

Hydrogeochemical Data from a Multilayer Aquifer System in Central Tunisia

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Abstract: The present study concerns the Ain Bou Mourra aquifer system (Central Tunisia). This basin is submitted to a semi-arid climate with rainfall ranging between 300 to 400 mm/y and marked by high spatial and temporal variability. The multi-tracing approach based on hydrochemistry of major elements and water molecule isotopes has been applied in Ain Bou Mourra basin to provide basic information on the processes that control groundwater mineralization and to infer recharge sources in the studied basin. A total of 27 groundwater samples were collected from wells, boreholes and springs of the study area. Chemical data showed that the main source of mineralization in the sampled groundwaters is related to feldspar and silicate weathering, dissolution of evaporitic and carbonate minerals and ionic exchange reactions. Isotopic study was carried out using stable (^{18}O , ^2H) and radiogenic (^3H) isotopes. It indicated that most of the groundwater samples were originated from infiltrating modern precipitation. Radiogenic data provided insight into the presence of significant contemporaneous recharge waters in the basin and indicated that groundwaters were recharged from the surface runoff on the local Oligocene–Miocene outcrops.

Key words: Ain Bou Mourra aquifer system • Geochemistry • Isotopes • Recharge • Dissolution process • Central Tunisia

INTRODUCTION

Studies of the origin of groundwater and processes leading to its mineralization are important for proper evaluation and management of water resources, especially in semi arid areas as Central Tunisia. In these regions, general scarcity and poor quality of surface water often results in extensive exploitation of groundwater resources, without taking into account its potential vulnerability to over-exploitation.

The groundwaters of the Ain Bou Mourra basin (Central Tunisia) are vital to the fresh water resources of the region. They contribute over 90% of the flow in many regional canals, which supplies the region with irrigation and potable water. As a consequence, gradual decrease of water table of aquifers is a wide-spread phenomenon in this basin, causing the disappearance of artesian conditions. To ensure the long-term sustainability of groundwater resources, managers need to have detailed information on the exploited groundwater systems. The integration of environmental tracers is very useful for the identification of recharge sources in a groundwater

system on both local and regional scales [1]. These tools provide valuable insights into recharge processes and are necessary for developing sustainable water resource management plans within the context of climate variability [1].

The goal of this study is to characterize water chemistry and to infer the recharge sources in the basin.

General Setting: The Ain Bou Mourra basin is located in Central Tunisia and covered a surface of 162.3 km². It is drained in its northern part by Nebhana River and bounded in its western part by Atlasian Heights and Mountains (Fig. 1). The semi arid climate is marked by distinct summer (warm and dry) and winter (cool and humid) seasons. The mean annual precipitation is 309.5 mm and the mean annual air temperature is 19°C.

The geological studies [2, 3] reveal that the major physiographic features of the region have been developed according to North East–South West extension [4]. Geological formations, recognized in the syncline, have been largely developed during the Paleogene-Neogene periods. The oldest outcrops in the

