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HYDROCHEMISTRY CHARACTERISATION OF GROUNDWATER SALINITY IN KERT AQUIFER, NE MOROCCO

Mohammed ELGETTAFI[1,2], Mahjoub HIMI[1], Albert CASAS[1],
Abdenabi ELMANDOUR[2]

ABSTRACT:
Increasing of groundwater salinity is one of significant signs of degradation of groundwater quality in arid and semi-arid regions. To determine the salinity origin in Kert plain located in NE of Morocco, 32 producing wells were studied. The hydrochemical data show that the freshwater (622 g/l) in NW of the plain are clearly distinct from saline waters (6018 mg/l) in the rest of the plain. Hydrochemical data also show the contribution of the local geology to the increased groundwater salinity. Indeed, the dissolution of evaporitic sediments (gypsum and halite) developed during messinian salinity crisis. The hydrodynamic interpretation allowed determining the influence of these minerals to the enrichment of groundwater with Ca^{2+}, Mg^{2+}, Na^+, Cl^- and SO_4^{2-}.

Keywords: ***Groundwater salinity, hydrochemistry, messinian salinity crisis, Kert NE Morocco.***

1. INTRODUCTION

In recent years, the scarcity of water resources, detorioration of groundwater and the impact of droughtar particulary taken into account by the authority and scientific community. In the objectif to guaranting access to safe drinking water, agricultural production for food security, Morocco has strated since the 1980s an integrated policy for water resources. This policy can be summarized in planning of water resources to sustain the adequacy of water resources and nation requirements.

Morocco is a country mainly a semi-arid climate in most parts of its territory. The contributions of rainfall across the country are estimated at 150 M of m^3 (*Riad, 2003*). Thus, over of 50% of these contributions are distributed on 15% of the total land area, and useful rain is only 20% (*Bzioui, 1996*).

In Mediterranean basin, groundwater salinity generaly are linked to Neogene basin, for example Ech-Chelif basin in NW of Algeria (*Achour et al., 1997*), Pisa plain in Italy (*Grassi et al,. 2005*), Palestine (*Gavrieli et al,. 1995*), Rhodop plain in Greece (*Petalas, 1999*) Sinae Sahara in Egypt (*Rosenthal et al., 2007*). Many works in northestearn of Morocco show that salinity increases in the majority of aquifers. In shallow coastal aquifer of Saidia the water is brakish (*Melloul et al., 2007*). In Triffa plain the electrical conductivity varies between 600 and 11120 µs/cm, and the chemical facies is Cl-Na (*Elmandour et al., 2008*). In Bou Arg unconfined aquifer, in northeastern mediterranean coast, the higher values of hydraulic conductivity facilitate seawater intrusion (*Elyaouti et al., 2009*). Hydrochemisrty is an essential tool for understanding the groundwater evolution (*Pilla et al., 2006*). It provides information on the water provenance, residence time, flow

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[1] *Barcelona University, Faculty of Geology, Dept de Geoquimica, Marti i Franquès s/n 08028 Barcelona, Spain.*
[2] *University of Cady Ayyad, Faculty of Semlalia Science, Labo GEOHYD, BP 2390, 40000 Marrakech, Morocco.*

direction and relation with surface waters. Freshwater strongly affected by interaction with minerals of the geological reservoir (*Manno et al,. 2007; Melish et al,. 2008*), is primarily controlled by weathering of aluminosilicates, dissolution of carbonate and evaporite minerals and cation exchange reactions. The aim of this study was to investigate the geochemical caractristics of water in order to identify the main hydrogeochemical process controlling the chemical composition based on major ion chemistry.

