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HYDROCHEMICAL ASSESSMENT OF THE QUALITY OF THERMAL MINERAL WATER FOR IRRIGATION: THE CASE OF HAMMAM MESKOUTINE (NORTHEAST ALGERIA)

HIDROKEMIJSKA OCENA KAKOVOSTI TERMOMINERALNE VODE ZA NAMAKANJE: PRIMER HAMMAM MESKOUTINE (SEVEROVZHODNA ALŽIRIJA)

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Abstract

This study was carried out to assess the state and quality of Hammam Meskoutine's thermal mineral water and its suitability for irrigation. To accomplish this, water samples from ten different thermal mineral springs were evaluated in February and June of 2016, respectively, in the region of Hammam Meskoutine in northeastern Algeria. The analyzed parameters are the water's physical and chemical characteristics (temperature, pH and electrical conductivity) as measured in situ, and the dosing of the major components (Cl^-, $SO4^{2-}$, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+) in the laboratory. Based on the chemical analyses, irrigation quality parameters were calculated, e.g. the sodium absorption ratio (SAR), the percent of sodium (% Na), residual sodium carbonate (RSC), permeability index (PI), and magnesium hazard (MH). The results showed the spring water there to be generally unsuitable for irrigation practices during the two sampling periods.

Keywords: Hammam Meskoutine, irrigation, residual sodium carbonate (RSC), sodium absorption ratio (SAR), water quality, thermal mineral water.

Izvleček

Namen te študije je bil ocena stanja in kakovosti termomineralne vode v kraju Hammam Meskoutine ter njene primernosti za namakanje. V ta namen smo februarja in junija 2016 analizirali vzorce vode iz desetih termomineralnih vrelcev na območju Hammam Meskoutine v severovzhodni Alžiriji. Opravili smo terenske meritve in analizo fizikalnih in kemijskih lastnosti (temperature, pH in električne prevodnosti), v laboratoriju pa določili vsebnost pomembnejših sestavin (Cl^-, $SO4^{2-}$, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+ in K^+). Na podlagi kemijskih analiz smo izračunali parametre kakovosti namakalne vode, npr. razmerje adsorpcije natrija (SAR), delež natrija (% Na), indeks preostalega natrijevega karbonata (RSC), indeks prepustnosti in nevarnost vsebnosti

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magnezija (MH). Rezultati so pokazali, da je izvirska voda med preučevanima obdobjema vzorčenja na splošno neprimerna za namakanje.
Ključne besede: Hammam Meskoutine, namakanje, preostali natrijev karbonat (RSC), razmerje adsorpcije natrija (SAR), kakovost vode, termomineralna voda.

1. Introduction

Most countries around the world have taken an interest in geothermal water as a suitable source of energy for industrial applications and heating (Lund, 2009). Water resources are set to be safeguarded as top agenda priorities (Derradji et al., 2004). There are a few countries in North Africa that suffer from a lack of water resources, such as Tunisia (Ahmed et al., 2012) and Algeria (Ouali et al., 2006), which have been using cooled geothermal water for irrigation purposes (PNUD/TUN, 1991).

In Algeria, more than 20% of irrigated soils are affected by salinity problems (Douaoui and Hartani, 2007). Irrigation with salt-rich water leaks into the sodium fixation in the soil's adsorbent environment. Thus, the salinization process has potential consequences for soil properties, such as its tendency to scatter clays, its degradation of the soil structure, loss of permeability, and asphyxiation of plants (Gouaidia et al., 2011). That is to say, for water to be usable, its concentration of Na must be less than 60%, which is the maximum allowable threshold for agricultural purposes.

The variety of agricultural practices and the establishment of many irrigation systems have affected water quality; specifically the excessive amounts of dissolved ions in irrigation water affects plants and agricultural soils physically and chemically by reducing their productivity (Hedjal et al., 2018).

The study area is an agricultural region, with a total agricultural area of 5087 hectares, of which 2884 hectares are not exploitable. Grain and legume crops occupy a large area, at 1420 hectares. It is noted that the irrigated area, which comprises about 17 hectares, has a smaller surface than the total agricultural area.

Meanwhile the non-irrigated area in the same region is around 80 hectares. Although the Bouhamdane dam is located at the northern side of the municipality, it does not concern the irrigation perimeter, despite being adjacent to the Bouhamdane valley, which is easily irrigable. To increase the irrigable area we proposed collecting hot water in reservoirs and transporting it to agricultural areas.

The use of geothermal water has increased opportunities for agricultural development (Hachicha et al., 2012). This study will highlight the use of the region's geothermal water for agricultural purposes. The study employed the methods of Richards (1954) and Wilcox (1948), which remain the most frequently used techniques in evaluating the risk of salinization and sodization.

