Carpathian Journal of Earth and Environmental Sciences, August 2018, Vol. 13, No. 2, p. 333 - 342; DOI:10.26471/cjees/2018/013/029

HYDRO-GEOCHEMICAL AND STATISTICAL CHARACTERIZATION OF GROUNDWATER IN THE SOUTH OF KHENCHELA, EL MEITA AREA (NORTHEASTERN ALGERIA)

Abdenour SEDRATI[1,2], Belgacem HOUHA[1], Gheorghe ROMANESCU[2*] & Cristian Constantin STOLERIU[2]

[1]University of Khenchela – Post Box 1252, Road of Batna - Khenchela 40004, Algeria
[2]Alexandru Ioan Cuza University of Iasi, Faculty of Geography and Geology, 22 Carol I Blvd, 700506, Iasi, Romania
**Corresponding author: romanescugheorghe@gmail.com*

Abstract: The need of water is stringent in the arid regions, mostly in those belonging to North Africa. For this reason, numerous hydrogeological studies have been conducted in southern Algeria, which is under the influence of the Saharan climate. These studies have determined the hydro-chemical characteristics and the origin of the salinity belonging to the aquifer within the terminal complex of the El Meita region, situated in northeastern Algeria. The climate of the region is arid: precipitations of 164.7 mm/year and very high temperatures during the summer. The aspects emphasized on include the annual evolution of the piezometric surface, the chemical facies of the water, binary diagrams (chloride, base exchange index, saturation index, etc.). In the month of April 2016, 29 samples were collected. The water sheet is radially convergent and runoff manifests itself on the northeast – southwest direction. The major elements are dominated by chlorides and calcium sulphate. Water mineralization may have two causes: dolomitization and the dissolution of gypsum; ionic exchange of bases between the water and the solid frame of the aquifer. Saturation index demonstrates that carbonated minerals are oversaturated, while saliferous evaporite minerals are undersaturated. The Principal Component Analysis (PCA) shows a rich participation of several mineralization elements, mostly of calcium. Mineralization is also induced by the anthropic factor.

Keywords: aridity, terminal complex, hydrochemistry, salinity, statistics

1. INTRODUCTION

Algerian Sahara represents a typical desert area. The water need is extremely high and sources are limited. The Saharan basin represents, from a hydro-geological perspective, a great multi-layered sedimentary entity. From a hydraulic point of view, the aquifer system in the north of the Sahara Desert features three overlapped aquifer systems, (separate or which communicate through semi-permeable formations): the continental inter-calcareous aquifer; the Turonian aquifer; the terminal complex aquifer (OSS, 2003).

The chemical composition of waters in wells and sources is influenced by the environment and also the period of stay within the aquifer (Fehdi et al., 2009). It is directly related to the nature of geological formations, to the meteoric precipitations in the analyzed area and in the surroundings, and to the value of evaporation (Zeddouri et al., 2010). The chemical composition of groundwater is important if the purpose is to use them in the agricultural, industrial or domestic field (Ishaku et al., 2015). The knowledge of hydro-chemical processes is fundamental to determine the origin of mineralization (Zeddouri et al., 2010). From this point of view, a great number of studies have been conducted throughout the world (Adopo et al., 2014; Beltrando, 2014; Brinis et al., 2014; Houha, 2007; Ghodbane et al., 2015; Nakayama & Maksyutov, 2014; Romanescu & Cojocaru, 2010; Romanescu et al., 2014, 2015; Tabouche & Achour 2004; Vainu et al., 2014).

The groundwater has been used more and more intensely by the Maghreb countries (Siebert et al., 2010, Aouidane & Belhamra, 2017). Irrigations in Algeria utilize the groundwater to a great extent (67%) (Zektser & Everett, 2004). The effective and sustainable management of water resources involves a great insight into the availability, quality and variability in space and time (Hamzaoui Azaza et al., 2012).

The Terminal Complex Aquifer has been increasingly used, despite low knowledge on its reserves, hydraulic functions and on regeneration capacity. Great attention should be paid to the permanent monitoring of the piezometric level and quality (mostly of the chemical composition). This aquifer constitutes the only water source for the El Meita Plain (Sedrati et al., 2017).

This study aims to determine the hydro-chemical characteristics of the aquifer in the El Meita region (Algerian Sahara) and of the sources used by the local population. Punctually, the elements targeting salinity and water quality are studied.

2. GEOGRAPHIC LOCATION

The El Meita Plain is situated in northeastern Algeria, in the south of the Khenchela region. It is limited by the Saharan Atlas to the north and by Chott Melghir to the south (Fig. 1). It belongs to the Melghir catchment basin situated in the south of the Saharan Atlas. It is the field of the Saharan platform, which is used intensely for agricultural purposes. The climate is typically arid, with mean multiannual precipitations of 164.7 mm/year and very high temperatures during the summer. The mean annual temperature is 22°C. The maximum altitude is 1,248 m to the north and it drops to almost sea level, or even below that, in certain inland depression sectors. From an administrative perspective, the region comprises three communes: Chechar, Babar and Djelal.

3. MATERIALS AND METHODS

Field campaigns were conducted to choose the sampling places throughout the entire El Meita Plain (Fig. 2). The water sampling campaign took place during the month of July 2016. A number of 29 samples were collected, according to the method recommended by Rodier et al., (2009). Polyethylene cylinders that were used had a volume of 0.5 liters: beforehand, a 15-minute drilling was performed in order to eliminate the water stored along the pipes until the temperature was stabilized. The water passed through a membrane filter with pores that measuring 0.45 µm. All samples were stored in a lightproof container at a temperature of 4°C.

