



Hydrogeochemical and stable isotope data of groundwater of a multi-aquifer system: Northern Gafsa basin – Central Tunisia



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ABSTRACT

The hydrodynamic of the multi-aquifer system (the Continental Intercalaire “C.I.” and the Complex Terminal “C.T.”) of the North Gafsa basin is largely determined by tectonics (Tebessa – Gafsa fault). The composition of groundwater is controlled by complex reactions at gas-liquid-solid “mineralogical composition of associated rocks” interfaces, which depend on the natural surrounding and potential anthropogenic impact. The hydrochemical data (major ion geochemistry) indicate that these groundwaters are characterized by the dominance a Ca–Mg–HCO₃/SO₄ and Na–Cl–NO₃ water types. Geochemical pattern is mainly controlled by the dissolution of halite, gypsum and/or anhydrite as well as by the incongruent dissolution of carbonate minerals. The pH of these samples range from 6.54 to 8.89, supporting the conclusion that the H₂CO₃/HCO₃ couple control pH buffering. Oxygen-18 (δ¹⁸O‰_{SMOW}) and deuterium (δD‰_{SMOW}) isotopic data show the exchange between the groundwater and the rock (water–rock interaction) and the evaporation effect. The isotopic content of the boreholes waters is of mixed Mediterranean – Atlantic origin and is opposite to the quantity of rainwater distribution, both in space and time in the study area. This is due to its geographical situation in the southern and south-western of the Mediterranean Sea and between the Atlas area and the Sahara Platform. The concentrations of the isotopic composition of the groundwater are significantly higher than the rainwater. This is indicative of the dissolution of salts and other processes modifying the rainwater geochemical composition during infiltration into the vadose zone. The hydraulic interconnection of these components of the system has led to the evolution of these interesting groundwater types.

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1. Introduction

In the North African basin, water harvesting played a crucial role in ancient civilisations such as the Roman. During the 20th century, modern techniques (groundwater drilling, “Foggara/Mkayel”, large

reservoir construction “Majel and/or Fiskhiya” etc.), which are favoured by government policy, slowly replaced traditional harvesting techniques. High demands for water during the industrial period and agricultural growing season, which coincides with the dry period of the Mediterranean climate, has resulted in the deterioration of the water and in the depletion of the piezometric water table in many regions of the North Africa and especially in Tunisia. The scarcity of water resources in semi-arid sedimentary basins, the low renewal rate of groundwater resources and the poor water quality in the Mediterranean basin make it necessary to find other water supplies and to revive traditional systems of water harvesting. Continuously increasing abstraction of groundwater resources

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to meet rising industrial, agricultural, domestic and touristic needs, coupled with severe drought periods during the past decades leads to growing deficit of water.

Due to different hydrogen and oxygen isotopic compositions of different water sources, stable hydrogen and oxygen isotopic ratios (δD and $\delta^{18}O$) are an excellent way to fingerprint the route of groundwater recharge and discharge (Craig, 1961; Clarke and Fritz, 1997). Tritium isotope (T) is always introduced into the hydrological circulation and dated with the fallout from atmospheric nuclear weapon tests conducted mainly during the early 1960s. It can be indirectly used to evaluate the rate of groundwater circulation and renewal rate (Clarke and Fritz, 1997). The application of isotope-based methods has become well established for water-resource assessment, development and management in the hydrological sciences, and is now an integral part of many water quality and environmental studies (Clark and Fritz, 1997; Cook and Herczeg, 2000). Environmental isotope techniques, hydrogeochemical analysis and hydraulic data are employed to identify the main recharge areas, the hydrodynamic, the mineralization of the hydrogeological basin and the impact of climate change on groundwater in the study area, one of the most important aquifers of central Tunisia. The utilization of these methods is the goals of the present paper.

2. Site description

North Africa and the southern Mediterranean basin during the Cretaceous that has held sway since the discovery of the salinity Crisis (Swezey, 2003) has been dominated by varying degrees of aridity (≈ 1000 m of evaporates in Tataouine basin and ≈ 250 m in Maknassy and in Thelja basins) and humidity (Continental Intercalaire groundwater in North Africa area) during the Cretaceous period (Hamed et al., 2012a,b; 2013b). These factors are surely indicators of dry and humid climates in North Africa. This is natural enough given the magnitude of the drying and warming of the Mediterranean Sea itself (Kallel et al., 1997; Jedoui et al., 2001; Boussetta et al., 2012).