2. Materials and Methods

2.1. Case study

Hammam Meskoutine is situated in the south of the city of Guelma (Figure 1). It is bound to the north by the cities of Annaba and Skikda, to the south by the cities of Oum-El Bouaghi and Souk Ahras, to the east by the cities of Souk Ahras and Eltaref, and to the west by the city of Constantine. The studied area is located in northeastern Algeria between the latitudes 36°36'00" and 36°27'00" north, and longitudes 7°12'00" and 7°24'00" east. The studied region's climate region is sub-humid, characterized by a rainy winter and a dry summer, with precipitation ranging from 500 to 600 mm/year, and temperatures varying between 10 and 30 degrees Celsius. The average annual evapotranspiration is on the order of 511 mm (Benamara, 2017). The population is 16,391 inhabitants (census 2008), with rudimentary economic resources that are limited mainly to tourism (hot spring baths of Hammam Meskoutine) and agriculture (vegetable growing, cereals, olive trees).

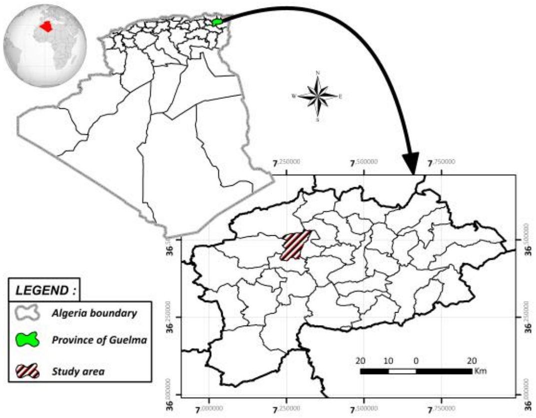

Figure 1: *Geography of the studied area.*

Slika 1: *Geografski prikaz območja preučevanja.*

2.2. Geology and Hydrogeology

The region of Hammam Meskoutine (Figure 2) belongs to the epi-Tellianaquifer (Bétier et al., 1937), which results from the southward thrust of the Jebel Debagh chain of Grar and Kef-Hahouner, where a substrate of Cretaceous limestone formed (Mansouri, 2009). There are several geological formations in the area, but the following are the four main ones in the study area.

- The Lower Cretaceous is represented by shale of Barremian age, and the Upper Cretaceous is characterized by shale dating back to the Albian and Cenomanian ages. These formations are found at the eastern end of the alluvial plain.

-The Upper Eocene and Oligocene were represented by flysch formations, with their usual sandstone and clay-sandstone facies. These formations are represented by sandstone and Numidian clay, covering most of Hammam Meskoutineat a thickness of 100 meters.

-The continental Miocene is represented by red powders with priabonian sandstone pebbles, Cretaceous limestone, and coarse sand, whose paste is vermilion red.

-The Quaternary includes marine formations (beach sand) and continental sedimentation (alluvial sandstone deposits, red earth, dunes, scree, alluvials).

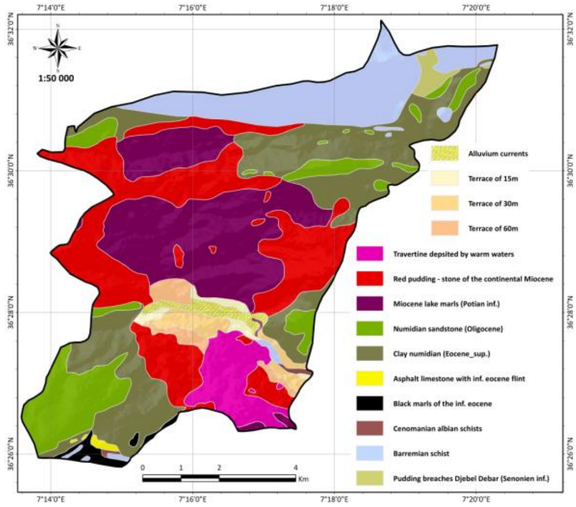

Figure 2: *Geological map of the study area (Deleau,1938).*

Slika 2: *Geološka karta območja (Deleau, 1938).*

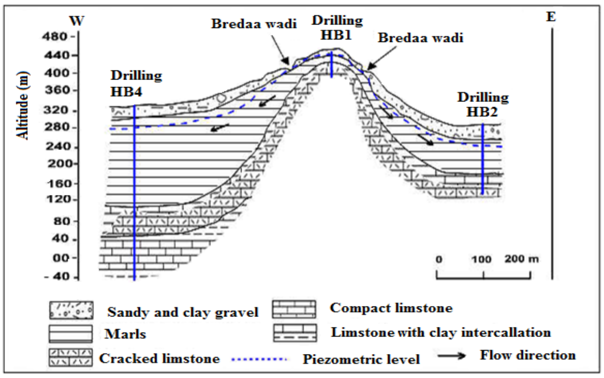

Figure 3: *Hydrogeological cross-section of the study area.*

Slika 3: *Hidrogeološki prerez območja.*

The hydrogeological context of Hammam Meskoutine mainly consists of three aquifers (Figure 3):

- The formations of the Mio-Plio-Quaternary cover comprise a superficial aquifer, which mainly groups together the old and recent alluvium from the various terraces.

-A second aquifer, corresponding to the heterogeneous formations of the Oligocene. These are the red pudding stones with Priabonian sandstone pebbles and an enormously thick layer of Numidian sandstone.

-A third, deeper aquifer corresponds to the carbonate formations of the Cretaceous.

It is in this last aquifer where the reservoir of the studied thermal springs is located.

