Libyan Agriculture Research Center Journal International 3 (6): 297-306, 2012
ISSN 2219-4304
© IDOSI Publications, 2012
DOI: 10.5829/idosi.larcji.2012.3.6.1503

The Continental Intercalaire Aquifer in Southern Tunisia: Hydrogeochemical and Isotopic Investigation

[1]Zahra Dhaoui, [1]Friha Hadj Ammar, [1]Kamel Zouari and [2]Aissa Agoun

[1]Laboratory of Radio–Analyses and Environment,
National Engineering School of Sfax, Tunisia
[2]Water Division of Kebili. BP 4200 Kebili, Tunisia

Abstract: Our study concerns the deep Continental Intercalaire (CI) aquifer in southern Tunisia. This groundwater reservoir constitutes one of the largest confined aquifers in the world. The present work investigates the chemical and isotopic composition of this aquifer as well as its geometry in Southern Tunisia. Indeed a great lateral extension of the aquifer and its relatively high thickness throughout the southern Tunisia were highlighted. Also it has been shown that this aquifer is differentiated into several units of continental formations of the Lower Cretaceous (Neocomian, Barremian, Aptian and Albian) giving rise to changes in piezometry and lithology. In southern Tunisia, large scale groundwater flow paths are towards the Chotts region. The main flow lines are those that continue from Algeria as well as those from the Dahar uplands. Geochemical processes occurring within groundwaters and reactions with aquifer minerals have a profound effect on water quality. Therefore, the assessment of the importance of such processes is essential for groundwater resources to be properly developed for human consumption or pastoral activities. This approach is likely to be involved in our case study; indeed, the water types are dominated by Na^+, $SO4^{2-}$, Cl^- and Ca^{2+} throughout most of the basin. The main source of salinity of the CI groundwaters is likely related to the dissolution of evaporitic minerals but also to the process of ionic exchange. The stable isotopes composition (^{18}O, ^{2}H) confirms that the recharge of CI groundwater in southern Tunisia occurs mainly in the Dahar uplands. The depleted stable isotope composition of CI groundwater, have shown also that the CI aquifer has been recharged under cooler paleoclimatic conditions.

Key words: Groundwater · Isotopes · Recharge · Palaeowaters · Continental Intercalaire · Southern Tunisia

INTRODUCTION

The CI aquifer is one of the largest confined aquifers in the world. It is shared between Algeria, Tunisia and Libya and covers a surface of more than 1 million Km^2 of which 700.000 Km^2 in Algeria; 80.000 Km^2 in Tunisia and 250.000 Km^2 in Libya [1].

Together with the Complex Terminal (CT) aquifer, the deep CI forms the major aquifer system in southern Tunisia. Indeed, the CI groundwater reservoir is contained in continental formations of the Lower Cretaceous (Neocomian, Barremian, Aptian and Albian), however the CT aquifer is hosted in the upper Cretaceous and tertiary formations.

With an increasing request and a rather ambitious development prospects, the management of groundwater resources in southern Tunisia has been a competitive request between the various economic sectors (agriculture, drinking water, tourism, industry) with preponderance of the agricultural needs.

The extension of irrigated zones as Rejim Maatoug, Dhafria, Kebili, Tozeur and Gabes regions generated the overexploitation of the CI aquifers. It is particularly in the regions of Tozeur and kebili where the principal oases of the country are located, that this exploitation respectively reaches 93% and 98% of the groundwater resources [2].

Corresponding Author: Zahra Dhaoui, Laboratory of Radio–Analyses and Environment, National Engineering School of Sfax. BP1173, 3038 Sfax, Tunisia. Tel: 00 216 74 677 425. Fax: 00 216 74 275 595,

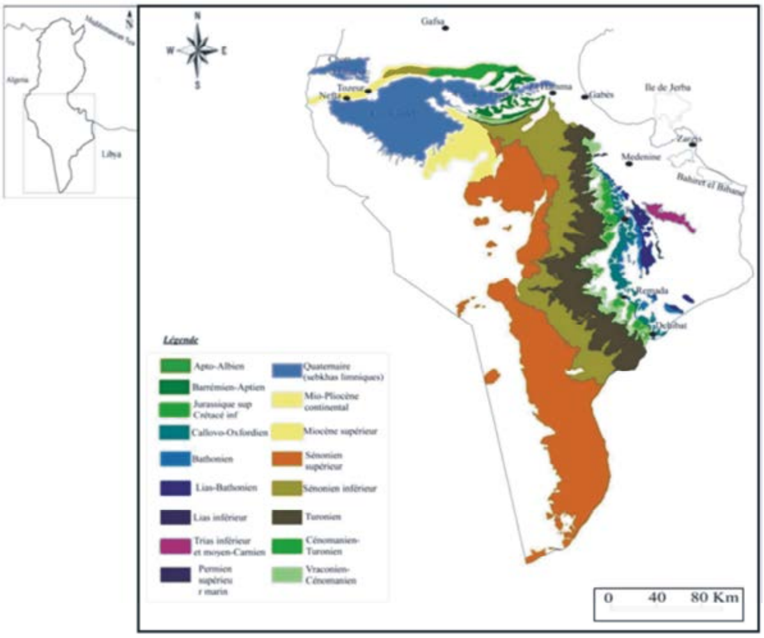

Fig. 1: Geological map of the study area

This exploitation has involved a total mobilisation of the water resources of deep aquifers, a decline in water quality and likely also the development of the hydromorphism in several irrigated perimeters.