2. GEOLOGICAL AND HYDROGEOLGICAL SETTING

The Kert basin, which covers a total area of about 250km^2, is located in the northeastern part of Morocco and extends between latitudes 34°55’ and 35°54’N, and longitudes 3°19’ and 3°34’W (**Fig. 1**). The kert depression received during the Miocene to Villafranchian a very mixed and varied thick marine and continental sedimentation. It is limited to the east by the western Gareb range. This foreland rifain chain formed by an anticlinal significantly oriented towards east-west and disappears in the west under the thrust masses of rifain domain. The Temsamane sequence which limits the plain in the north was affected by a compressive tectonic event generating a N120ºE fracture cleavage associated with green shale (*Frizon de Lamotte, 1985*). In the south part we found intra rifain nappes and marls of Miocene. The Jurassic and Cretaceous deposits mostly constitute of carbonates rocks; limit the plain in the west of Midar city and in the south (**Fig. 1**). Several studies have been done to date the opening of Kert basin. During early-middle Tortonian a series of conjugate strike-slipe faults (N70ºE to N90ºE) occurs east of Nekor fault, related to the formation of Kert basin (*Ait Brahim et al,. 2004*). While, (*Azdimousa et al,. 2007*) suggest that the younger normal fault system records N-S extension controlling the formation of the Kert Basin dates the Messinian-Pliocene age. In the Messinian, Kert basin deepened with the Messinian Sea level rise (*Haq et al., 1987*). It is known that in the occidental Mediterranean Neogene basin the sedimentological history is marked by evaporates series related to messinian salinity crisis caused by closing of Gibraltar strait (*Bourgois, 1977*). Whereof, *Hervouet* (*1985*) defined a complex tectono-sedimentary (Gareb-Kebdana chaotic unit) extending from Kebdana in the east towards the Midar city in the west, often composed by a gypseous marl. In the west of plain, the scrapes were principally a fragment of gravity-driven nappes of internal and external rifain domain slided westward along the foreland (*Hervouet, 1985*). The plain contains a transgressed post nappe deposits (*Azdimousa, 1999*). The micropaleontological datation of the sedimentary filling the Kert basin indicate upper Miocene and Pliocene ages (*Feinberg, 1986*).

The hydrogeology character of the study area were described by (*Carlier, 1973*), based on data obtained from pumping tests and electrical geophysics. There is an unconfined aquifer which extends under the Kert plain and flows on the Miocene blue marls (substratum of aquifer). The strata of various hydrogeological formations can be identified as follows. The substratum of the aquifer is represented by the Miocene transgressed marls, which is overlaid by a contemporary deposit made up of limestone and conglomerate. We assume that the Miocene formation contains the gypsum as well as the one outcrop in the region. The series ends with gravel, silt and clay Villafranchian age. Two vertical faults have controlled the Kert basin during the Miocene. These faults have collapsed the center of the plain and have raised the borders north and south. Consequently, the aquifer might be hydraulically connected through those faults with the underlying Jurassic unit. Two knowledge boreholes were drilled in this latter unit in order to find an aquifer in the deep resisting formation determined by geophysics (*Zeryouhi, 1971*). The first borehole number is 1635/6 with the depth of 801m (X= 685,.18 Y= 486,85 Lambert coordinates) and the second borehole number is 1636/6, 684m in depth (X= 679,14 Y= 484,05 Lambert coordinates). Both of them had not given the expected result.

Thirty two Pumping tests were performed on the plain. Permeability and transmissivity computed using classical Theis-Jacob method amount from $0,4.10^{-5}$ to 18.10^{-5} m/s and from $0,1.10^{-3}$ to 34.10^{-3} m^2/s respectively. Storage coefficient estimated from these tests is 0,3% to 3,5%.