2.3. Sampling and analytical techniques

The work involved assessing the irrigational quality of thermal mineral water from the 10 hot springs that make up the Hammam Meskoutine region. The water samples were taken during two periods (according to seasons): a low water period during the month of June 2016, and a high water period during the month of February 2016.

The coordinates of the various water stations were positioned using a Garmin Wap Global Positioning System (GPS) (62 STC 79946) (Figure 4).

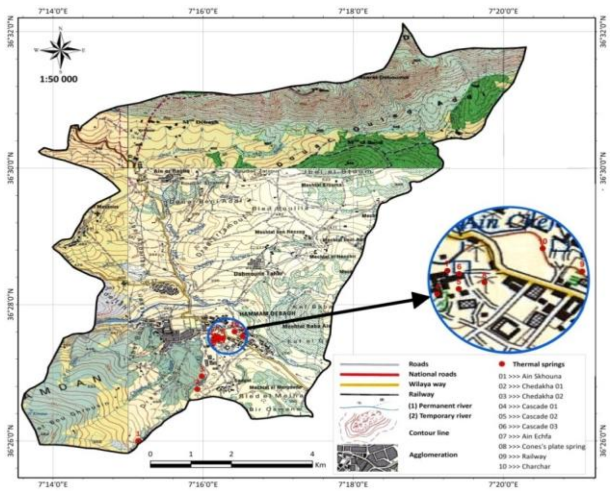

***Figure 4:** Sampling point location within Algeria.*

***Slika 4:** Lokacija točk vzorčenja, prikazano na karti Alžirije.*

2.4. Physical and chemical analytical methods

The water samples collected were stored in polyethylene bottles, washed in advance with distilled water, rinsed with the water to be analyzed, and then transported to the laboratory (Central ADE Laboratory of the city of Skikda) and analyzed on the same day. The measured physical and chemical parameters are as follows:

-Cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+})

-Anions (SO_4^{2-}, Cl^{-}, HCO^{-}_3)

The water's physical parameters (temperature, pH, and electrical conductivity) were measured in situ using a multi-parameter Type Consort C 65.

Concerning the major elements, the chloride content was determined by the Mohr method under neutral conditions using a standard solution of silver nitrate in the presence of potassium chromate (Rodier, 1982). Bicarbonate, calcium, and magnesium were affected by the titrimetry method (colorimetric method). Sodium and potassium are determined by the atomic absorption spectrophotometer (Malek et al., 2019).

To verify the analytical error of analyzed ion concentration, ionic balance was computed by following equation:

$$E = \frac{(\sum \text{Cations}-\sum \text{Anions})*100}{(\sum \text{Cations}+\sum \text{Anions})} \quad (1)$$

The sum of major cations and anions are expressed in meq/L, and **E** is the error in percent.

The ionic balances for the analyses vary between 5.22 and 9.7%. The analysis error of all groundwater samples was less than the accepted limit of ±10% (Hem, 1985), providing additional evidence for the data's veracity.

Water's irrigational capacity can be judged not only from its total salt concentration but also by the types of salts and ions that constitute it (Ayers and Westcot, 1985; Hedjal et al., 2018). It is therefore imperative to study the parameters that define the characteristics of the water destined for irrigation. These parameters include sodium adsorption (SAR), sodium percentage (% Na), residual sodium carbonates (RSC), magnesium hazard (MgR), and the permeability index (PI). Table 1 summarizes the most important parameters affecting the quality of the water intended for irrigation. The suitability of springs was analyzed based on a comparison of the obtained results and the evaluated indices with the classification suggested by various authors (Table 2).

Table 1: *Irrigation water quality parameters.*

Preglednica 1: *Parametri kakovosti namakalne vode.*

Parameters	**Equations**
Residual sodium carbonates	RSC = $(CO_3^-+HCO_3^-)-(Ca^{2+}+Mg^{+2})$ (meq/l) Eaton 1950
Sodium percentage	%Na = $[(Na^++K)/(Ca^{2+}+Mg^{2+}+Na^++K)]*100$ (%) Wilcox 1948
permeability index	IP = $[(Na^++\sqrt{HCO3})/(Ca^{2+}+Mg^{2+}+Na^+)]*100$ (%) Doneen, 1962
sodium adsorption	SAR = $Na^+/[Ca^{2+}+Mg^{2+})/2]^{1/2}$ (meq/l) Richards, 1954
Risk of magnesium	Mg.R = $[(Mg^{2+})/(Ca^{2+}+Mg^{2+})]*100$ (%) Paliwal, 1972

Table 2: *Classification of water quality for irrigation.*

Preglednica 2: *Klasifikacija kakovosti vode za namakanje.*

Quality	**Degree of Restrictions on Use**	**Electrical Conductivity (EC)**	**Sodium Absorption Rate (SAR)**	**Residual Sodium Carbonate (RSC)**	**Percentage of Sodium (% Na)**	**Permeability Index (IP)**
		Wilcox, 1955	Richards, 1954	Eaton, 1950	Wilcox, 1948	Doneen, 1964
Excellent	**None**	<250	0-10	<1.25	<20	>70
Good		250-750	10-18		20-40	25-75
Marginal	**Slight to Moderate**	750-2000	18-26	1.25–2.5	40-60	
Poor	**Severe**	2000-3000		>2.5	60-80	<25
Harmful		>3000	26		>80	

2.5. Uncertainties and shortcomings

This study is unique; studies on water's irrigational capacity tend to envision fresh, natural waters (lake, wadi, well, etc.), but using thermal mineral waters for agriculture is a new direction in the field. As such, we have attempted to develop this research direction by proposing several solutions, for example the rational management of thermal waters for agriculture, the protection of thermal sources in quality and in quantity, the impact of overexploitation of thermal mineral sources on the environment, the ability of thermal waters to irrigation, etc.