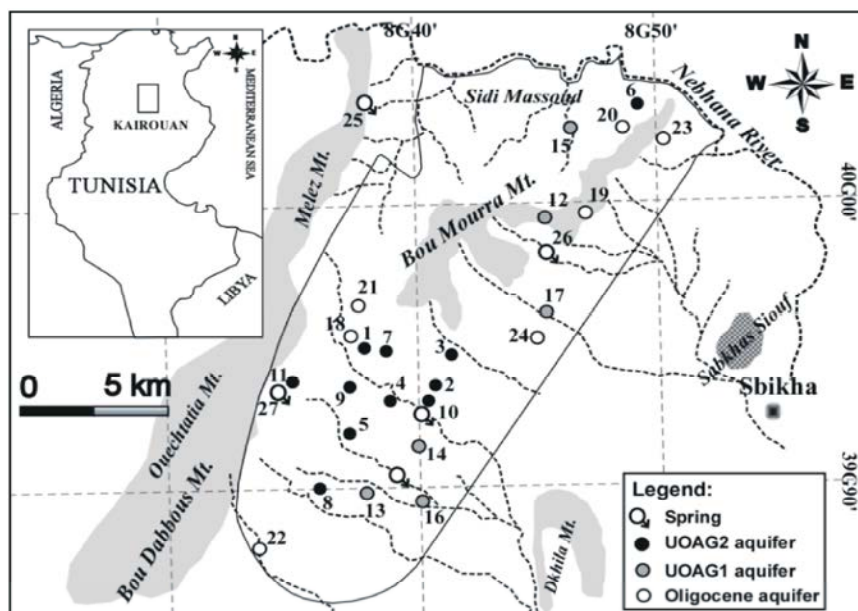


Fig. 1: Location and sampling map

syncline are formed by Cretaceous deposits and consist of marine limestone which appeared in the occidental reliefs. The Paleocene formation is characterized by clayey sand with some intercalations of sandy limestone, gypsum and Glauconeous clays [4, 5]. It outcrops on more than 390 m at the foot of the western highlands. The Lower Eocene limestone and the Upper Eocene marl deposits are found in the boundaries of the basin. The Oligocene deposits outcrops largely and covers more than 70 km² of the syncline [6]. This formation is overlaid partially by recent Quaternary sediments. The Mio-Pliocene formation outcrops and includes detrital sediments of sandy and sandy clays [4].

Geophysical investigations and boreholes completed recently in the region have allowed a more detailed understanding of the hydrogeology of Ain Bou Mourra. These data reveal that the aquifer system is dominated by a SSW–NNE synclinal structure and consists of three principal hydrostratigraphic series [2]: (i) the upper aquifer logged in the sandstone formations of the Upper Oligocene Aquifer (group 2) (UOAG2), (ii) the middle aquifer hosted in the continental formations of Upper Oligocene Aquifer (group 1) (UOAG1) and (iii) the lower aquifer logged in the Oligocene formations.

- The UOAG2 aquifer is formed mainly by coarse-to medium-grained sands, sandstones, gravel sediments and constitutes an unconfined aquifer layer. This aquifer, thick of about 150 m, represents the most productive aquifer in the region.

- The UOAG1 aquifer consists of sandstones succession intercalated with clay and clayey sandstone layers of limited extent and varying in thickness from few tens of meters in the boundaries of the syncline to 150 m in the central area [6, 2].
- The Oligocene aquifer comprises inter-bedded fine sandstone, sands, marls and discontinuous sandy marl lenses which give aquifer characteristics ranging from a unconfined, semi-confined to confined type [6, 2]. It represents the lowest productive aquifer. This unit outcrops locally in the borders of the syncline and becomes 300 m thick in the central part [6, 7].

The Upper Eocene marl deposits represent the substratum in the syncline.

Previous hydrogeological studies [6, 7] showed that the three aquifer layers are often interconnected and exploited on their edges.

Between 1960 and 2010, many fields of forty boreholes, were drilled to 100–250 m depth near Oligocene–Miocene outcrops to explore the groundwater potential, yielded a flow with a total discharge varying from 3.7 to 43 l/s [8].

The regional potentiometric surface of the aquifers reveals high levels in the north western highlands, a general decline towards the southeast. The general flow is from North West to South East. In the boundaries of the basin, the groundwater overflows in the form of

springs and emerge along the faults to the east of the basin. They indicate discharge of deeply circulating groundwaters. The spring's waters are used for domestic and agricultural purposes. For this reason, the discharge of the springs has varied largely in the last period. A continuous decrease in static water levels recorded in piezometers between 1960 and 2010. The drawdown produced in the water levels of the aquifers by the intensive abstraction over the past 50 years has caused a significant decline in groundwater flow.

Sampling and Analytical Procedure: Sampling of groundwaters within Ain Bou Mourra basin was carried out during September 2008 and April 2009.

A total of 27 samples, including 11, 6 and 7 samples, were collected from pumping wells and boreholes exploiting the UOAG2, UOAG1 and Oligocene aquifers, respectively. Three samples were taken from artesian springs of the region (Fig. 1).

The measurements of pH, temperature and electrical conductivity (EC) were performed in the field. Water samples were collected in 1000 ml polyethylene bottles with poly-seal caps for major elements. Chemical analyses and isotopic measurements were determined in the Radio-Analysis and Environment Laboratory of the National Engineering School of Sfax (Tunisia).

Major elements (Cl^- , SO_4^{2-} , HCO_3^- , Na^+ , Mg^{2+} , K^+ and Ca^{2+}) were analyzed by ion liquid chromatography.

The total dissolved solids (TDS) are measured in the laboratory by evaporating of 100 ml of water sample during 24h at 105°C .

Stable isotope ratio ($^{18}\text{O}/^{16}\text{O}$ and $^2\text{H}/^1\text{H}$) analyses were performed by using the Laser Absorption Spectrometry measurements LGR DLT 100 [9]. Results are reported in ‰ versus VSMOW standard (Vienna-Standard Mean Oceanic Water).