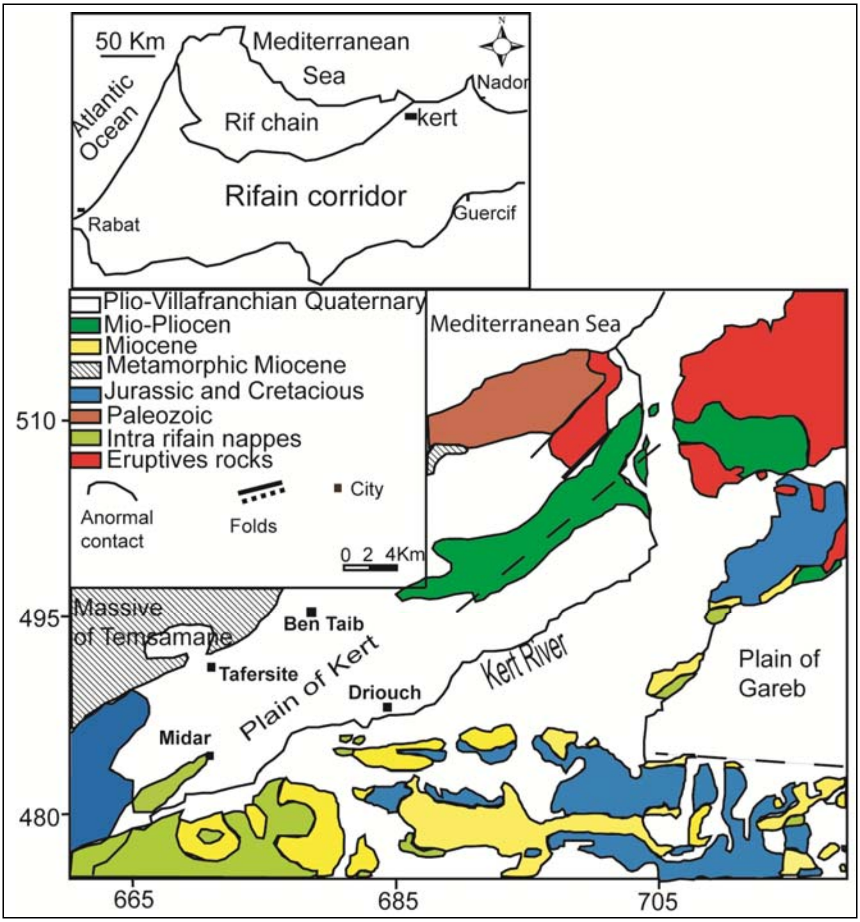

Fig. 1 Carte géologique de la plaine de Kert (*Carlier, 1973,* modifié)

3. METHODOLOGY

The pH, temperature and specific electrical conductivity (SEC) measurments were maked in situ. The electrical conductivity was measured by a VWR EC300 instrument, previously calibrated by the conductivity solution HI 70031 (HANNA). pH measurements were carried out using a glass electrode connected to a VWR pH100-meter, after calibration with pH 4.01 and 7.00 buffer solution. All of the water samples, were analysed for major cation (Na^+, K^+, Ca^{2+}, Mg^{2+}) major anions (Cl^-, SO_4^{2-}, HCO_3^-), and total dissolved solids

(TDS), in Hydraulic Laboratory of Moulouya Agency, Oujda, using standard analitical procedures. Ca^{2+}, Mg^{2+}, Cl^{-} and HCO$_3^{-}$ were determined by trimetrique methodes. The concentration of Na^{+}, k^{+}, SO$_4^{2-}$ and NO$_3^{-}$ was measured by atomic absorption spectrophotometry. The values of saturation index (SI) are less than or equal 5%, which is an acceptable error for the purpose of this study (SI= log(PAI/Ks)) (*Appelo and Postma, 1996*). IAP being the ion activity product of the mineral-water reaction and Ks the thermodynamic equilibrium constant at the measured temperature, were calculated by ion activities. Goundwater is oversaturated with respect to calcite and dolomite (0 to 0,73 and 0 to 1,5 respectively), and undersaturated with respect to gypsum and halite (-1,57 to 0,08 and -6,5 to -4 respectively).

4. RESULTS AND DISCUSSION

Analyses of chemical results of 32 wells are listed in **Table 1**. SEC values are in the range of 1130-10130 µs/cm. The dominant cations are Na^{+} and Ca^{2+} (max values are 1750 and 580 mg/l respectively) and the dominants anions are Cl^{-} and SO$_4^{-}$ (max values are 2712 and 1536 mg/l respectively). Ion ration Ca/Mg varies from 0,23 to 1,95. Bicarbonates concentration ranges from 128 to 982 mg/l. Salinization increases gradually from the north to the south, with high concentration in Midar and Driouch region (**Fig. 2**). Freshwater is situed in Tafersite and Ben-Taib (622 mg/l, 1130 µs/cm). pH ranges from 6,5 to 7,75. Temperature values are (19ºC to 26ºC).