Hence, it seems fundamental to better understand the hydrodynamics and the recharge conditions for these groundwater-resources management.

The CI aquifer has been the subject of multiple studies. It was demonstrated that the CI aquifer consists of several horizons with strong artesian pressure (5-25 bars) and with temperatures from 65 to 75°C [3, 4]. It has been shown that the CI water chemistry is of Na-SO_4-Cl composition and the mineralisation increases along the flow lines from 1.5 to 3 g/l. Edmunds *et al* have shown that the δ^{18}O and δ^{2}H values indicate a cooler recharge regime with rainfall having lower primary evaporation than today which is indicative of late Pleistocene recharge.

The main objective of this paper is to provide a better understanding of the hydrodynamic functioning of the CI aquifer based on the combination of hydrochemical and isotopic data coupled with the analyses of the stratigraphic settings of the study area.

Study Area: Southern Tunisia is limited to the West by the Algerian border, to the East by the Dahar reliefs, to the North by the Chott el Gharsa and Chott el Fedjej depressions and to the South by the Algerian-libyan border.

The climate is arid to semi arid with Saharan tendencies. The mean annual temperature is 21°C. Potential evapotranspiration exceeds 1,700 mm/year and precipitations are characterized by their irregularity and they exceptionally exceed 100 mm/year.

Geology and Hydrogeology: In Southern Tunisia, a large extension of sedimentary deposits of Mesozoic age was highlighted from the area of Gafsa and Chotts in the North to the Libyan frontier in the South [5].

The Cretaceous, main objective of water wells in southern Tunisia is largely outcropping along Gafsa and Chotts ranges as well as in the Dahar upland. The lower cretaceous is characterized by significant variations in facies and thickness extending from the saharan platform to the Chott area (Fig. 1).

This period corresponds to an episode of continental sedimentation continued until Vraco-Cenomanian [6]. Therefore, it is also known as Continental Intercalaire; a succession of detrital sediments separated by clay rich strata and gypsum intercalations leading to an extent of heterogeneity within this aquifer.

In Southern Tunisia, tectonic processes have generated several geological provinces of stratigraphic and structural particularities different from one province to another:

- The Dahar upland which consists of a N-S trending [5, 7-9]. It is located between the plain of El-Ouara in the east and the oriental Erg in the West. The Chotts depression constitutes its Northern boundary.
- The Djeffara coastal plain which consists of a NW-SE trending [5, 8, 9] separating the Mesozoic outcrops of the Dahar to the West from the Mediterranean coast to the East. It is limited by the dome of Chott el Fedjej to the North and extends to Tripoli towards the South.
- The Northern range of Chotts which corresponds to the Southern Atlas Saharan Mountains and consists of a E-W trending [5] stretching to Chott el Fedjej area towards the South and to Djerid and Nefzaoua towards the West.
- The Southern range of Chotts which corresponds to the Tebga of Kebili chain and constitutes also of a E-W trending of cretaceous age. This massif borders the Chotts of Djerid and El Fedjej to the North [5].

The Djeffara coastal plain is affected by a system of faults generated by the different orogenic phases that have given rise to a structure into uplands and sedimentary basins.

The overthrow faults in southern Tunisia constitute a set of faults which consists of a NW-SE trending in relay from the region of Gafsa up to Chott el Fedjej and which constitutes also a set of echelon faults between the Matmata and the Mediterranean sea in the form of stepped levels.

This set of faults extends towards the SE across the faults of Ben Gerdane and Djerba Zarzis constituting therefore the continuity of the NW-SE trending faults of El-Hamma region whose role in the communication between the CI aquifer in Chott el Fedjej and the Djeffara aquifer of Gabes is determining.

These faults are at the origin of the subsidence of the eastern flank of the Djeffara dome under the Mediterranean Sea. The most important one is the fault of Medenine of a NW-SE trending as well. The throw of this fault seems to increase in the range of 200m from North to South. At Matmata, it seems to reach 1000m [3]. This fault extends across the coastal Djeffara plain [6]. The age of this tectonic activity may be reported to the end of the Atlasic movements (Post Oligo-Miocene) [10, 11]. These faults are part of a complex called the South Tunisian accident [10].

The compressive faults consist of a NE-SW trending which is pursued throughout the Quaternary period [12]. The major tectonic features of these movements are shown in the Draa Djerid Ridge of a NE-SW trending as well and formed during the Alpine (Late Cretaceous-Early Eocene) tectonic phases [7]. This ridge is a horst separating the subsiding Chott el Gharsa to the NW from Chott Djerid to the SE.

This structural configuration in southern Tunisia leading to the individualization of horsts and grabens is so important in the hydrogeological scheme obviously in the hydraulic communications between aquifers.

Lithostratigraphic correlation along a SE-NW cross section has been established to study the geometry and lateral extension of the CI aquifer system, as shown in Fig. 2.

Indeed, this cross section shows a/Great lateral extension of the aquifer and its relatively high thickness b/Disturbance of the hydrodynamic continuity within the aquifer c/Heterogeneity of the aquifer system d/ Differentiation of the aquifer into several levels isolated from each other e/Variations in the position of the roof and the wall of the different clastic formations constituting the reservoir f/Deepening and thickening of the layers towards the Chotts region.