In reality, though, there are several obstacles, such as:

- A lack of data
- Insufficient research
- A lack of coordination between managers and farmers
- The absence of organizations that occupy the large amount of unused surfaces in the agricultural areas

3. Results and discussions

Table 3 presents the physical and chemical parameters of the water samples from the studied area, while Table 4 shows the various factors affecting the quality of water for irrigation.

According to Table 3, the variation coefficient between the two sampling periods is characterized by a low rate of change. Thermal spring water can thus be said to be independent from surface hydrological process.

Table 3 shows that the average temperature of irrigation water samples of the Hammam Meskoutine was 81 °C and ranges between 41 and 96 °C and between 39 and 94 °C during the two sampling periods of June and February, respectively.

Table 3: *Chemical composition of thermal mineral sources of the Hammam Meskoutine (2016).*

Preglednica 3: *Kemijska sestava termomineralnih izvirov na območju Hammam Meskoutine (2016).*

Sources	T (C°)	pH	EC (µS/cm)	Ca^{2+} (mg/l)	Mg^{2+}	Na^+	K^+	Cl^-	HCO^-_3	SO_4^{2-}
Low water (June)										
Ain Skhouna	41	7.1	733	75	165	116.95	39	149.1	544	309.2
Chadakha 1	73	6.8	1992	160	202	134.32	27.3	120.7	855	403.3
Chadakha 2	96	6.8	2200	154	192	140.3	39	142	622	636
Cascade N°1	94	6.8	1754	148	176	142.99	39	92.3	700	500
Cascade N°2	83	7.2	1982	150	182	185.95	31.2	142	720	600
Cascade N°3	95	7.6	1850	170	160	128.7	56.6	116.7	693	523
Ain Chfa	92	7.0	1691	96	228	227.6	1.56	106.5	900	480
Plateau des cônes	92	**6.9**	1965	180	204	165.5	31 .2	184.6	661	586
Charchar	95	7.0	1982	175	180	103.7	39	120.5	650	540
Chemin de fer	68	6.7	1980	160	204	1663	29.64	2413	580	520
CV%	21.39	3.7	22.34	23.36	10.95	24.02	41.65	30.70	16.16	18.91
High water (February)										
Ain Skhouna	39	6.9	810	78.0	100	105	3.9	106.5	373	240
Chadakha 1	72	7.5	2120	116.0	150	109.9	7.8	122.1	393	446
Chadakha 2	94	6.7	2170	172.0	161.4	148.1	39	248.5	322	602
Cascade N°1	93	6.3	2130	155.0	168	130.8	34.3	276.9	450	474
Cascade N°2	94	7.3	2140	135.0	156	153	48.8	287.9	463	442
Cascade N°3	92	6.9	2210	106.0	132	107.5	50.9	213	469	287
Ain Chfa	90	6.4	2090	165.0	149	122	56.9	227.2	510	443
Plateau des cônes	91	6.0	2360	166.2	158	99	21.5	213	453	483
Charchar	84	6.2	2120	123.0	161	92.2	30	138.5	421.0	463
Chemin de fer	65	6.4	1937	144.4	178	114	48	262.7	489.0	435
CV%	22.02	7.2	21.61	22.34	14.39	17.15	53.67	31.27	13.20	23.50

Table 4: *Parameters of irrigation water quality in Hammam Meskoutine (2016).*

Preglednica 4: *Parametri kakovosti vode za namakanje na območju Hammam Meskoutine (2016).*

Sources	CE (µS/cm)	Cl^- (meq/l)	SAR	RSC	Na (%)	IP	Mg R
low water *(June)*							
Ain Skhouna	733	4.2	1.7	-8.6	25.8	78.6	78.57
Chadakha 1	1992	3.4	1.7	-10.8	20.8	67.8	67.79
Chadakha 2	2200	4.0	1.8	-13.5	23.1	67.5	67.51
Cascade N°1	1754	2.6	1.9	-10.6	24.6	66.5	66.47
Cascade N°2	1982	4.0	2.4	-10.9	28.2	66.9	66.91
Cascade N°3	1850	3.3	1.7	-10.5	24.4	61.1	61.07
Ain Chfa	1691	3.0	2.9	-9.0	29.4	79.8	79.83
Plateau des cônes	1965	5.2	2.0	-15.2	23.5	65.4	65.38
Charchar	1982	3.4	1.3	-13.1	18.8	63.2	63.16