12 samples were selected to be analyzed for Tritium content using electrolytic enrichment and liquid scintillation spectrometry [10]. ^3H concentration is expressed in Tritium Units (TU). One TU is defined as the isotope ratio $^3\text{H}/^1\text{H} = 10^{-18}$.

Precision of measurement for stable isotope and radioactive analysis was $\pm 0.1\text{‰}$ for the $\delta^{18}\text{O}$, $\pm 1\text{‰}$ for the $\delta^2\text{H}$ and $\pm 0.3\text{ TU}$ for ^3H .

RESULTS AND DISCUSSION

Geochemical Data: The EC values of the groundwater samples reveal steadily increasing values from the top to

bottom. In general, these data vary between 0.6 and 5.3 mS/cm. The highest value are recorded in Oligocene aquifer whilst, the lowest values are revealed in the UOAG2 aquifer.

In fact, the EC values vary in the range of 0.6 – 1.1 mS/cm, 1.2 – 1.9 mS/cm and 1.9 – 5.3 mS/cm in the UOAG2, UOAG1 and Oligocene aquifers, respectively. This variation could be related to geological facies change along the Oligocene–Miocene contact.

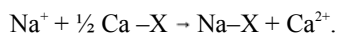
In order to highlight different mechanisms which contribute to groundwater mineralization, the relationships between major elements and the total dissolved salts (TDS) were investigated (Fig. 2).

These diagrams indicate that, in particular, Na, Ca, Mg, Cl and SO_4 and to a lesser extent HCO_3 ions are positively correlated with TDS for the majority of groundwater samples. This indicates that these elements contribute to the groundwater mineralization in the aquifer system.

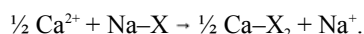
Several bivariate diagrams of major elements are used to precisely determine the origins of the referred ions and the processes that control their concentrations in groundwaters.

The Na/Cl relationship (Fig. 3a) shows three plots:

- The first plot includes samples lying on the 1:1 line and suggest the halite dissolution process.
- The second plot comprises samples of UOAG1 and UOAG2 whose molar ratio mNa/Cl is clearly lower than one (points located below the halite dissolution line; Fig. 3a), meaning that its composition cannot be attributed only to dissolution of halite. Some reaction of silicate and feldspar minerals or cation exchange (Type I) absorbing Na at the expense of some other cation can explain the decrease in this ratio below 1 (Fig. 3c). This exchange can take place by reaction with clay minerals existing in the matrix of sandstones according to the following equation:



- The third plot is formed by Oligocene samples which reveal high mNa/Cl (> 1) and plot above the 1:1 line, suggesting mineral dissolution or a second type of cation exchange (Type II) leading to a Ca^{2+} adsorption on clay minerals and a simultaneous release of Na^+ ions (Fig. 3c) according to:



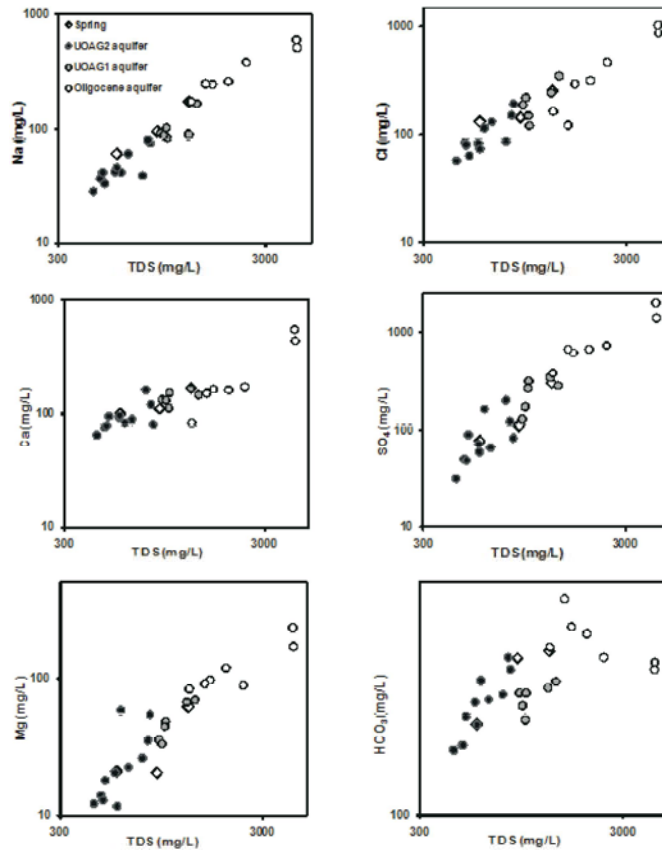


Fig. 2: Major elements versus TDS relationships

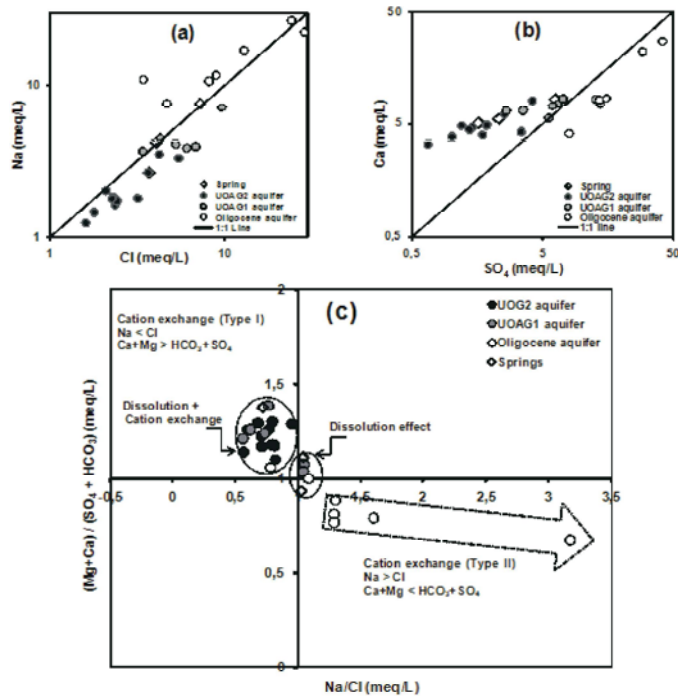


Fig. 3: Relationships between major elements in the analyzed groundwater samples: Na vs. Cl (a), Ca vs. SO_4 (b) and $[Ca + Mg / (HCO_3 + SO_4)]$ vs. $[Na/Cl]$ (c)

The Ca/ SO₄ relationship (Fig. 3b) reveals three groups:

- The first group includes samples of UOAG1 aquifer plotting on 1:1 line. This pattern suggests a linear increase of Ca and SO₄ ions which could be related to the probable gypsum/anhydrite mineral dissolution.
- The second group comprises samples of UOAG2 aquifer plotting above 1:1 line. Their molar Ca²⁺/SO₄²⁻ ratio is largely higher than 1. Calcium excess compared to sulfate content (Table 1) may be derived from carbonate dissolution as confirmed by the linear increase of HCO₃ with TDS (Fig. 2).
- The third group is formed by Oligocene samples plotting below the 1:1 line. The low molar Ca²⁺/SO₄²⁻ ratio could indicate either mineral dissolution or loss of Ca²⁺ instead of Na⁺ during the cation exchange reaction (Type II). These processes are clearly confirmed by Fig. 3c.

Isotope Data

Stable isotopes $\delta^{18}\text{O}$ and $\delta^2\text{H}$: The stable isotope ratio ($\delta^{18}\text{O}/\delta^2\text{H}$) can be used in the present study to obtain information on the possible source of water, its mode of recharge and whether it is part of the modern hydrological regime.

The $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values of the UOAG2 aquifer range, respectively, from -5.91 to -4.64 ‰ for oxygen-18 and from -34.53 to -27.31 ‰ for deuterium. Those of the UOAG1 aquifer vary between -5.71 and -4.10 ‰ for oxygen-18 and from -33.84 to -24.04 ‰ for deuterium. The isotope contents of the Oligocene aquifer fluctuate between -5.95 and -4.53 ‰ for oxygen-18 and between -36.07 and -27.92 ‰ for deuterium.

Values of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ from groundwater samples are plotted in Fig. 4. The majority of groundwater samples fall on the Global Meteoric Water Line (GMWL) as reported by Craig [11] and the Local Meteoric Water Line (LMWL) as reported by Celle [12]; Celle Jeanton et al. [13] and Gay [14] for the Western Mediterranean, indicating that the groundwaters have been recharged under climatic conditions which are similar to those which prevail today in the region [15].

The mean isotopic composition of the sampled groundwaters from the aquifer system is similar to local precipitation recorded in the Sbikha station (Fig. 1). This similarity in isotopic composition between most groundwater and local precipitation supports the mechanism of an infiltration of runoff water before significant evaporation at the soil surface can take place.