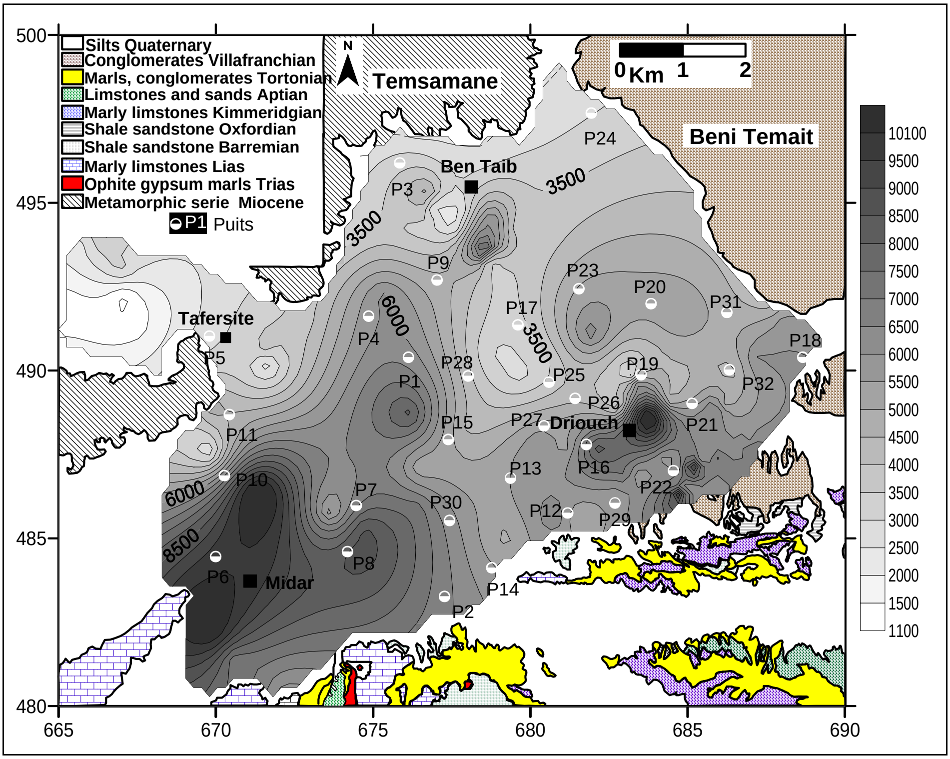

Fig. 2 Elecrtical conductivity distribution in Kert aquifer

Table 1. ***Hydrochimical analyses of groundwater in Kert aquifer***

	T°C	**pH**	**TDS (mg/l)**	**CE (µS/cm)**	**Cations (mg/l)**				**Anions (mg/l)**		
					Na^+	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**SO^{2-}_4**	**HCO_3^-**	**Cl^-**
P1	23	7,1	1439	2980	320	6	120	51	163	238	541
P2	25	7,41	4250	7745	1090	8	148	151	1536	305	1012
P3	23	7,2	1538	1940	295	3	160	75	192	164	649
P4	24	7,05	2772	5010	575	6	156	168	537	274	1056
P5	21	7,52	622	1130	112	2	56	22	105	250	131
P6	22	6,5	5897	9650	1750	45	60	155	278	982	2627
P7	23	6,99	2828	6200	515	3	171	132	568	378	1061
P8	25	7,1	6018	10130	936	8	580	357	1065	360	2712
P9	22	7,57	1900	3570	400	6	140	87	297	171	799
P10	21	7,57	3600	5560	680	9	344	158	509	171	1729
P11	23	7,52	1721	2500	370	6	145	58	505	250	387
P12	22	7,1	4497	6450	880	7	248	262	1413	238	1448
P13	23	7,5	3399	4410	620	40	242	153	724	171	1448
P14	23	7,5	3979	4740	880	6	220	177	1401	177	1118
P15	22	7,48	3290	5360	810	5	152	126	949	183	1065
P16	21	7,5	4330	6278	770	6	354	204	1233	286	1477
P17	24	7,57	3348	5960	800	7	202	182	485	195	1697
P18	23	7,5	3592	6440	749	9	264	197	345	189	1839
P19	25	7,4	3968	6920	920	6	292	120	806	262	1562
P20	23	7,25	1983	3640	479	6	106	90	192	152	958
P21	23	7,6	3161	5550	810	7	156	87	696	225	1180
P22	24	7,7	3626	5965	640	5	368	177	1382	158	896