Chemin de fer	1980	6.8	2.0	-15.5	24.2	68.0	68.00
high water ***(February)***							
Ain Skhouna	810	3.0	1.8	-6.1	27.6	68.1	68.12
Chadakha 1	2120	3.4	3.5	-11.9	21.4	68.3	68.31
Chadakha 2	2170	7.0	3.2	-16.8	25.2	61.0	61.00
Cascade N°1	2130	7.8	2.7	-14.4	23.2	64.4	64.37
Cascade N°2	2140	8.1	3.1	-12.2	28.6	65.8	65.82
Cascade N°3	2210	6.0	2.4	-8.6	26.8	67.5	67.48
Ain Chfa	2090	6.4	2.7	-12.3	24.7	60.1	60.08
Plateau des cônes	2360	6.0	2.4	-14.1	18.4	61.3	61.31
Charchar	2120	3.9	2.6	-12.7	19.6	68.6	68.57
Chemin de fer	1937	7.4	2.4	-14.0	21.9	67.3	67.26

3.1. pH

The pH influences the form and availability of nutrients in irrigation water. The pH value in this case should be between 6.5 and 8.4 (Ayers and Westcot, 1985; DOE, 1997; UCCC, 1974).Such values make for optimum conditions for the solubility of most microelements. The pH value of irrigation water ranges from 6.0 to 7.6, with an average value of 7.0 during the two sampling periods, which is considered within the permissible limits for irrigated agriculture.

3.2. Electrical conductivity (EC)

Electrical conductivity is an excellent indicator of mineralization, reflecting the concentration of all dissolved minerals (Rodier, 2009). Generally, water for irrigation purposes with an EC less than 2000 µS/cm is considered an appropriate value, except in certain situations (sensitive crops and highly argillaceous soils) with poor permeability. The ideal EC value is usually less than 750 µs/cm (Wilcox, 1955).

In the present study, electrical conductivity measurements (Table 3) gave values ranging from 2360 µS/cm (high water) to733 µS/cm (low water). According to (Wilcox, 1955), in low water periods, 80% of Hammam Meskoutine's springs are suitable for irrigation (EC 2000 µs/cm), while 90% of the samples were of poor quality for irrigation during the high water period (Figure 5b).

3.3. The chlorides

Chloride ionsare classified as toxic to plants (Ayers and Westcot, 1985), and they originate from double geological interaction sources caused by the dissolution of evaporitic formation sand various human activities. The following classification (Guasmi et al., 2013., Bouaroudj et al., 2014) was used to assess the quality of water from thermal mineral sources for

Cl^- < 4 meq/l No toxicity
4< Cl^- < 10 meq/l Moderate toxicity
Cl^- > 10 meq/l Severe toxicity

The chloride concentrations in the thermal mineral sources range from 3 to 8.1 meq/l and from 2.6 to 6.8 meq/l during the high and low-water periods, respectively (Table 4). Figure 5c shows over 30% of thermal mineral springs are of moderate toxicity, yielding water that is unsuitable for irrigation purposes.

3.4. Residual sodium carbonate (RSC)

The quantity of bicarbonate and carbonate in excess of alkaline soils (Ca^{2+} + Mg^{2+}) also influences water's suitability for irrigation. When the sum of carbonates and bicarbonates exceeds that of calcium and magnesium, the carbonates and bicarbonates are precipitated to the equivalent quantity of Ca and Mg; the excess of carbonates and bicarbonates will then react with Na to appear as *RSC.*

For this, residual alkalinity (Table 1) was considered as another approach in the assessment of water quality (Richards, 1954).

Figure 5d shows that values of RSC remained negative for all the water samples in this study, demonstrating that the water is of good quality for irrigation (Table 4).

3.5. The permeability index (IP)

The Permeability Index (PI) values also indicate the suitability of water for irrigation, as the soil's permeability is affected by the long-term use of irrigation water, as influenced by the soil's sodium, calcium, magnesium, and bicarbonate content.

Doneen (1964) classified irrigation waters (Table 2) based on the permeability index (IP) (Table 1).

According to Table 4, the permeability index values range from 60.1 to 79.8% with an average value of 61%. They indicate good quality of the thermal mineral water sources destined for irrigation (Figure 5e).

3.6. Risk of magnesium (Mg R (%))

It is widely reported that Ca and Mg do not behave identically in soil systems, and that Mg deteriorates soil structure particularly where water is dominated by sodium. A high level of Mg usually promotes the speeding process of exchangeable Na in irrigated soils (FAO, 2008). If the magnesium hazard is less than 50, the water is considered suitable for irrigation. Meanwhile values above 50% in Mg are unsuitable (Paliwal, 1972).

In the Hammam Meskoutine area, the magnesium hazard (Mg R) values ranged between 60 and 80% (Figure 5f), which means that all of the thermal mineral springs are unsuitable for irrigation. The high values of the magnesium concentration are attributed to dolomite and dolomitic limestone in the Hammam Meskoutine (Benamara, 2017).

3.7. Percentage of sodium (%Na)

High sodium levels change soil's physical structure due to the swelling of clay particles (Derradji et al., 2004). These will then be dispersed, impeding the flow of water through the ground. This degradation of the physical characteristics of the soil results in the decrease of permeability and ventilation (Hadj-said, 2007; Raoubhia and Derradji, 2010), because plants do not hold well in sodium-saturated soils. The water points were classified according to Wilcox (1948) (Table 1). This approach showed that the water is of good quality for irrigation. The percentage of Na is between 18.4% and 28.6% during the highwater periods and between 18.8% and 29.4% in low water (Table 4; Figure 5g).