The study area is characterized by hilly topography and flat plateau surfaces with average elevation of 800 m a.s.l. The central of Tunisia is characterized by the absence of high mountains and a relatively limited geographic extension, allowing the integration of Saharan Platform air streams into the atmospheric circulation (Celle-Jeanton et al., 2001a). However, due to its position in the western and in the southern of the Mediterranean Sea, it represents a climatic transition zone open to desert and monsoon system (Kallel et al., 1997, 2000; Jedoui et al., 2001; Zouari et al., 2003; Hamed, 2004; Kamel et al., 2005; Abidi, 2007; Essalami et al., 2007; Dassi, 2009; Ben Moussa et al., 2010a,b; Rouis-Zargouni et al., 2010; Hamed et al., 2012a; Mokadem et al., 2014). Indeed, regional hydro-meteorological studies (Celle, 2000; Celle-Jeanton et al., 2001b) mention the existence of two major trajectories for dominant air masses (Fig. 1A). These are: (i) the North Atlantic warm air masses that circulate from the west over the Northern Africa and (ii) the Mediterranean cool air masses that derive from the north. The study area, which is located in central Tunisia, covers an area of 3750 km² and lies between the longitudes 7°30'–9°00'E and the latitudes 33°00'–34°30'N (Fig. 1B). It corresponds to a synclinal structure limited in the South by the Gafsa Mountains (J.Bouramli, J.Ben Younes and J.Orbata), in the north by the Monts of Sidi Aïch and Souinia, in the west by Algerian territory and in the east by the Gabes Gulf (Fig. 1B). The North Gafsa basin is located approximately 100 km east of the Atlas Monts of North Africa. Elevations decrease from 2000 m above mean sea level in the west (Algerian Atlas: recharge area) to 500 m in the east (Aguila-El Jar plain: discharge area). In the study area, the spatial distribution of

precipitation is strongly influenced by the relief.

The study area has undergone an arid to semi-arid climate changes marked by seasonal contrasting climatic variables. Influenced by a temperate Mediterranean climate, with moderately hot summers and cold winters. Rainfall gradually decreases from the Atlas range (North) to the Sahara Platform (South). It shows a mean annual rainfall of about 350 mm.year⁻¹ (data based on observations from 1964 to 2013, Yermani et al., 2002; Mokadem et al., 2012, 2014) with a maximum amount of rainfall from November to February. The maximum rainfall amounts are associated with the highest elevations (J.Orbata ≈ 1100 m) of the study area (Fig. 1B). Mokadem et al. (2012) estimated an average annual precipitation of about 150–250 mm.year⁻¹ and a potential evapo-transpiration of about 1680 mm year⁻¹ (Yermani et al., 2002; Mokadem et al., 2012, 2014). The mean annual temperature is 25 °C; in January (winter) temperature is about 10 °C. In July (summer) temperature ranges between 35 and 45 °C (data from 1984 to 2013). The drainage net is composed of the Al Kebir, Sidi Aïch, El Maleh and Bayeich non-perennial wadis which collect surface runoff from the surrounding hills of Gafsa, Sidi Aïch, Souinia ranges and especially from the Algerian territories (Bir El Ater and Tebessa basins). The surface water of these wadis is carried to the large continental depression of Chott Djerid, south of the Gafsa basin (Fig. 1B).

3. Geology and hydrogeology

Depositional facies of the aquifer sediments in the study area change from west to east and from north to south, from alluvium in the west and the north to marine sediments on the Gafsa plain (piedmont area). In the North Gafsa basin, the hydrogeology is largely controlled by tectonics. This basin has been affected by both compressional and extensional fault networks during the Mesozoic (Bédir et al., 2001; Zouaghi et al., 2009, 2011), which created several multi-layered framework (Coque, 1962; Boltenhagen, 1985; Zargouni, 1985; Soyer and Tricart, 1987; Zouari et al., 1990; Outtani et al., 1995; Bouaziz et al., 2002; Feki et al., 2005a,b; Ahmadi et al., 2006, 2013; Hamed, 2011; Mokadem et al., 2014). This basin is covered by Mio-Plio-Quaternary sediments which may reach 500 m in thickness according to drilling data and geophysical studies (Zouaghi et al., 2011) lying on sedimentary relicts from Cretaceous and Tertiary periods. The hydrostratigraphic units in the North Gafsa region are shown in Fig. 2. The lithologic units in the study area extend from the Trias to the Quaternary. The Cretaceous series, which outcrops in the surrounding Mountains of the study area, constituted mainly of fractured/karstified carbonates, clay and sandstone deposits (Zargouni, 1985; Outtani et al., 1995; Henchiri and S'Himi, 2006). The study area consists of three groundwater systems, the shallow and the unconfined Tertiary-Quaternary aquifer systems, which unconformably overlies the confined aquifers of C.I of North Africa. These units consist of three main aquifer systems, namely, from the bottom to the top, the Continental Intercalaire (C.I), the Complex Terminal (C.T) and the alluvial aquifer of Om al Gsab (western part of the study area). They are from the bottom to the top (Figs. 1 and 2):

- (i) The deepest aquifer, which is a confined reservoir in almost the entire of the study area, with the exception of Sidi Aïch region. The geological formations which host the C.I aquifer are composed by fluvio-deltaic continental deposits (Cornet, 1964; Castany, 1982; M'Rabet, 1987; OSS, 2003, 2008; Gallala et al., 2009) producing intercalations of detrital levels with horizons of clay silts and frequent gypsum layers. The C.I aquifer is located within a succession of clastic sediment of Mesozoic age, the thickness and lithology of which vary laterally (UNESCO, 1972; M'Rabet, 1987). The groundwater of

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