P23	24	7,75	1497	1438	312	4	88	59	192	232	610
P24	25	7,7	1522	2745	300	2	118	69	278	152	603
P25	22	7,2	2782	4465	605	5	252	129	480	168	1143
P26	26	7,15	3947	6790	920	8	294	121	782	207	1615
P27	25	7,1	3386	5605	920	5	62	136	590	317	1356
P28	23	7,6	1396	3570	310	5	132	41	283	128	497
P29	24	7,5	3676	3850	750	5	264	187	1229	183	1056
P30	23	7,7	3534	6675	630	4	336	153	1469	152	790
P31	24	7,27	2321	4120	572	10	120	113	105	311	1090
P32	25	7,2	4049	7150	880	3	270	191	528	164	2013

5. ORIGIN OF MINERALIZATION

Calculation of the saturation index show that the saturation index the saturation vis-à-vis the calcite and dolomie is generalised in the water s of the aquifer, and therefore regardless of total mineralization. The saturation index of gypsum and halite ranges from under-saturation at equilibrium and are strongly related to chemicals elements (**Fig. 3**, **4**).

So, the presence of gypsum and halite explain so much the high electrical conductivity measured in groundwater. **Fig. 5** shows a tendency to alignment points indicating a common origin of Cl^- and Na^+ which is the dissolution of NaCl. Cl^- is a conservative element, however, some wells (8, 10, 18 and 32) have an excess of Cl^- in comparison with Na^+. This excess suggests that removal of Na+ is due to the reveres cation exchange reaction between water and the aquifer (**Fig. 5**).