As shown in Figure 3, groundwater flow in the CI of the Great Oriental Erg takes place towards a single discharge area in the Gulf of Gabes and in the Chott region of Tunisia (Fig. 3):

- SW-NE direction: the principal groundwater flow line in the Continental Intercalaire comes from the Algerian frontier towards the discharge zone in the Gulf of Gabes and in the coastal aquifer of Djeffara. The hydraulic gradient increases at El-Hamma region; this explains the discharge effect through vertical leakage of water of the Kebeur el Hadj series.
  The fault of El-Hamma is responsible of this configuration which makes of the Chott el Fedjej region the single discharge zone of the CI aquifer in Southern Tunisia [3, 13, 14].
- SE-NW direction: this flow direction highlights the flow line coming from the Cretaceous outcrops located in the Dahar reliefs. Indeed, the piezometric lines indicate a local recharge area of the CI aquifer via water runoff.
- SSW-NNE coming from the Algerian-libyan frontier towards the discharge area of the aquifer.

Groundwater Chemistry: Groundwater well head temperatures range between 21°C in the Dahar area and 86°C in the Djerid area. Well depths are between 124m in the Dahar reliefs and over 2900m in the deepest part of

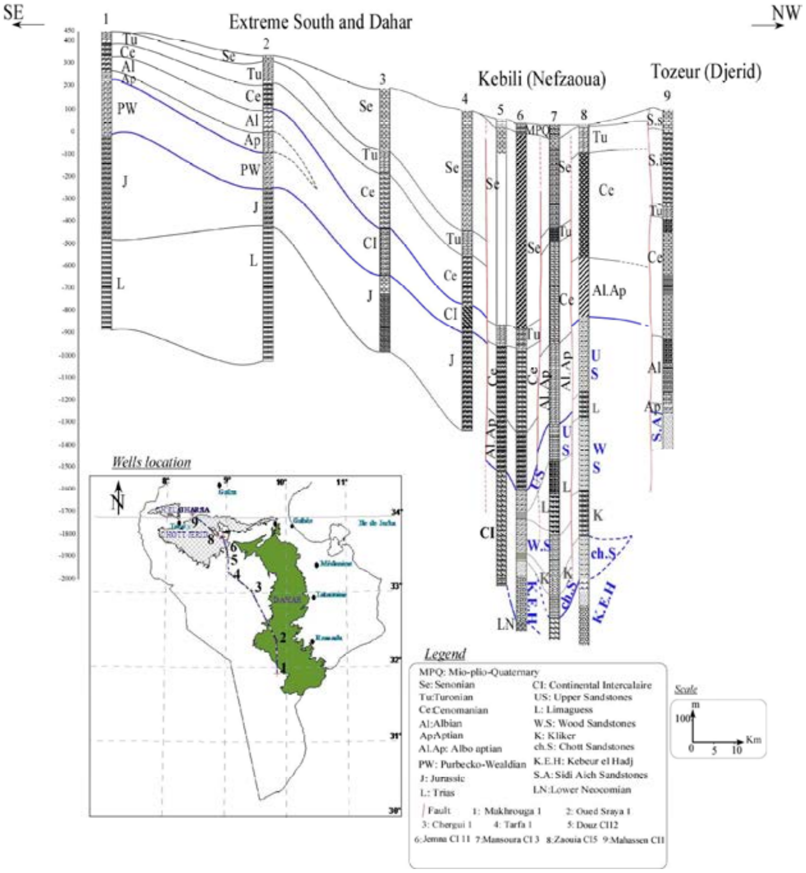

Fig. 2: SE-NW lithostratigraphic cross section showing the structure and the extension of the CI aquifer in southern Tunisia

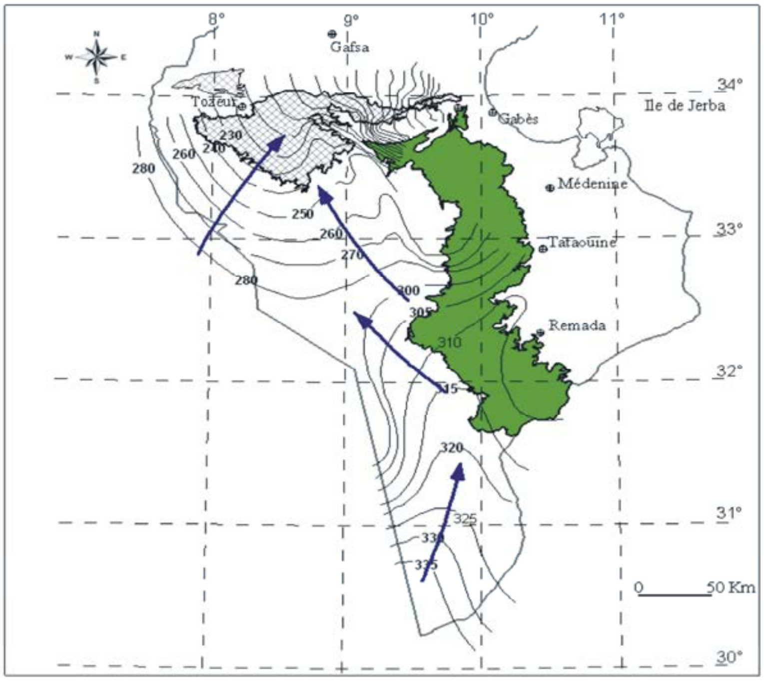

Fig. 3: Piezometric map of the CI aquifer in Southern Tunisia (Abid, 2004. Edited [25])