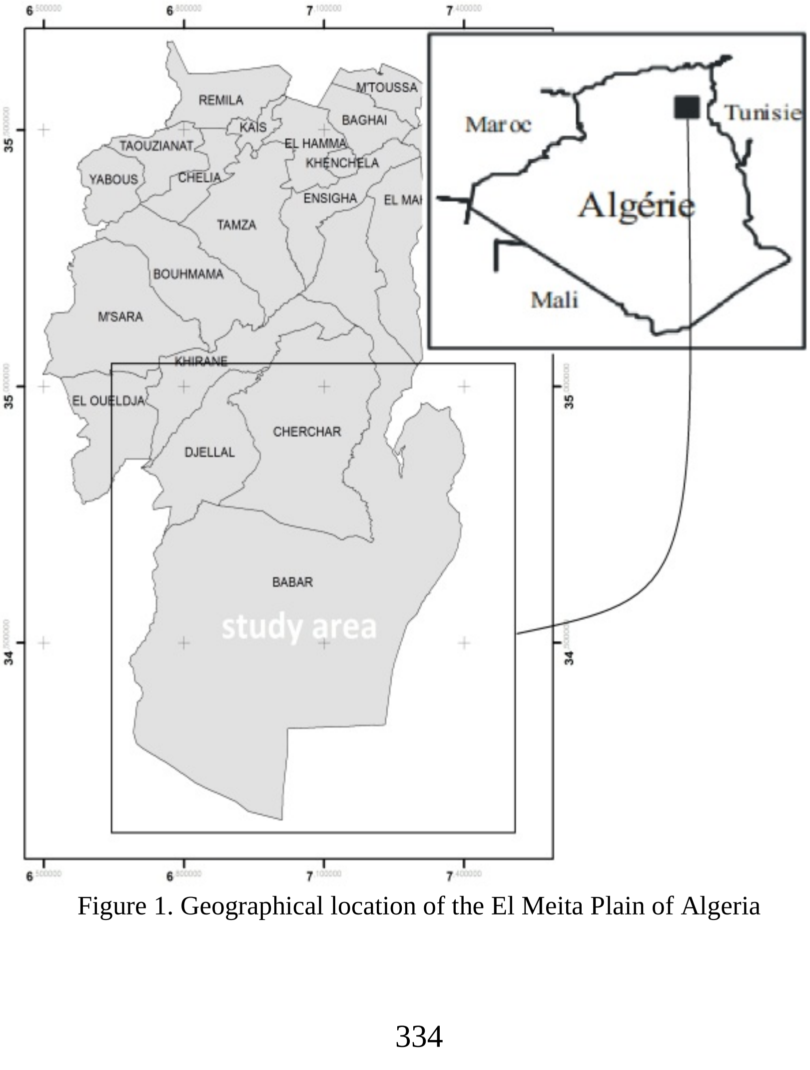

Figure 1. Geographical location of the El Meita Plain of Algeria

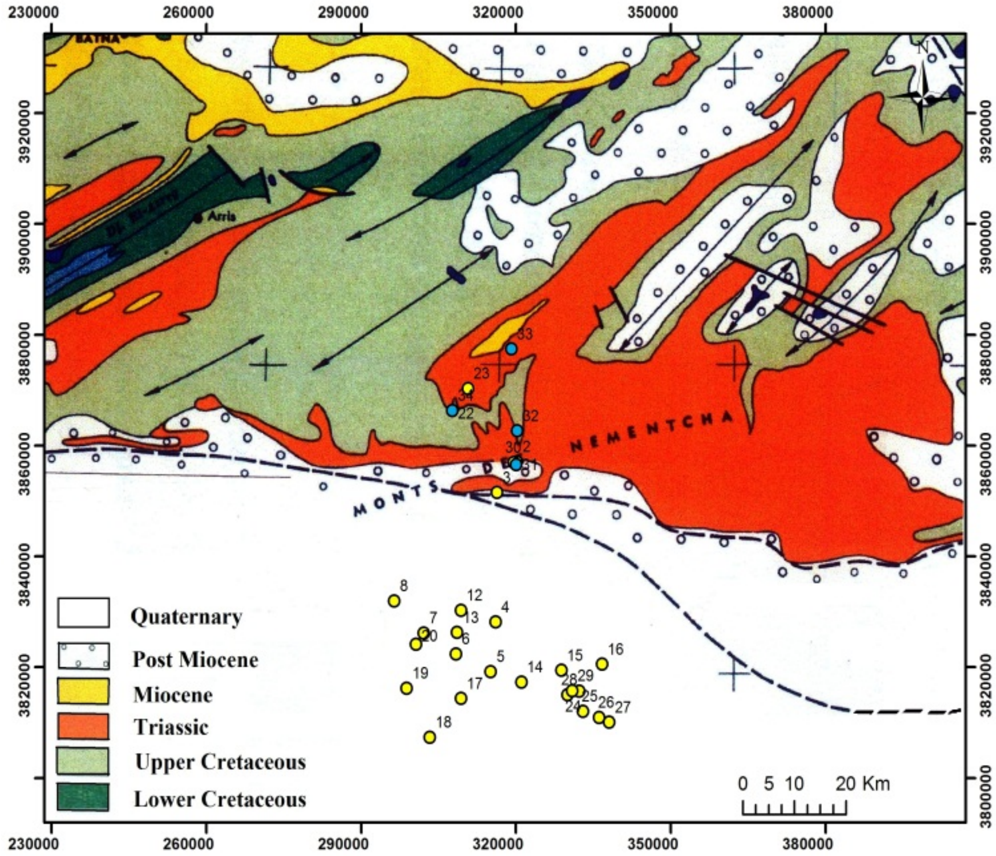

Figure 2. Geological map of the El Meita region and distribution of sampling points

In parallel with water sampling, physical-chemical measurements were conducted using the Consort C931 multiparameter analyzer: temperature - T°C, pH, electrical conductivity (EC). The ionic chromatography base was used for cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (Cl^{-}, SO_4^{2-}, HCO_3^{+}, NO_2^{-}, NO_3^{-}). The analyses were performed in the Laboratory of Environmental Analyses and Chemical Tests on Materials (Ain M'Lila). The ionic balance ranged under 5% in most samples.