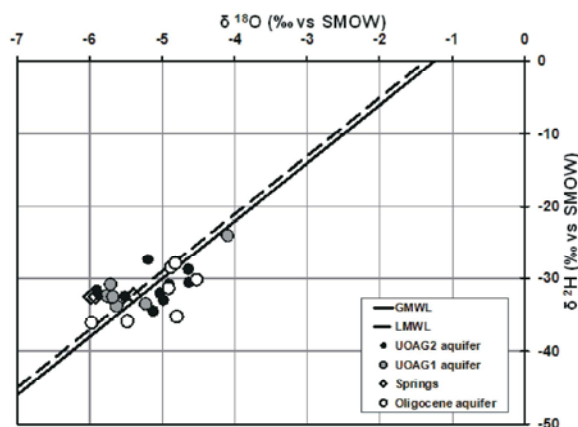


Fig. 4: Relationship $\delta^{18}\text{O}/\delta^2\text{H}$ of groundwater samples in the Ain Bou Mourra aquifer system

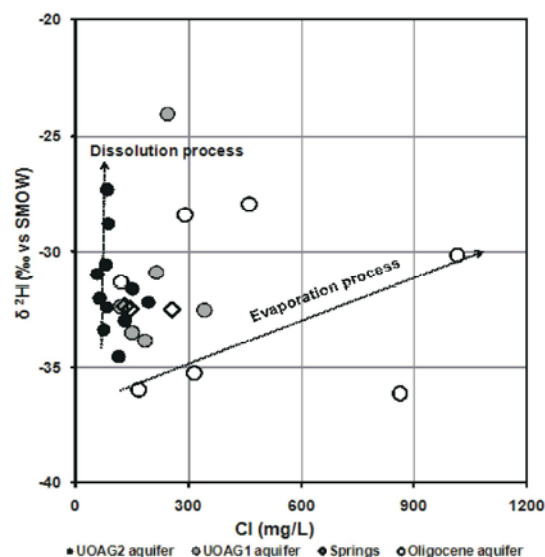


Fig. 5: Relationship $\delta^2\text{H}/\text{Cl}$ of groundwater samples in the Ain Bou Mourra aquifer system

However, some data lie widely below the GMWL and reveal enriched isotopic compositions due to the evaporation process. In fact, slower infiltration or seepage of the surface water through the clayey sandstone of the unsaturated zone would have exposed much of the water to evaporation, resulting in an enriched composition of the groundwater. This process is clearly confirmed by the $\delta^2\text{H}$ -Cl relationship (Fig. 5) which shows that the isotopic content of these groundwater samples are relatively correlative with chloride contents. In contrast, the observed change in $\delta^2\text{H}$ of the non-evaporated groundwaters is not accompanied with linear change in chloride concentrations. This supports that the salinity of these groundwaters is mainly governed by a dissolution process previously highlighted by hydrochemical study.

Tritium Isotope: ^3H isotope is an important tracer for water flow and it can give indication of the relative age of waters varying on time scale of 50 years before present.

The measured tritium concentrations of the analyzed samples are within the ranges 1.0–3.0, 3.1–4.4 and 1.9–4.1 TU for the UOAG2, UOAG1 and Oligocene aquifer, respectively. These data suggest clearly the occurrence of recent recharge in the Ain Bou Mourra basin probably during the last two decades.

The ^3H data from spring's water shows that ^3H concentrations range from 1.0 to 2.9 TU. This indicates that these waters are recharged by the direct infiltration of meteoric water through the local Oligocene–Miocene outcrops of the study area.

CONCLUSION

Groundwater isotopes combined with chemistry provided useful initial tracers for understanding the processes that control groundwater mineralization and identifying recharge sources in Ain Bou Mourra basin (central Tunisia) under semi-arid climatic conditions.

Chemical data based on the chemistry of several major ions has revealed that the principal changes in chemical composition of groundwater are caused by chemical reactions such as feldspar and silicate weathering, dissolution of evaporitic and carbonate minerals and ionic exchange.

Isotopic data indicate that all groundwaters are characterized by a modern stable isotope signature. This suggests that the sampled groundwaters receive a recent recharge which is facilitated by the high permeability characterizing Oligocene sandstones.

Tritium data confirm the occurrence of recent recharge which is assumed by rainfall infiltration on the local Oligocene outcrops of the study area.

The resources in the Oligocene aquifer represent a significant reserve of good quality water which needs to be properly managed as high quality resources and as part of integrated plans for the basin's future supplies.

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