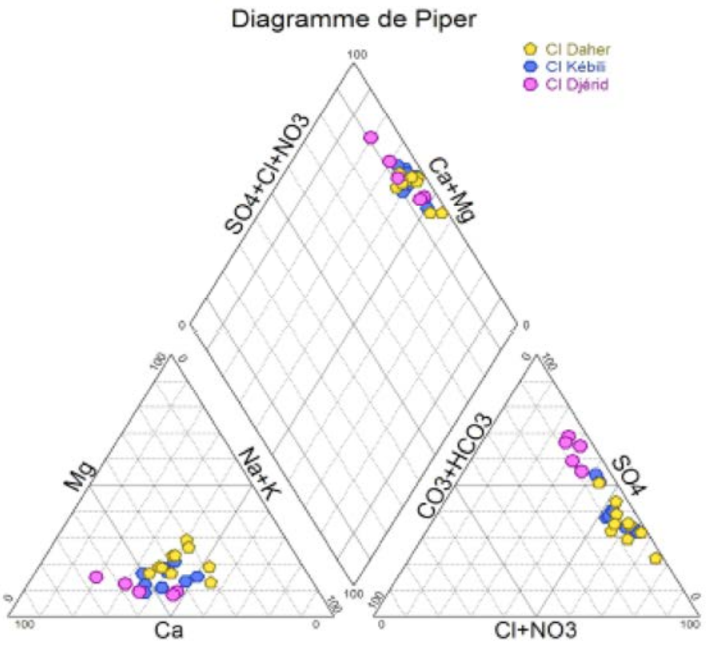

Fig. 4: Piper diagram showing some major chemical compositions of Continental Intercalaire aquifer from southern Tunisia

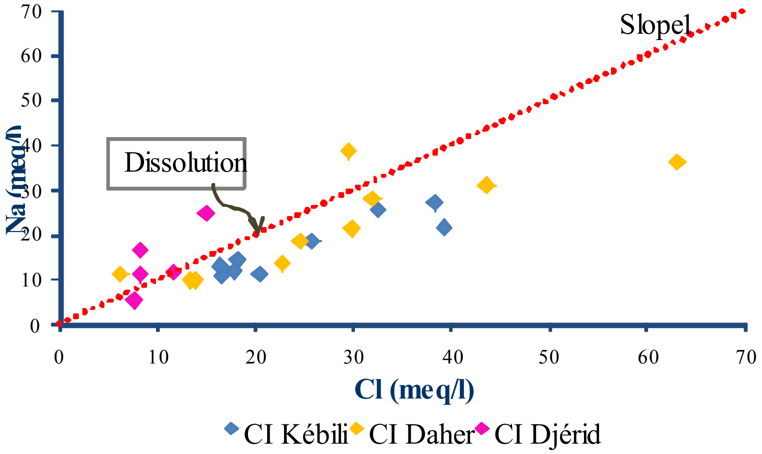

Fig. 5: Relationship between major elements Na/Cl of the analysed groundwater samples

the basin. These two physical parameters are positively correlated. Indeed, the CI groundwater flowing from the Dahar reliefs up to the Chott region shows a progressive increase in temperature with the deepening of the aquifer which highlights the thermal gradient in accordance to the SE-NW flow path of the aquifer.

The conductivity values vary between 1991µs/cm and 9030 µs/cm. The electrical conductivity and the total dissolved solids over the study area are somewhat similar. They show an increase from the Dahar reliefs towards the discharge area (Chott el Fedjej) [14, 15].

In this study, piper triangular diagram is used to obtain a preliminary geochemical characterisation through the identification of different groundwater types, shown in Fig. 4.

The CI groundwaters are generally enriched in Ca and Na. In terms of anion contents they are typically dominated by sulphate and chloride. These anions and cations contents show two main groundwater types Ca-SO4 and Na-Cl.

The positive correlation between Na^+ and Cl^- (Fig. 5) for most groundwater samples suggests that these waters seem to have the same origin of mineralisation which is

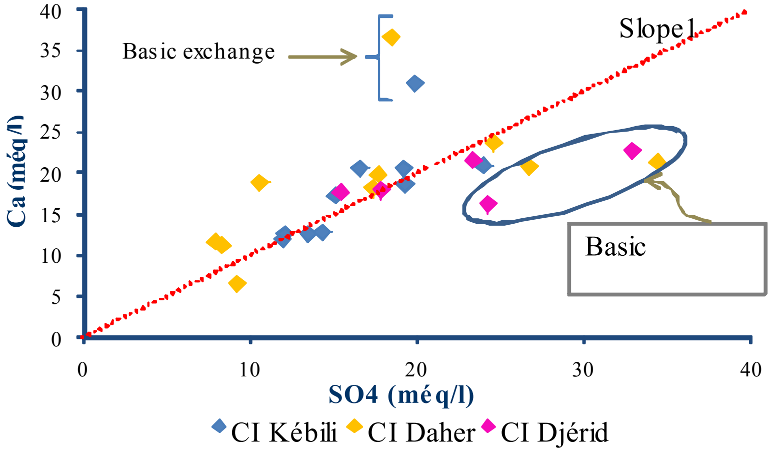

Fig. 6: Relationship between major elements Ca/SO_4 of the analysed groundwater samples