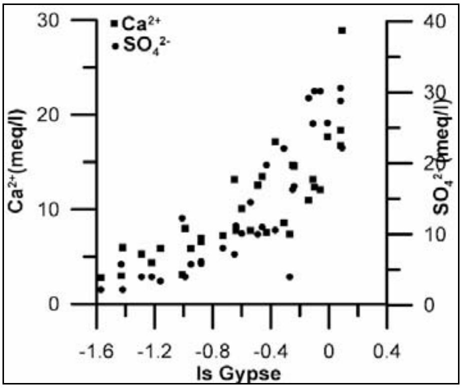

Fig. 3 Relation entre l'indice de saturation de gypse et Ca^{2+} et SO_4^{2-}

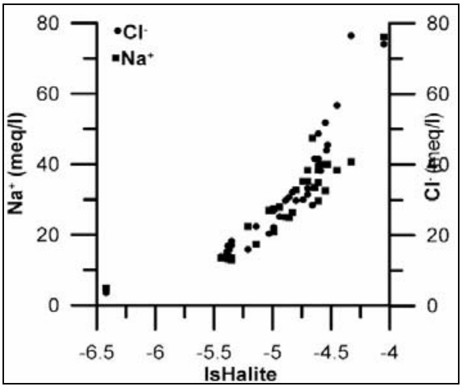

Fig. 4 Relation entre l'indice de saturation de l'halite et Cl^- et le Na^+

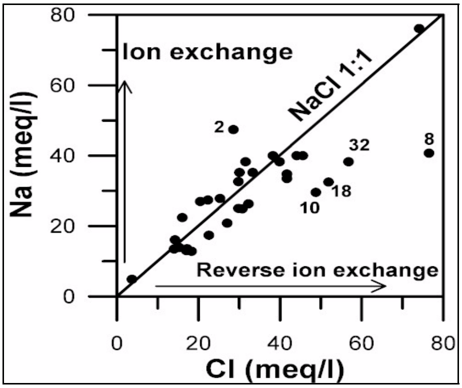

Fig. 5 Relation entre le Cl et le Na

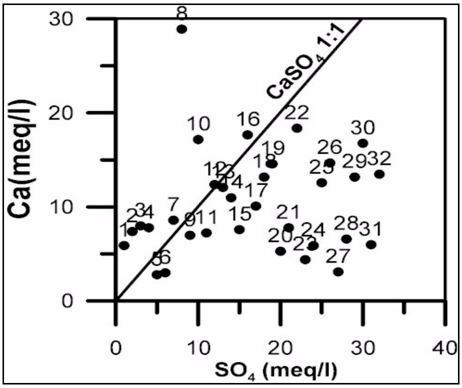

Fig. 6 Relation entre SO_4 et Ca

The SO_4^{2-}/Ca^{2+} graph (**Fig. 6**) does not show a perfect alignment along of Ca/SO_4 aqual concentration line such as Na^+/Cl^-, but rather an enrichment of SO_4^{2-}, except some wells (1, 2, 3, 4 and 8). However, the evolution indicates a common origin would be the dissolution of gypsum. Decrease of sulfate concentration is either by a biological reduction or gypsum precipitation. However, gypsum precipitation cannot take place because index saturation is less than 0. The majority of wells show a high concentration of sulfate. This increase is due both to dissolution of gypsum and or oxidation of sulphide minerals. On the other hand, calcium deficiency is due to cation exchange and carbonate precipitation, two factors known to reduce the concentration of calcium in groundwater.

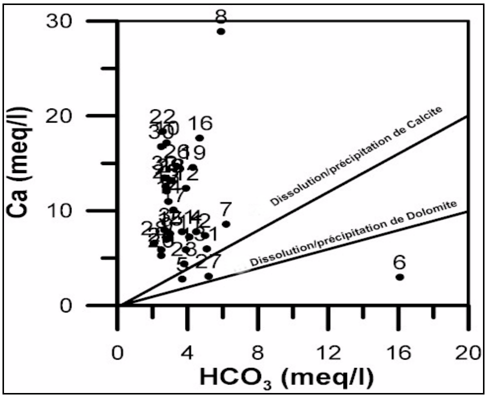

Fig. 7 Relation entre Ca et HCO_3

Calcium concentration evolution is independent of bicarbonates (**Fig. 7**), this means that the concentration of calcium is not related to the dissolution of bicarbonates. This result is relevant because it shows the link between the concentration of Ca^{2+} and gypsum dissolution.

6. CONCLUSIONS

In Kert aquifer groundwater salinity increases gradually from the north to the south in the direction of water flow. This increase follows the same pattern of major elements. These waters have a Cl-Na facies in the north and a Cl-SO_4-Na-Ca/Mg facies in the south.

The hydrochemical study shows that Cl^-, Na^+, Ca^{2+}, SO_4^{2-} and Mg^{2+} are the main elements that cause the salinity. In addition, the hydrodynamic of evaporitc minerals present in a state of under-saturation despite thier presence in high concentration. This condition results from a continuous dissolution leading to enrichment water by evaporitic element. Thus, gypsum dissolution increases Ca^{2+} and Ca/Mg ration. In this case, the phenomenon of dedolomitisation is generated which explains the over-saturation of calcite and dolomite. The geochemical stock og gypsum and halite can be explain the increasing of Cl^-, Na^+, Ca^{2+}, SO_4^{2-} and Mg^{2+} concentration. In fact, this stock is more important for water circulating in the southern part of the plain. Mineralisation required is faster and does not require a long time for the existence of evaporitic sediments. Calcium and magnesium concentration are directly correlated to that of sulfate. Thus, divalent cations concentrations are not controlled by carbonate chemical but rather, by gypsum dissolution. So, the alteration degree of Miocene evaporitic formation which controls the concentration of all major elements.

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