4. RESULTS AND DISCUSSIONS

4.1. Hydro-geological context

From the geological perspective, the El Meita Plain is situated in an area of immersion along the fault extended to the south of the Atlas Mountains. The geo-morphological landscape is represented by folds and faults that correspond to alpine paroxysm (Fig. 2). It comprises Quaternary sediments that make up the Saharan platforms. The stratigraphic series are represented by sand, gravels and clays that repose on marls and lacustrine limestones.

The main wadi dredging the El Meita Plain are Mehane, Ouzzern and El Meita. These temporary flows of water spring from the north and discharge into the endorheic depression of Melghir.

The drilling depths ranged between 30 and 200 m. The drills were placed on the surface of the entire Pliocene-Quaternary phreatic aquifer, made of gravels, sand and clays, with thicknesses reaching 525 m. This is the first sheet of the terminal complex that reposes on an impermeable layer of marls. There is also a deeper aquifer, Miocene-Pliocene, which is captive. The piezometric map generated by ENERGOPROJECT in 2002 shows the presence of radially convergent sheets, the runoff of each manifests itself on the northeast – southwest direction.

The dominance of major ions in the groundwater is: $Ca^{2+}>Na^{+}>Mg^{2+}$ and $Cl^{-}>SO_4^{2-}>HCO_3^{-}$. A dominance of the ions such as Ca^{2+}, SO_4^{2-} and Cl^{-}, which constitutes a facies, is observed in mineralized waters running off on the upstream-downstream direction. The mineralization concentration map (for total dissolved solids - TDS) was generated using ArcMap 10.3. It helped deciphering the hydrodynamic process that controls the movement of groundwater and the washing off occurring towards Chott (Fig. 3).

4.2. Binary diagram

Binary diagrams were used to identify the origin of the chemical elements (salinity, in our case) (Fig. 4). This kind of charts are used to visualize the evolution of major cation and anion content based on chlorine levels, which is considered a conservative element (Kloppmann et al., 2010). The position of the various points of aquifers, in relation to the mixing exchanges, dissolution, precipitation, sorption, etc) line between rainwater and seawater, may prove extremely useful to identify other phenomena that accompanying the mixing processes (Fehdi et al., 2009). The major cations and anions reflect the interactions of saline waters with the geological formations that they cross (ionic (Lamini, 2012).

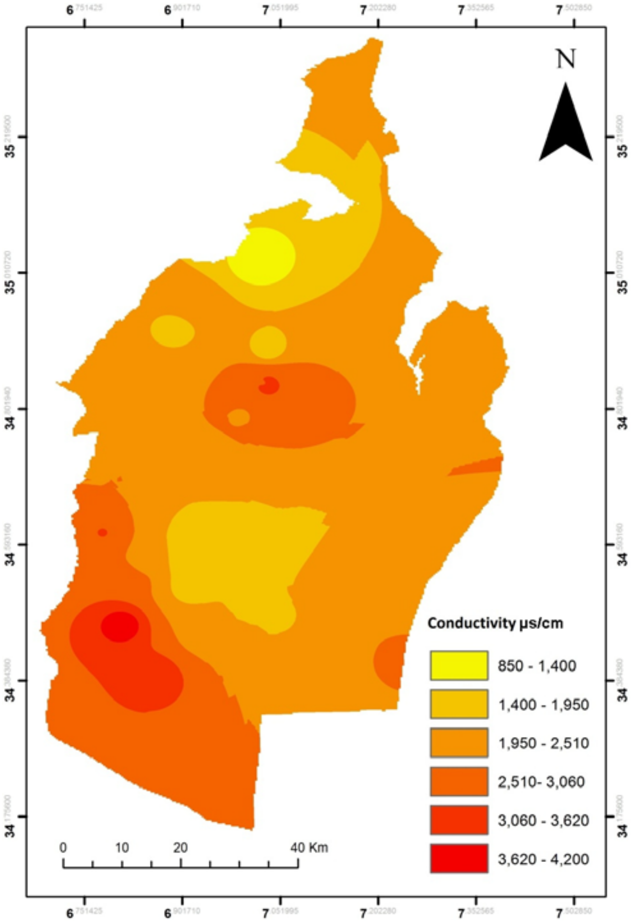

Figure 3. Spatial distribution of electrical conductivity in the aquifer of the El Meita Plain