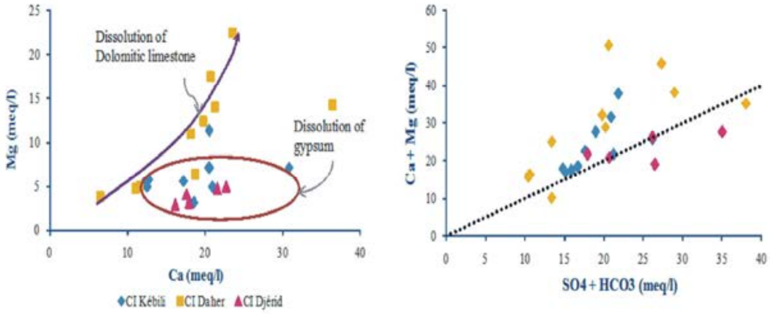

Fig. 7: Relationship between Ca/Mg and (Ca+Mg)/(SO4+HCO3) of the analysed groundwater samples

Halite dissolution. However, the excess of Cl^- with respect to Na^+ ions for some water samples is probably due to the cation exchange process which absorb Ca^{2+} on the clay fraction as Na^+ is released [14].

This phenomenon can be also observed in the Ca^{2+} Vs $SO4^{2-}$ diagram (Fig. 6). This correlation shows a progressive increase in Ca^{2+} contents with sulphate ions for the most of groundwater samples except for Tozeur CI2 and El Hamma CI4 samples located in the Djerid area and also for Khouhil 5 and El Angoud samples located in the Dahar reliefs. These samples show depletion in Ca^{2+} contents relative to SO_4^{2-} unlike kamour SP4 and Menchia CI6 samples that show an excess in Ca^{2+} versus SO_4^{2-}.

This correlation suggests therefore that these ions (Ca^{2+} and SO_4^{2-}) are the result of the dissolution of gypsum ($CaSO_4$, $2H_2O$) or anhydrite ($CaSO_4$) across most of the aquifer with however the presence of other phenomena at the origin of this excess and/or Ca depletion. This is probably due to cation exchange reactions in clay minerals and/or calcite precipitation.

In order to highlight the contribution of the Mg^{2+} and Ca^{2+} ions to the mineralisation of the CI groundwaters, we have established the relations Mg^{2+}/Ca^{2+} and (Mg^{2+} + Ca^{2+})/ (HCO_3 + SO_4) (Fig. 7).

Most groundwater samples located in Dahar uplands show a progressive increase in Mg^{2+} contents compared to samples located in Nefzaoua and Djerid areas. These relatively high contents in Mg^{2+} are related to the dissolution of dolomitic limestones located in Dahar reliefs.Whereas, at Djerid and Nefzaoua, the increase in Ca^{2+} contents is due to the dissolution of gypsum and highlights therefore the limited effect of the dissolution of carbonate minerals. Such an outcome is confirmed by the relation between (Ca^{2+} + Mg^{2+}) Vs (HCO_3^- + SO_4^{2-}) where several water samples lie above the line of slope 1.

The dissolution of evaporites and the precipitation of calcite are also confirmed by the saturation indexes, calculated with WATEQ program [15]. They show that water is undersaturated with respect to Halite, saturated to undersaturated with respect to gypsum and Anhydrite and saturated with respect to calcite (Fig. 8).

It is noticeable that the evolution of the major elements contents through the SE-NW flow line shows the contribution of the infiltrated rain water in the local recharge of the CI aquifer in the Dahar upland [14, 16, 17]. This evolution profile reveals generally a systematic increase in the total depth, the temperature and the major elements contents along the flow path. The lowest values

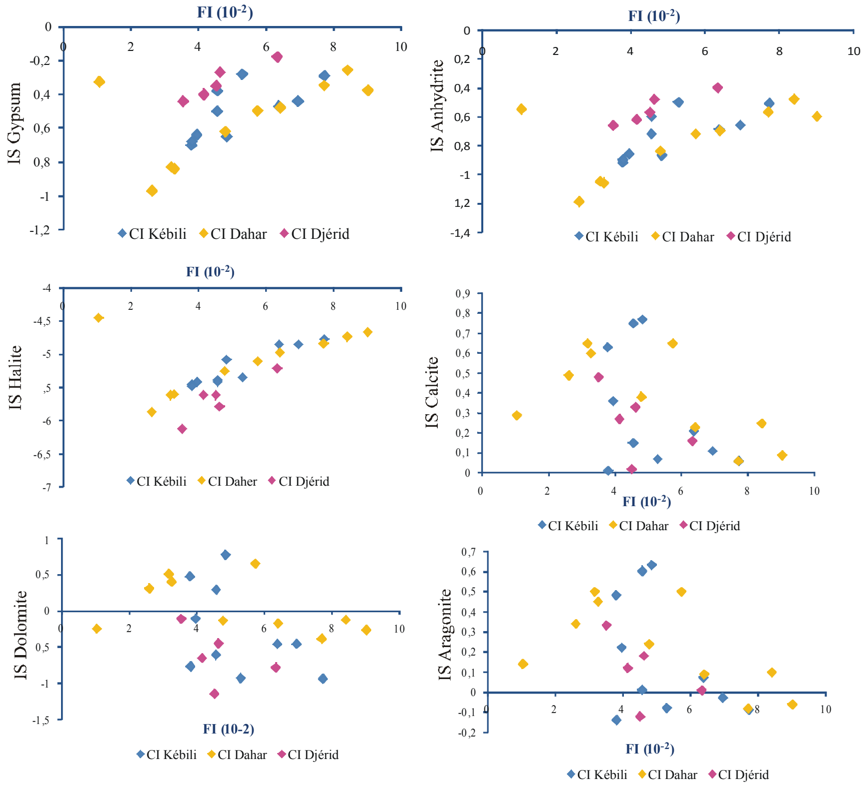

Fig. 8: Relationships between saturation indexes and ionic strength in the analysed groundwater samples