3.8. Sodium absorption rate (SAR)

The suitability of water samples was assessed by determining the value of the sodium adsorption ratio (SAR) and they were categorized according to the different irrigation classes based on the risks of salinity and alkalinity. The sodium adsorption ratio parameter assesses the risk of sodium versus calcium and magnesium levels. Sodium adsorption levels are used to predict the potential for sodium accumulation in the soil, which would result from the continued use of saline water.

When SAR is greater than 5 meq/l, the water may cause a risk of soil alkalinization (O.M.S, 2000; Subramani et al., 2005).

SAR values ranged from 1.8 to 3.5 in high water and from 1.3 to 2.9 in low water (Table 4; Figure 5h). This implies that there is no risk of alkaline for crops. However, these low values [SAR <10] suggesting that there is an excellent adequacy to irrigation.

3.9. Richards classification

The Richards method is used to study the quality of mineral water in irrigation. It highlights various classes of water, defined based on their sodium absorption rate [SAR] and on the concentration of water in the form of electrical conductivity [in μs/cm at 25°C].

The values from the Richards diagram (Figure 6) resulted in three classes:

Class 2: This class characterizes water that is good for irrigation and can be used without any particular control for irrigating plants that are moderately tolerant to salts; thus presenting a low danger of salinity and alkalinity, wherefore they are moderately accepted for irrigation. This class represents waters of low mineralization that are found in the Ain Skhouna source during low water periods.

Class 3: Generally, this class contains water eligible for irrigating salt-tolerant crops, provided that these soils are well-drained or of good permeability and salinity. This class makes up the near totality (90%) of sources for the two collecting periods.

Class 4: This class represents highly mineralized water that can be suitable for irrigating certain salt-tolerant species on well-drained and leached soils. This class comprises 10% of the water found in the S8 spring during high water periods.

For both sampling periods, the thermal mineral water springs generally retain the same quality for irrigation purposes.

The majority of the samples (90%) belong to Class 3.

3.10. Practical implementation of results

Our field research led us to elaborate two visions of using water from thermal mineral springs for irrigation. The scientific community has also started taking interest in using thermal water for agriculture, which may include several research topics such as the impact of using thermal water on the quality of irrigated soil, and the geochemical and physical properties of soil irrigated with thermal water. However, farmers view such water merely as another source for irrigation, without taking into consideration its quality.

Currently the thermal springs are managed by the Environmental Management as a tourist heritage and are used medicinally. For the Water Resources Directorate, no law currently protects this heritage.

So, we note that there are overlapping prerogatives between the different directorates, a lack of coordination, different statuses, differences in interests between the directorates (environment, forest management, and water resources management), etc. To resolve these conflicts, a management regime must be designed in which all managers and users are involved in the decision-making process. Example of a local water management committee: RPD, DAS, DGF, farmer, local community, etc.

According to Table 5, it can be said that waters from thermal mineral springs pose a problem of salinity, moderate chloride toxicity, and severe magnesium, which reduce their suitability for irrigation.

However, for the other parameters, the sources of both sampling periods are of good to excellent quality.

The following table (Table 5) summarizes the results obtained from the different methods used.