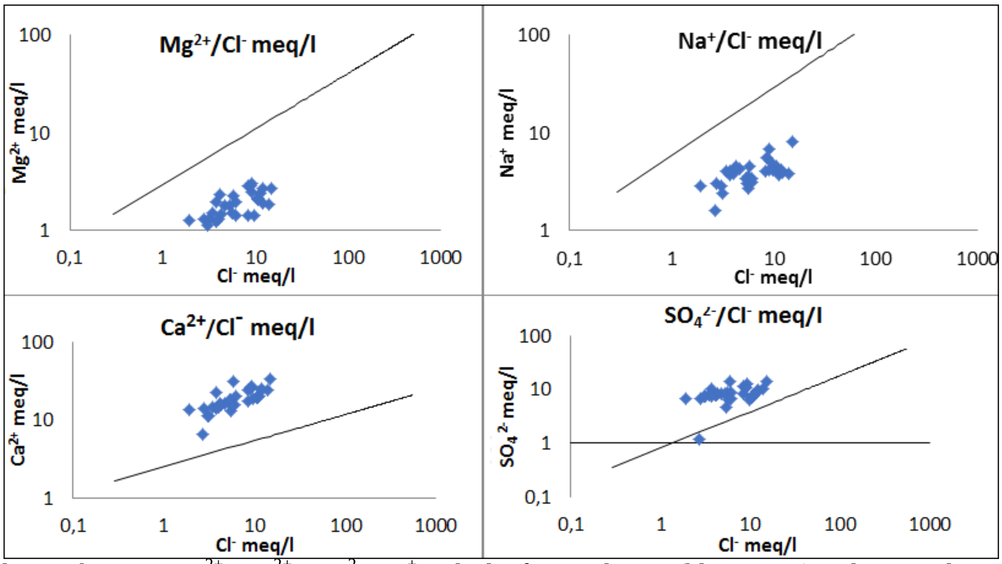

Figure 4. Relations between Ca^{2+}, Mg^{2+}, SO_4^{2-}, Na^+ and Cl^- of groundwater (blue points) and mixing line of rainwater-seawater

The carbonated aquifer, which is simultaneously enriched with Ca^{2+} and low in Mg^{2+}, is explained by the interaction between water and rock, where dolomitization, dissolution and precipitation are manifested. The Ca^{2+} – Mg^{2+} exchange through dolomitization was signaled as the main cause of the Mg^{2+}/Ca^{2+} ratio reduction (Fehdi et al., 2009). In this case, the Mg^{2+}/Ca^{2+} ratio is very low. The Na^+ contents must balance the Cl^- contents. As can be seen in figure 4, all Na^+ and Cl^- points are found under the mixing line of the rainwater-seawater, which demonstrates a Na^+ deficit. This phenomenon is explained by the reverse exchange of ionic bases between the water and the aquifer. Na^+ is fixed by the geological substrate, while it releases Ca^{2+} (Nadher et al., 1980). The explanation is validated by the existing relation between Ca^{2+} and Cl^-, where all points are situated above the mixing line of rainwater-seawater.

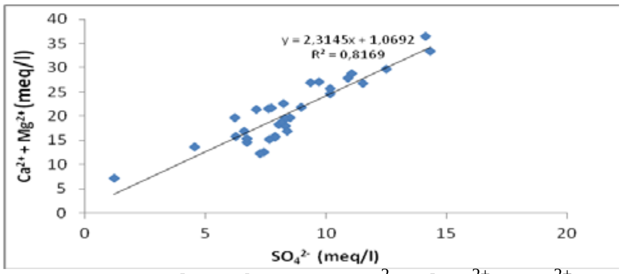

Figure 5 Relation between SO_4^{2-} and $Ca^{2+} + Mg^{2+}$

The relation between SO_4^{2-} and Cl^- shows that most points are situated above the mixing line of rainwater-seawater line, except for one point (P33 - source). P33 has very low TDS contents and it is very close to a state of balance. The enrichment of the other samples is explained by the presence of evaporites at the northern limit of the region and by the gypsum and marly substrate. Agricultural contamination also contributes to it by a lesser extent (Kouzana et al., 2009). In this region, sulphated fertilizers are intensely used, and it is known that they infiltrate easily due to the sandy substrate and to irrigations. The correlation between (Ca^{2+} + Mg^{2+}) and SO_4^{2-} is strong, with $R^2 = 0.81$ and a value of + 2.31 for slope), which demonstrates that water is in balance and the presence of Ca^{2+}, Mg^{2+} and SO_4^- is provided by the dissolution of gypsum (Fig. 5). Consequently, the salt within the El Meita Plain has two sources: dolomitization and the reverse ionic exchange of bases between water and the substrate fixing the sodium while releasing calcium.

4.3. Base exchange index (BEI)

Base exchange index represents the ratio between exchangeable ions and primitive ions of the same nature. Water, throughout its underground journey, reacts with different substances that have the property of changing ions against those contained in it, (minerals, iron hydroxide, organic substances) (Belksier, 2009). Base exchange index is expressed using the following formula:

$$BEI = [rCl^- – r\,(Na^+ + K^+)]/\,rCl^-.$$

where r is milliequivalent

The values of the base exchange index interpreted as follows:

- If it is negative, then Ca^{2+} and Mg^{2+} ions in the water are exchanged for the K^+ and Na^+ ions inside the geological formations;

- If it is positive, then the Na^+ and K^+ ions are replaced by the Mg^{2+} and Ca^{2+} ions inside the geological formations;

- If it is 0, then there is a balance between the chemical composition of water and that of the geological formations (Hamzaoui Azaza et al., 2012) (Fig. 6).