of salinity are measured in the CI aquifer of the Dahar area and indicate therefore the importance of these reliefs in the local recharge of this reservoir. The concentration of the major elements in groundwater increases in accordance to the leaching of salts during water rock interactions and in combination with the evaporation losses [17].

Isotopic Investigation: The measured stable isotope composition of the CI groundwater samples is quite variable. It shows a wide scatter of $\delta^{18}O$ and $\delta^{2}H$ contents. This great variation in stable isotope composition suggests therefore differences in origin that are likely considered to indicate separate flow paths and recharge areas [17].

$\delta^{18}O$ and $\delta^{2}H$ values range respectively from -6 to -8,6‰ vs V-SMOW and from -39,78 to -67,01‰ vs V-SMOW. The depleted isotopic signatures shown in the deeper groundwater of the CI aquifer, typical of old water, are probably related to humid periods of the Late Pleistocene and early Holocene [4, 16, 18-20]. This paleowater is consistent with the negligible radiocarbon contents [23].

Samples collected Closest to Dahar outcrops, have values of $\delta^{18}O$ that vary from -6 to -6,5‰ vs V-SMOW and from -39,78 to -47,74‰ vs V-SMOW for $\delta^{2}H$ respectively. In this region the CI aquifer lies at shallow depths and high altitudes favouring therefore the runoff and the infiltration of rainwater. Moreover this relatively enriched composition compared to the CI groundwater in Nefzaoua and Djerid regions suggests a mixing process with most recent water from the Turonian overlying aquifers [22].

The measured stable isotopes compositions were plotted in the $\delta^{2}H/\delta^{18}O$ diagram. The Global Meteoric Water Line (GMWL) [23] and the Sfax Meteoric Water Line (SMWL) defined by Maliki *et al.*, [24], are also plotted for comparison (Fig.9).

The composition of the CI groundwater lies slightly below the GMWL, in particular for Mohsen Naili and Khouhil 5 water samples.

Most likely, these enriched values of the CI aquifer represent recent infiltration water although they remain significantly depleted relative to modern rainfall (the weighted mean values of precipitation for Sfax region are $\delta^{18}O$ -4,6‰ and $\delta^{2}H$ -23,3‰ vs V-SMOW, Maliki *et al.*, [24].

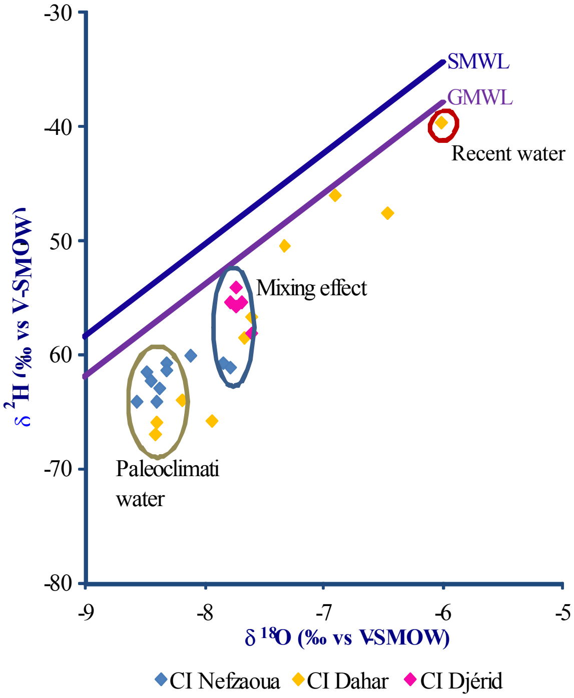

Fig. 9: Stable isotope composition of CI groundwaters in southern Tunisia

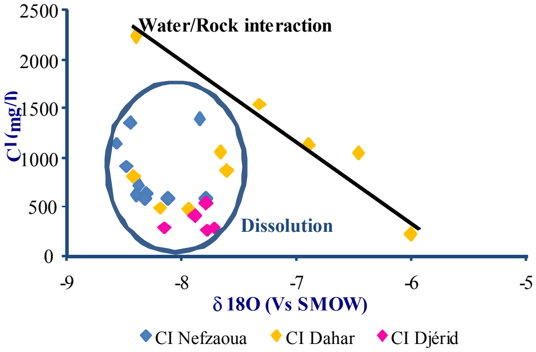

Fig. 10: Relationship between Cl/^{18}O in the analyzed sampled water

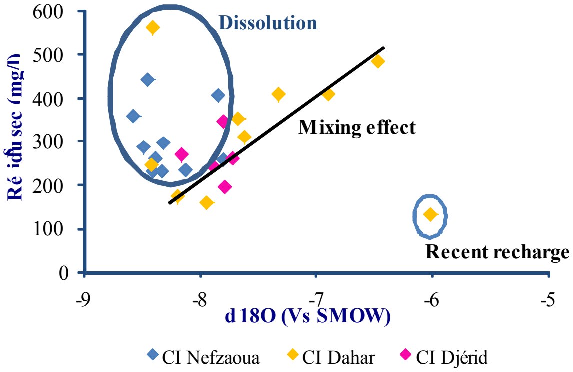

Fig. 11: Relationship between TDS/^{18}O in the analyzed sampled water

They indicate also the contribution of the Dahar cretaceous outcrops to the local recharge of the CI aquifer.

