75-2	Permissible	26	72.22
2-3	Doubtful	5	13.89
>3	Unsuitable	3	8.33
SAR (meq/l)			
2-10.	Low	18	50.00
10-26	High	3	8.33
>26	Very High	-	
MAR (meq/l)			
<50	Permissible	36	100
>50	Unsuitable	-	-
PI (meq/l)			
>75	Very Good	3	8.33
25/75	Good	30	83.33
<25	Unsuitable	3	8.33
RSC (meq/l)			
<1.25	Good	36	100
1.25-2.5	Doubtful	-	-
>1.5	Unsuitable	-	-

The samples of this group are heavily mineralized. Cl^-, Na^+ and SO_4^{2-} are the most dominant ions.

The Stuyfzand classification revealed that the waters are moderately to moderately high alkaline, refreshing brackish. The fundamental interactions between the fluids and the clay minerals are reflected in these classes. The distribution of the physico-chemical characteristics showed that the Triassic formations are located near the high levels of RS, Cl^- and Na^+, either near the discharges or downstream of the wadis. The analysis of water quality indicators for irrigation use showed that, overall, the waters can be used without special treatment during the irrigation of crops with moderate salt tolerance on well-drained or well-permeable soils.

Hydrothermal effluents are highly charged waters and discharged into the environment without prior treatment. To better assess this impact, it would be necessary to monitor its evolution in time and space. The work requires more in-depth field studies and specific protocols. The planned next study will deal with trace metals (TMEs) and surfactants in order to monitor and predict the impact of effluents on surface and groundwater.

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