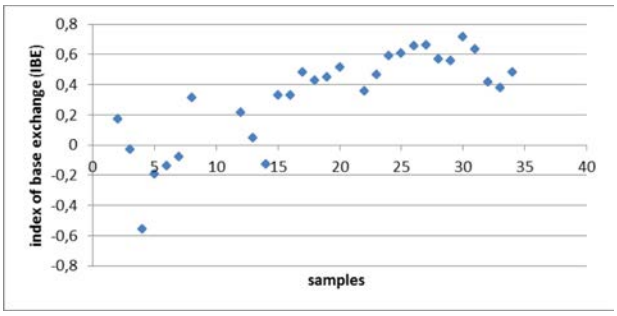

Figure 6 Values of the base exchange index

For the Terminal Complex Aquifer in the El Meita region, waters have a base exchange index ranging between -0.554 and 0.717. The points 3, 4, 5, 6, 7 and 14 have a base exchange index lower than 0. Most of them are close to 0 and they indicate a balance between the chemical composition of the water and the geological formations. Only point 4 has an index of -0.554, which stands to demonstrate a release of K^+ and Na^+ ions and a fixing of Ca^{2+} and Mg^{2+} ions. This aspect indicates the presence of Na^+-charged clay. The rest of the points have positive values of the exchange base index, which suggests a replacement of Na^+ and K^+ in the water by the Mg^{2+} and Ca^{2+} ions inside the geological formations.

4.4. Saturation index

Saturation index expresses the degree of chemical balance between water and mineral in the aquifer matrix, and it may be considered as a measure of the process of dissolution and/or precipitation concerning the water-rock interaction (Drever, 1997).

The knowledge of water saturation in relation to certain minerals explains the chemical form under which minerals are transported in solutions. The saturation index with the value 0 represents the existing balance between water and mineral. Water is under-saturated if the value is <0. Mineral dissolution is over-saturated if the value is IS>0 (mineral precipitation) (Peter-Borie et al., 2009).

The thermodynamic study was conducted using the Diagramme software. In this case, the saturation index is calculated for anhydrite, aragonite, calcite, dolomite, gypsum and halite. It serves to evaluate the geo-chemical processes underlying mineralization (Fig. 7**)**. In this case, the following equation is used (Chapelle, 2001):

$$IS = \log (IAP/K).$$

Where: IAP=ion activation product;

K= thermodynamic equilibrium constant.

The groundwater in El Meita is saturated and over-saturated in relation to carbonated minerals (calcite, dolomite and aragonite) with calcium precipitation and under-saturated in relation to saliferous minerals with the dissolution of evaporite minerals and a contribution of sodium sulphate. Calcium and magnesium increase mainly with the direction of flow due to the presence of carbonate minerals in the aquifer. The calculation of the saturation index for minerals shows that carbonated minerals tend to precipitate while saliferous evaporite minerals tend to dissolve.

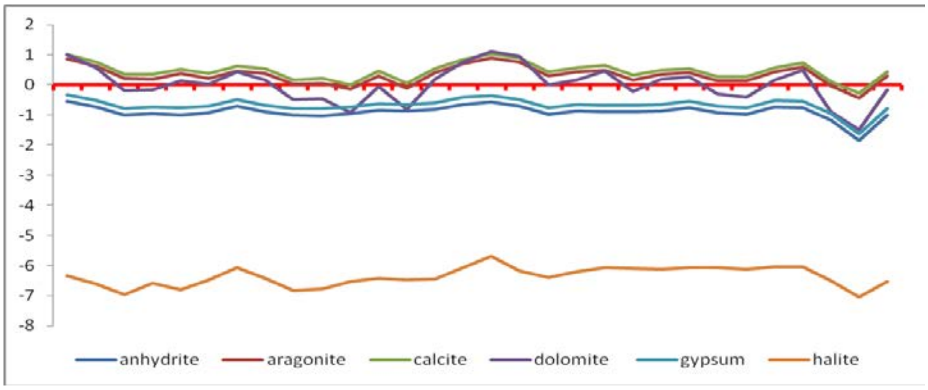

Figure 7 Variation of the saturation index in the groundwater of the El Meita Plain