In the Nefzaoua region, most groundwater samples form an homogeneous group located below the global meteoric water line in the domain of old waters. Stable isotope contents in this area vary from -8,6 to -7,8‰ vs V-SMOW for δ^{18}O and from -60,8 to -64,2‰ vs V-SMOW for δ^{2}H.

This depletion in stable isotope composition is probably due to the long residence time of these waters in the reservoir or likely seems to result of a mixing with the Extreme south groundwaters corresponding to the most confined part of the basin [14].

The mixing process between these different groundwater masses seems to be controlled by the tectonic activity and the hydraulic head differences in these aquifers [17].

In the Djerid region, the groundwater contents of δ^{18}O and δ^{2}H are relatively higher compared to those in Nefzaoua area. The range of values are δ^{18}O -7,79 to -7,61‰ vs V-SMOW and δ^{2}H -58,17 to -54,21‰ vs V-SMOW indicating the paleoclimatic signature of waters.

In order to better understand processes that control the CI groundwaters, we studied relationships between isotopic compositions with Chloride content. As shown in Figure 10, we note that δ ^{18}O contents vary along two trends in relation with chloride contents. These trends indicate that evaporation process do not contribute to the groundwaters mineralisation of the CI aquifer. This is in good agreement with the δ^{2}H/ δ^{18}O diagram showing no enrichment in stable isotope due to evaporation effect.

However, the majority of samples which are located in Dahar uplands demonstrate an increase in Cl contents with the depletion in δ^{18}O. The non-evaporated isotopic signal and high chloride contents indicate a long residence time of groundwaters in the aquifer, favouring therefore significant water/rock interactions. Hence, the CI groundwaters mineralization is somewhat attributed to minerals dissolution constituting the surrounding rocks material.

In order to further focus on the mechanisms controlling the CI groundwaters mineralisation in southern Tunisia, the correlation between TDS and δ^{18}O was established on (Fig. 11). Three trends could be observed. The first shows an increase in total dissolved solids (TDS) while δ^{18}O contents remain quite homogeneous. This array of sample points indicates also the contribution of minerals dissolution to the groundwaters mineralisation.

The second trend reveals an increase in TDS which is coupled with an increase of $\delta^{18}O$ contents. It might be interpreted as mixing with water characterized by low salinity and relatively enriched $\delta^{18}O$ values.

We note that sample No.17 is characterised by low temperature, low depth and high $\delta^{18}O$ content relative to other samples. This well is located in southern Dahar where the contribution of the lower cretaceous outcrops to the local recent recharge of the CI aquifer has been proven to be significant [17].

CONCLUSION

The association of hydro-chemical methods with environmental tracers ($\delta^{18}O$ and $\delta^{2}H$) for the study of the CI aquifer in Southern Tunisia has determined the groundwater origin, the mixing between aquifer horizons and the geochemical evolution of the groundwater facies from the Dahar outcrops (recharge area) towards the basin outlet (Chott El Fedjej).

The hydrochemical study of the CI aquifer shows that the water types are dominated by Na^{+}, SO_4^{2-}, Cl^{-} and Ca^{2+} throughout most of the basin reflecting therefore the abundance of evaporitic lands in this area. Thus the mineralisation of water is related to the dissolution of evaporitic minerals but also to the process of cation exchange with clay minerals.

The isotopic analyses of the CI aquifer indicate that this latter is exclusively formed by old water particularly in the regions of Djerid and Nefzaoua having homogeneous isotopic signatures. This is explained by a long residence time of water in the aquifer and its paleorecharge under a wetter climate corresponding to the Pleistocene period. However, the measured stable isotopes of the CI groundwater closest to the Dahar outcrops are more enriched. This suggests the contribution of these outcrops in the local recharge of this aquifer system.

Most studies of the CI aquifer generally focus on both approaches however the use of several age tracers and the combination with reactive transport modelling tools would obviously offer a more complete picture of such an aquifer system.

ACKNOWLEDGMENTS

The authors wish to thank the technical staff of the Laboratory of Radio-Analyses and Environment of the National Engineering School of Sfax (ENIS) for the chemical and isotopic analysis. We thank the staff members of Kebili Water Resources Division/Agriculture Ministry.