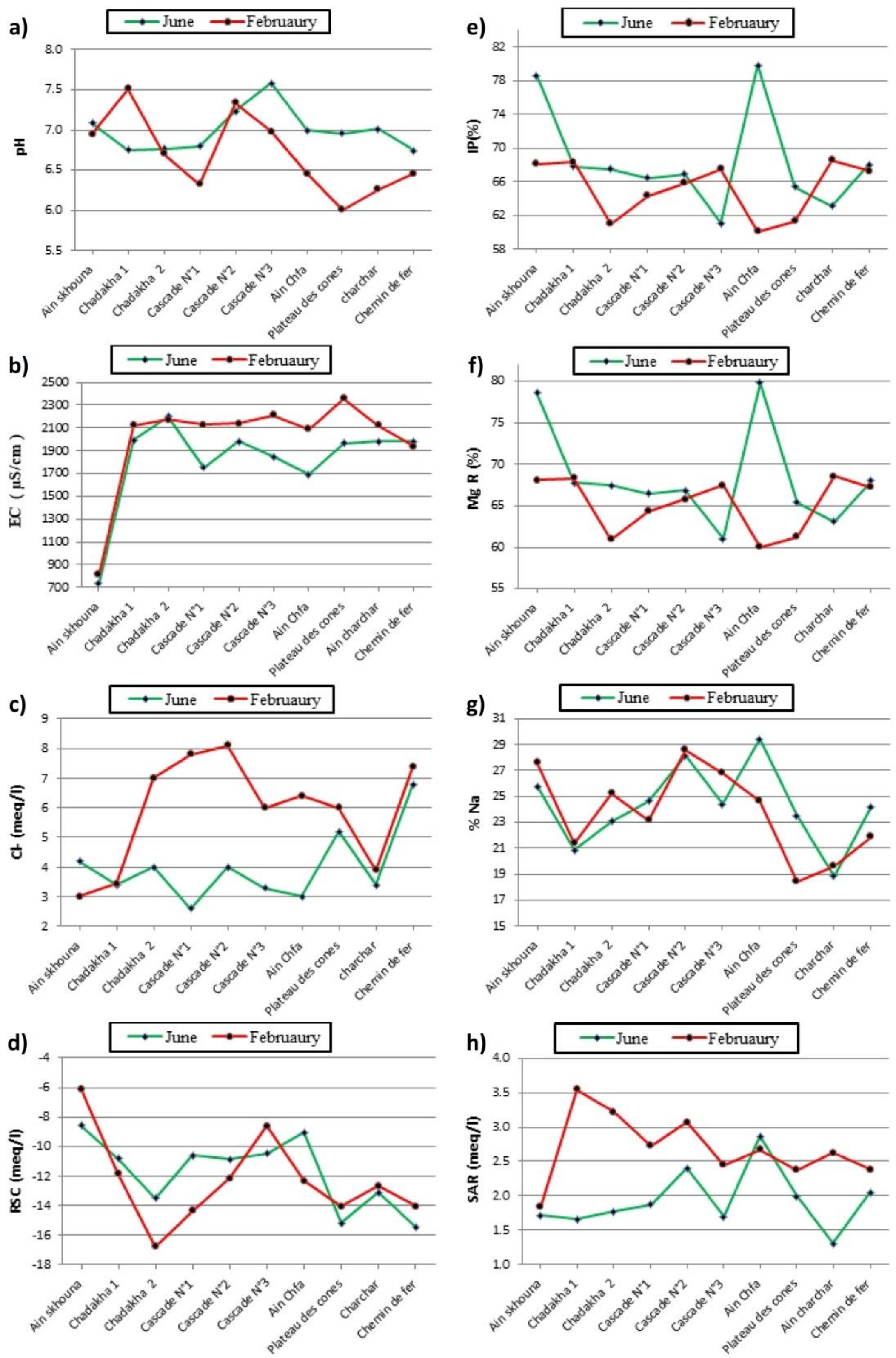

Figure 5: *Classification of spring water from Hammam Meskoutine according to the parameters of irrigation water quality. a) pH; b) electrical conductivity; c) chlorides; d) residual sodium carbonate; e) permeability index; f) risk of magnesium; g) percentage of sodium; h) sodium absorption rate.*

Slika 5:*Razvrstitev izvirske vode na območju Hammam Meskoutine glede na parametre kakovosti vode za namakanje. a) pH; b) električna prevodnost; c) kloridi; d) preostali natrijev karbonat; e) indeks prepustnosti; f) nevarnost vsebnosti magnezija; g) delež natrija; h) razmerje adsorpcije natrija*.