Table 1 Physico-chemical parameters of the collected samples

No	°C	EC µS/cm	pH	TDS	K^+	Na^+	Ca^{2+}	Mg^{2+}	NH_4^+	HCO_3^-	NO_3^-	NO_2^-	Cl^-	SO_4^{2-}
2	22.1	3143	7.11	2433	9.8	105.8	623.54	27.55	0.099	744.12	49.51	0.016	206.88	688.06
3	24.6	2465	7.03	1869	6.3	84.6	453.76	23.41	0.087	623.98	66.83	0.034	132.44	487.11
4	25	1578	7.01	1163	3.9	66.3	266.51	15.17	0.056	355.71	73.31	0.023	67.91	321.77
5	25.5	1929	6.95	1339	4.6	91.6	287.38	18.32	0.063	396.11	49.81	0.041	121.66	378.84
6	25.6	1582	7.2	1154	4	70	279.82	15.77	0.066	323.87	54.62	0.016	97.73	321.55
7	27.3	2193	6.85	1520	4.9	99.3	319.66	27.98	0.052	487.58	63.06	0.013	145.95	384.84
8	25.2	3084	6.86	2221	5.6	129.7	479.93	34.12	0.072	657.77	72.61	0.017	297.84	553.05
12	23.3	1536	6.96	1148	2.6	55.9	224.42	15.67	0.053	307.07	82.72	0.032	112.65	355.82
13	23.9	1502	7.02	1134	3.7	64.8	221.61	13.63	0.066	297.21	75.66	0.016	108.05	349.21
14	27.9	1821	6.72	1490	4.7	94.1	281.08	14.76	0.025	312.11	68.85	0.009	132.29	366.84
15	24.8	2183	6.98	1631	4.9	83.4	365.1	17.88	0.073	396.56	79.08	0.006	197.55	408.74
16	26.3	2093	6.58	2454	4.7	78.5	355.77	21.26	0.031	380.04	75.55	0.017	186.86	398.87
17	25.3	2358	7	3097	3.2	71.7	397.32	23.78	0.018	431.22	65.43	0.023	218.52	429.91
18	24.2	3578	6.97	2210	5.6	118.5	544.21	29.65	0.064	778.09	59.84	0.025	327.18	599.06
19	27.7	4173	7.06	2327	6.9	186.2	676.72	32.05	0.083	897.55	103.53	0.917	532.51	677.23
20	26	3027	7.11	1290	4.7	97	502.09	33.94	0.044	665.78	66.93	0.024	315.73	523
22	17.4	1935	7.07	2432	18.8	79	308.7	16.98	0.063	343.61	76.97	0.027	216.06	316.83
23	17.7	2342	7.1	1640	16.3	93.2	347.43	17.06	0.072	405.02	84.21	0.014	296.53	391.77
24	24.8	2241	7.09	1762	3.3	98.7	389.51	25.66	0.014	451.66	60.61	0.005	377.96	364.41
25	25.1	2394	6.75	1781	4.2	95.2	391.48	25.14	0.053	463.44	49.06	0.017	381.59	370.1
26	25.1	2666	6.91	1848	5.8	85.6	404.98	28.61	0.013	477.06	63.96	0.021	398.74	394.62
27	24.5	2824	6.84	2108	4.9	90.4	486.69	32.77	0.036	566.72	42.66	0.025	427.83	465.56
28	25.4	2258	6.79	1670	3	102.9	385.32	24.82	0.041	382.77	69.77	0.024	372.77	341.25
29	26	2166	6.78	1598	4.6	95.6	366.39	17.19	0.017	404.25	77.06	0.011	344.85	298.66
30	24.8	3009	6.9	2165	5.3	86.8	477.66	22.27	0.032	523.68	83.73	0.016	489.58	488.87
31	21.5	3228	6.98	2176	7.4	96.5	501.61	22.96	0.036	618.72	65.94	0.023	423.66	449.13
32	16.9	1457	6.85	1090	4.8	70.1	257.05	9.38	0.023	284.17	64.12	0.021	192.07	218.56
33	17.5	848	6.91	596	2.3	37	132.11	6.99	0.018	153.96	57.78	0.018	95.33	57.77
34	17.8	1789	7.08	1654	10.1	61.3	295.76	12.11	0.051	339.87	77.72	0.013	200.17	300.18

Table 2 Correlation matrix

Variables	**T °C**	**EC**	**pH**	**TDS**	**K^+**	**Na^+**	**Ca^{2+}**	**Mg^{2+}**	**HCO_3^-**	**NO_3^-**	**Cl^-**	**SO_4^{2-}**	**NO_2^-**	**NH_4^+**
T °C														
EC	0.387													
pH	0.273	0.829												
TDS	0.052	0.624	0.568											
K^+	**-0.410**	0.194	0.194	0.329										
Na^+	0.584	**0.812**	**0.660**	0.351	0.132									
Ca^{2+}	0.359	**0.970**	**0.830**	**0.648**	0.186	**0.768**								
Mg^{2+}	0.591	**0.848**	**0.766**	0.494	0.000	**0.734**	**0.829**							
HCO_3^-	0.406	**0.955**	**0.829**	0.527	0.142	**0.810**	**0.954**	**0.842**						
NO_3^-	0.206	0.175	-0.028	0.023	0.222	0.364	0.092	-0.004	0.112					
Cl^-	0.169	**0.765**	0.518	0.485	0.131	0.580	**0.721**	**0.623**	0.597	0.138				
SO_4^{2-}	0.448	**0.891**	**0.751**	0.597	0.161	**0.747**	**0.902**	**0.783**	**0.925**	0.156	0.463			
NO_2^-	0.174	0.480	0.218	0.208	0.060	**0.620**	0.454	0.258	0.484	0.454	0.398	0.406		
NH_4^+	0.057	0.337	0.311	0.126	0.399	0.347	0.372	0.241	0.452	0.151	-0.102	**0.532**	0.283	

Values in bold express significant correlations

4.5. Statistical study

The Principal Component Analysis (PCA) is part of the group of multidimensional descriptive methods known as factorial methods. These methods emerged in the early 30s. PCA proposes, starting from the rectangular data table concerning the quantitative variable p values for n units, the geometrical representation of units and variables (Duby & Robin, 2006). The table is constituted, in line, by "individuals" (drills, springs) starting from which one measures the quantitative "variables" disposed as columns (T°C, EC, pH, TDS, K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_2^- and NH_4^+). The Principal Component Analysis (PCA) of chemical data is established using the XLSTAT software for all the 29 samples and 14 variables.

The correlation matrix

The linear correlations between relevant chemical elements allow seeking the origin of mineralization by assessing the degrees of dependence between various parameters. The assessment is conducted using the correlation coefficient determined by statistical calculations. The correlation between two parameters will be more significant when the correlation coefficient R is close to the value 1. Consequently, the correlations were established between all major elements taken in pairs. Hence, correlation binary diagrams were obtained (Fekrache, 2015) (Table 1).

A strong correlation between mineralization (EC) and calcium, bicarbonates and sulphates means that the elements participate strongly to the mineralization of waters. These data lead us to say that, if the mineralization is estimated by a single element it will be calcium, if we want to add others it will be the sulphate ion then the calcium. The correlation between these ions indicates the existence of ionic exchange reactions between the solution and the absorbing complex (Table 2).