REFERENCES

2. SASS. 2003. Système aquifère de Sahara Septentrional, 2ème édition, Volume II, Hydrogéologie.
3. ERESS. 1972. Etude des Ressources en Eau de Sahara Septentrional. UNESCO, Paris (7 Vols. and Annexes).
4. Edmunds, W.M., A.H. Guendouz, A. Mamou, A. Moula, P. Shand and K. Zouari, 2003. Groundwater evolution in the continental Intercalaire aquifer of southern Algeria and Tunisia: trace element and isotopic indicators, Appl Geochem, 18: 805-822.
5. Bouaziz, S., 1995. Etude de la tectonique cassante dans la plate-forme et l'Atlas sahariens, (Tunisie méridionale), évolution des plaéochamps de contraintes et implications géodynamiques. Thèse Doct Etat, Univ. Tunis II, Fac. Sc. Tunis., pp: 485. et annexes, 1995.
6. Mamou, A., 1990. Caractéristiques, evaluation, gestion des ressources en eau du Sud tunisien. Thèse de Doctorat, Univ Paris Sud France.
7. Zargouni, F., M.C.H. Rabia and C. Abbes, 1985. Rôle des couloirs de cisaillement de Gafsa et de Negrine-Tozeur dans la structuration du Faisceau Sud-atlasique, CR Acad Sci. Paris. T-301, série II, pp: 831-834.
8. Bouaziz, S., E. Barrier, M. Soussi, M.M. Turki and H. Zouari, 2002. Tectonic evolution of the northern African margin in Tunisia from paleostress data and sedimentary record, Tectonophysics, 357: 227-253.
9. Gabtni, H., C. Jallouli, KL. Mickus, H. Zouari and M.M. Turki, 2009. Deep structure and crustal configuration of the Jeffara basin (Southern Tunisia) based on regional gravity, seismic reflection and borehole data: How to explain a gravity maximum within a large sedimentary basin, J. Geodyn, 47: 142-152.
1. SASS. 2002. Système aquifère du Sahara septentrional, Gestion commune d'un bassin transfrontière. Rapport de synthèse, OSS, pp: 129.
10. Castany, G., 1954. L'accident sud tunisien et ses relations avec l'accident sud atlasique. G. R. Acad. Sci.
11. Rouatbi, R., 1967. Contribution à l'étude hydrogéologique du karst en terre de Gabès Sud, Thèse Doc Montpellier.

12. Castany, G., 1949. Etude hydrogéologique de la région d'ARRAM (contrôle civil de Gabès), pp: 32.
13. Trabelsi, R., A. Kacem, K. Zouari and K Rozanski, 2008. Quantifying regional groundwater flow between continental intercalaire and Djeffara aquifers in Southern Tunisia using isotope methods, Environ Geol., 58: 171-183.
14. Abid, K. R. Trabelsi, K. Zouari and B. Abidi, 2009. Caractérisation hydrogéochimique de la nappe du continental intercalaire (Sud tunisien), Hydrological Sciences–Journal–des Sciences Hydrologiques, 54(3): 526-537.
15. Plummer, L.N., B.F. Jones and A.H. Truesdell, 1976. WATEQF, a Fortan IV version of WATEQ, a computer program for calculating chemical equilibrium of natural waters, US Geol Surv Water Res Invest, 76: 61.
16. Gonfiantini, R., G. Conrad, J.C. Fontes, G. Sauzay and B.R. Payne, 1974. Etude isotpique de la nappe du CI et ses relations avec les autres nappes du Sahara septentrional. In: Proceedings of symposium on isotope hydrology. IAEA, Vienna, pp: 227-241.
17. Abid, K., K. Zouari and B. Abidi, 2010. Identification and characterisation of hydrogeological relays of continental Intercalaire aquifer of southern Tunisia, Carbonates Evaporites, 25: 65-75.
18. Fontes, J.C., R. Coque, L. Dever, A. Filly and A. Mamou, 1983. Paléohydrologie isotopique de l'wadi el Akarit (Sud Tunisien) au Pléistocène at à l'Holocène, Palaeolgeogr Palaeoclimatol Palaeoecol., 43: 41-61.
19. Zouari, K., 1988. Géochimie et sédimentologie des dépôts continentaux d'origine aquatique du Quaternaire supérieur du Sud Tunisien, PhD thesis, University of Paris-Sud Orsay.
20. Zouari, K., N. Chkir and B. Ouda, 2003. Palaeoclimatic variation in Meknassi basin (Central Tunisia) during Holocene period using multidisciplinary approaches, IAEA, Vienna, pp: 80-28.
21. Guendouz, A., A. Moulla, W.M. Edmunds, P. Shand, J. Poole, K. Zouari and A. Mamou, 1997. Paleoclimatic information contained in groundwaters of the Grand Erg Oriental, N Africa. Isotope techniques in the study of past and current environmental changes in the hydrosphere and atmosphere, IAEA, Vienne, pp: 555-571.
22. Abid, K., M. Dulinski, F. Hadj Ammar, K. Rozanski and K. Zouari, 2011. Deciphering interaction of regional aquifers in Southern Tunisia using hydrochemistry and isotopic tools. Applied Geochemistry.
23. Craig, H., 1961. Isotopic variations in meteoric water, Science, 133: 1702-1703.
24. Maliki, M.A., M. Krimissa, J.L. Michelot and K. Zouari, 2000. Relation entre nappes superficielles et aquife`re profond dans le bassin de Sfax (Tunisie) CR Acad. Sci. Paris, se´rie Iia, 331(6): 1-6.
25. Abid, K., 2004. Identification et caractérisation des relais hydrogéologiques de la nappe du Continental Intercalaire, Master en génie de l'environnement et de l'aménagement, Ecole nationale des ingénieurs de Sfax.