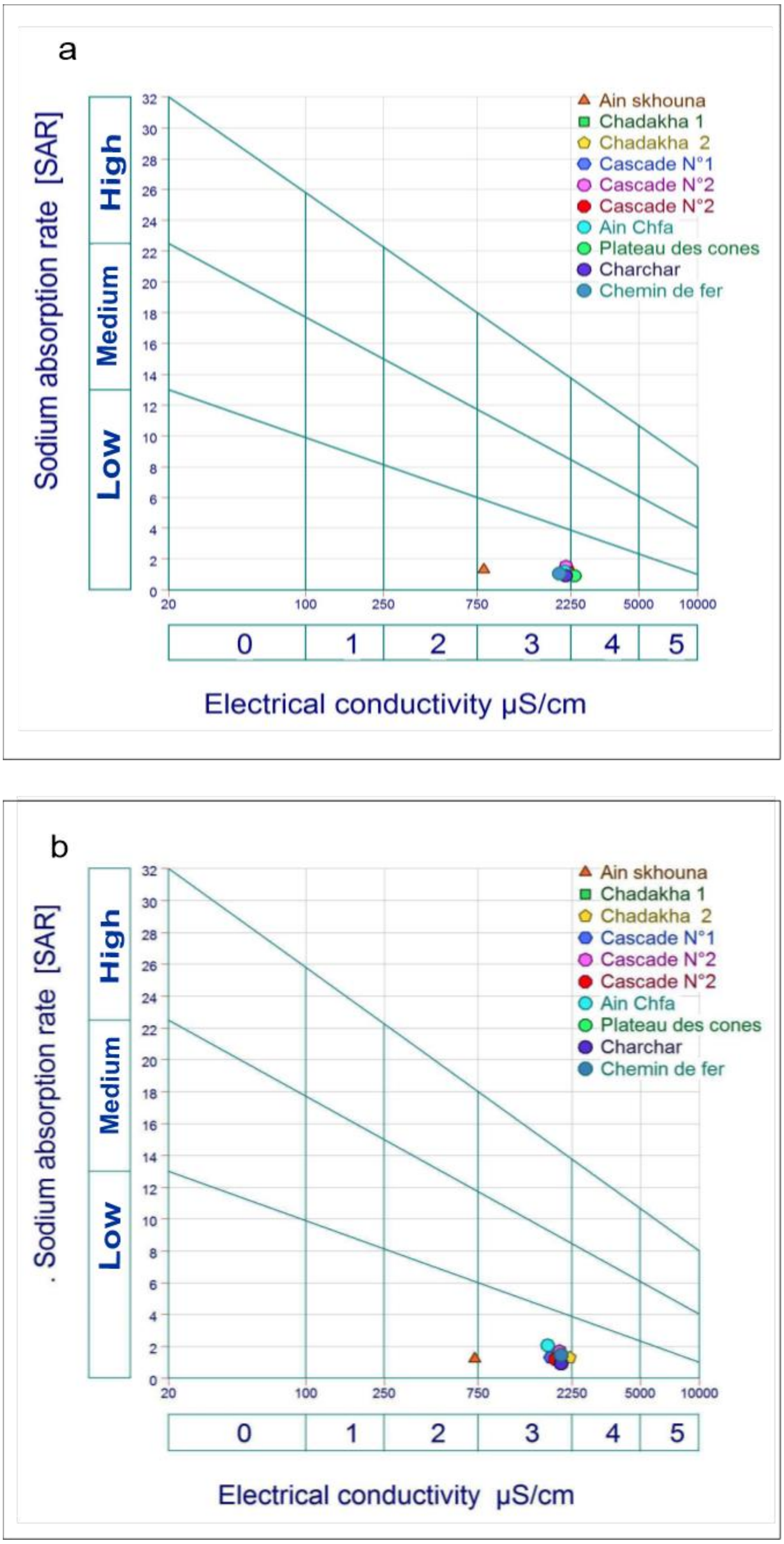

Figure 6: *Hammam Meskoutine's thermal mineral water's irrigational capacity according to Richards classification: a) high water,b) low water.*

Slika 6: *Kapaciteta termomineralne vode za namakanje na območju Hammam Meskoutine po klasifikaciji po Richardsu: a) visoke vode, b) nizke vode.*

Table 5: *The results obtained from the different methods.*

Preglednica 5: *Rezultati, pridobljeni z uporabo različnih metod.*

Parameters		**The classes of water quality for irrigation**				
		Excellent	**Good**	**Permissible**	**Doubtful**	**Unsuitable**
RSC meq/l		**<1.25**	**1.25-2.50**			**>2.50**
Study site	***a***	1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10				
	b	1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10				
SAR méq/l		**0-10**	**10-18**	**18-26**		**26**
Study site	***a***	1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10				
	b	1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10				
IP%		**>70**	**25-75**			**<25**
Study site	***a***		1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10			
	b	1,7	2, 3, 4, 5, 6, 8 ,9 ,10			
MgR%		**< 50**			**> 50**	
Study site	***a***				1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10	
	b				1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10	
%Na		**<20**	**20-40**	**40-60**	**60-80**	**>80**
Study site	***a***	8,9	1, 2, 3, 4, 5, 6, 7, 10			
	b	2	1 ,2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,10			
Cl^- meq/l		**< 4**			**4 -10**	**> 10**
Study site	***a***	1, 2, 8			3 ,4 ,5 ,6 ,7 , 9 ,10	
	b	2, 4, 6, 7, 9			1, 3, 5, 8, 10	
EC µS/cm		**<250**	**250-750**	**750-2000**	**2000-3000**	**>3000**
Study site	***a***			1, 10	2 ,3 ,4 ,5 ,6 ,7 ,8 ,9 ,	
	b		1	2,4 ,5 ,6 ,7 ,8 ,9 ,10	3	

Where:

1: Ain Skhouna
2: Chadakha 1
3: Chadakha 2
4: Cascade N°1
5: Cascade N°2
6: Cascade N°3
7: Ain Chfa
8: Plateau des cônes
9: Charchar
10: Chemin de fer

a: Low water
b: High water

4. Conclusions

The purpose of this study was to determine the physical and chemical characteristics of the thermal mineral water springs of the Hammam Meskoutine for irrigation, and to assess their adequacy according to various parameters and the RICHARDS diagram.

-The analysis of all parameters in characterizing the salinity during the studied period for the water quality assessments were based on conventional methods. This assessment revealed that the waters were highly saline. Hence, there is the possibility of using the water for irrigation during drought periods, though it is unsuitable for irrigation during flood periods.

- The value of SAR, which remained low, showed that there is a low risk of alkalization. This assumption is confirmed by the RSC values, which are less than 1.25 meq/l, where such waters could be used for irrigation on any type of soil.

- The percentage of magnesium risk was more than 50% in all sources and during the sampling period. Thatis to say, the water from these sources is inappropriate for irrigation.

- According to SAR, the waters are characterized by a low sodium content. This implies that there is no risk of alkaline for crops and confirms that the springs are classified as excellent waters for irrigation purposes.

Water from thermal mineral springs generally retained the same qualities for irrigation throughout the study period, where 90% of the water belonged to the class of waters ineligible for irrigating salt-tolerant crops, provided that these soils are well-drained or of good permeability, and provided that the salinity is controlled.

In terms of perspective, we can evaluate and study the mixture of spring water with Bouhamdane's wadi or with the runoff during the winter to minimize the concentrations of the physical and chemical parameters.

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