Principal Component Analysis (PCA)

Three important factors account for 85 % of the information: The F1 appears as the mineralization axis, it is defined by the salinity and the ions Ca^{2+}, Na^+, Mg^{2+}, Cl^-, HCO_3^- and SO_4^{2-} probably due to evaporite dissolution and participating in mineralization of groundwater in the plain of El Meita. The axis F2 shows that the waters rich in K^+ and $NH4^+$ are opposed to the warm waters. This means that these ions come mainly from the anthropic contribution, thus not caused by the dissolution of the minerals. The pollution does not reaches the deep waters. The third axis F3 is interpreted as a contamination factor, containing nitrites (NO_2^-) and nitrates (NO_3^-) which are opposed to salinity; this means that these parameters have no influence on the mineralization of plain's groundwater of the plain. The fourth axis F4 shows that the Cl^- opposes with the NH_4^+ this indicates that the presence of the Chloride is due to the dissolution of the halite and not by the anthropic activity. (Table 3).

Table 3 Correlation between variables and factors

	F1	**F2**	**F3**	**F4**
T °C	0.462	-0.677	0.322	0,237
EC	**0.981**	0.003	-0.072	-0,087
pH	**0.839**	0.019	-0.301	0,102
TDS	**0.629**	0.251	-0.378	-0,240
K^+	0.197	**0.873**	-0.066	-0,057
Na^+	**0.870**	-0.102	0.324	-0,011
Ca^{2+}	**0.968**	0.020	-0.136	-0,026
Mg^{2+}	**0.874**	**-0.285**	-0.165	0,086
HCO_3^-	**0.963**	-0.011	-0.039	0,122
NO_3^-	0.207	0.218	**0.788**	-0,263
Cl^-	**0.696**	-0.073	-0.134	**-0,596**
SO_4^{2-}	**0.921**	0.035	-0.015	0,241
NO_2^-	0.523	0.121	**0.587**	-0,254
NH_4^+	0.411	**0.494**	0.228	**0,669**
% variability	53.698	12.059	10.954	8,233
Cumulated %	53.698	65.757	76.710	84,943

5. CONCLUSION

The dominance of major elements in the groundwater of the El Meita plain is provided by the chloride and calcium sulphate within salt waters. Mineralization increases from northeast towards southwest, in the direction of the general runoff of groundwater. Binary diagrams of element-chloride were elaborated in order to understand water mineralization. Findings have shown two possible origins: dolomitization and the dissolution of gypsum or reverse ionic exchange base between water and the geological formation fixing sodium and releasing calcium (a hypothesis confirmed by exchange base index). Mineral saturation index indicates that carbonated minerals (dolomite, calcite and aragonite) tend to precipitate while saliferous evaporite minerals tend to dissolve.

The findings obtained after the interpretation of the Principal Component Analysis (PCA) demonstrate the participation of several elements to the mineralization of groundwater in the El Meita Plain (mostly of calcium). Results indicate three main factors: axis F1 for mineralization; axis F2 represented by K^+ and NH_4^+, which demonstrates that the elements are anthropic; axis F3 is a contamination factor, reason for which it does not participate to the mineralization process. Waters used for irrigations are fit for cultures that resist to certain values of salinization.

Acknowledgments

Our thanks go to the Geo-Archaeology Laboratory within the Faculty of Geography and Geology, “Alexandru Ioan Cuza” University of Iasi (Romania), which provided the tools and carried out the data processing. The infrastructure was provided through the POSCCE-O 2.2.1, SMIS-CSNR 13984-901, No. 257/28.09.2010 Project, CERNESIM.

REFERENCES

Adopo, K.L., Romanescu, G., N'Guessan, A.I. & Stoleriu C., 2014. *Relations between man and nature and environmental dynamics at the mouth of the Komoé river, Grand-Bassam (Ivory Coast).* Carpathian Journal of Earth and Environmental Sciences, 9(4), 137-148.

Aouidane, L. & Belhamra, M., 2017. *Hydrogeochemical processes in the Plio-Quaternary Remila aquifer (Khenchela, Algeria).* Journal of African Earth Sciences, 130, 38-47.

Belksier, M.S., 2009. *Hydrogéologie et hydrochimie de la nappe superficielle dans la région de l'Oued Righ et l’évaluation de sa vulnérabilité,* 2009. Thèse de magister, Département des Sciences de la Terre, Université d’Annaba.

Beltrando, G., 2014. *Groundwater in the plain of the Crau (south-east of France): between historical abundance and modern vulnerability*, In: *Water resources and wetlands, Conference Proceedings, 11-13 September 2014, Tulcea-Romania* (eds. Gastescu P., Marszelewski W. & Bretcan P.), Transversal Publishing House, Targoviste, p. 44-50.

Brinis, N., Boudoukha, A. & Djaiz, F., 2014. *Case of aquifer of El-Outaya North-west of Biskra-Algeria.* International Journal of Environment & Water, 3(1), 44-51.

Chapelle, F., 2001. *Groundwater Microbiology And Geochemistry.* John Wiley & Sons, Inc. NY.

Drever, J.F., 1997. *The geochemistry of natural waters.* 3rd ed. New York – Prentice-Hall INC.

Duby, C. & Robin, S., 2006. *Analyse en Composantes Principales.* Institut National Agronomique Paris – Grignon, p. 1-54.

Fehdi, C., Boudoukha, A., Rouabhia, A. & Salameh, E., 2009. *Caractérisation hydrogéochimique des* *eaux souterraines du complexe aquifère Morsott-Laouinet, (Sud-Est algérien).* Afrique Science, 5(2), 217-231.

Fekrache, F., 2015. *Contribution à l'étude de l'origine de la salinité des eaux du lac Fetzara-Annaba, Département de biologie.* Thèse de Doctorat, Université d'Annaba.

Ghodbane, M., Boudoukha, A. & Benaabidate, L., 2015. *Hydrochemical and statistical characterization of groundwater in the Chemora area, Northeastern Algeria.* Desalination and water treatment, 1-11.

Hamzaoui Azaza, F., Bouhlila, R. & Gueddari, M., 2012. *Characterization of the mineralization of the Triassic water table (South-East Tunisia) by geochemical and statistical methods.* Geo-Eco-Trop, 36, 49-62.

Houha, B., 2007. *Étude du fonctionnement hydrogéochimique, salin et isotopique des eaux de Khenchela.* Doctoral Thesis, University of Annaba, Algeria.

Ishaku, J.M., Ankidawa, B.A. & Abbo, A.M., 2015. *Groundwater Quality and Hydrogeochemistry of Toungo Area, Adamawa State, North Eastern Nigeria.* American Journal of Mining and Metallurgy, 3(3), 63-73.

Kloppmann, W., Bourhane, A. & Asfirane, F., 2010. *Méthodologie de diagnostic de l'origine de la salinité des masses d'eau.* BRGM, *action* 3, Orléans-France.

Kouzana, L., Ben Mammou A. & Sfar Felfoul, M., 2009. *Seawater intrusion and associated processes: Case of the Korba aquifer (Cap-Bon, Tunisia).* Académie des sciences Geosciences, 341, 21-35.

Lamini, A., 2012. *Étude Géochimique Et Minéralogique Des Chotts De La Région D'el Hadjira, Département des sciences de la terre.* Thèse de magister, Université Kasdi Merbah Ouargla.

Nadher, A., Magaritz, M. & Mazor, E., 1980. *Chemical reactions of seawater with rocks and freshwater: experimental and field observations on brackish waters in Israel.* Geoch. Et Cosmoch. Acta, 44, 879-886.

Nakayama, T. & Maksyutov, S., 2014. *Surface - groundwater interaction and its effect on carbon cycle in terrestrial-aquatic continuum,* In: *Water resources and wetlands, Conference Proceedings, 11-13 September 2014, Tulcea-Romania* (eds. Gastescu P., Marszelewski W. & Bretcan P.), Transversal Publishing House, Targoviste, p. 44-50.

OSS (Observatoire du Sahara et du Sahel), 2003. *Gestion commune d'un bassin aquifère transfrontière.* Système Aquifère du Sahara Septentrional, 1ère édition, Projet SASS.

Peter-Borie, M., Lucassou, F. & Aubie, S., 2009. *Contexte Hydrogéologique Et Hydraulique Du Littoral Basique Français, Observation De La Côte Aquitaine.* BRGM, 31, *France.*

Rodier, J., Legube, B. & Merlet, N., 2009. *L'analyse de L'eau.* 9th Edition, Dunod, Paris.

Romanescu, G. & Cojocaru, I., 2010. *Hydrogeological considerations on the western sector of the Danube Delta – a case study for the Caraorman and Saraturile fluvial-marine levees (with similarities for the Letea levee).* Environmental Engineering and Management Journal, 9(6), 795-806.

Romanescu, G., Paun,. E., Sandu, I., Jora, I., Panaitescu, E., Machidon, O. & Stoleriu, C., 2014. *Quantitative and Qualitative Assessments of Groundwater into the Catchment of Vaslui River.* Rev. Chim. (Bucharest), 65(4), 401-410.

Romanescu, G., Curca, R.G. & Sandu, I.G., 2015. *Salt deposits in the Romanian Subcarpathians - genesis, repartition and ethnomanagement.* International Journal of Conservation Science, 6(3), 261-269.

Sedrati, A., Houha, B., Romanescu, G., Sandu I.G., Diaconu, D.C. & Sandu, I., 2017. *Impact of Agriculture upon the Chemical Quality of Groundwaters within the Saharian Atlas Steppe El Meita (Khenchela-Algeria).* Rev. Chim. (Bucharest), 68(2), 420-423.

Siebert, S., Burke, J., Faures, J.M., Frenken, K., Hoogeveen, J., Doll, P. & Portmann, F.T., 2010. *Groundwater use for irrigation – a global inventory.* Hydrology Earth Syst. Sci., 14, 1863-1880.

Tabouche, N. & Achour S., 2004. *Étude de la qualité des eaux souterraines de la région orientale du Sahara septentrional algérien,* Larhyss Journal, 3, 99-113.

Vainu, M., Terasmaa, J., Vaasma, T. & Vandel, E., 2014. *Groundwater seepage patterns in a closed-basin lake before and after an increase in groundwater pumping rates from an unconfined aquifer in the Kurtna Kame field, Estonia,* In: *Water resources and wetlands, Conference Proceedings, 11-13 September 2014, Tulcea-Romania* (eds. Gastescu P., Marszelewski W. & Bretcan P.), Transversal Publishing House, Targoviste, p. 189-196.

Zeddouri, A., Derradji, F. & Hadj-Saïd, S., 2010. *Salinity origin of terminal complex water in Ouargla region (south east of Algeria).* Phys. Chem. News, 53(5), 62-69.

Zektser, I.S. & Everett, L.G., 2004. *Resources of The World And Their Use.* UNESCO, Paris.

Received at: 10. 08. 2017

Revised at: 20. 10. 2017
Accepted for publication at: 21. 12. 2017