BIO Web of Conferences **115**, 02002 (2024) https://doi.org/10.1051/bioconf/202411502002
RENA23

Aquifer systems in dry regions: hydro-geophysical and geochemical investigations providing insights into water resources in southeast Tunisia

Bilel Abdelkarim[1,2,3], *Margarida* Antunes[2,*], *Belgacem* Agoubi[1,3]

[1]Higher Institute of Water Sciences and Techniques, University of Gabès, University Campus, 6033 Gabes Applied - Hydrosciences Laboratory, Gabès, Tunisia
[2] Institute of Earth Sciences, Pole of University of Minho, Campus de Gualtar, 4710-057 Braga, Portugal
[3]LR: Applied Hydro-Sciences Laboratory Research Campus Universitaire, 6072 Zrig, Gabès, Tunisia

Abstract. Water demands from agriculture and industry have intensified groundwater extraction, prompting a focused study to bolster water resources, particularly at Gabès region (Southeastern Tunisia). Through extensive geologic and geophysical investigations, the reservoir geometry and structural architecture of crucial aquifers, notably the Mio-Plio-Quaternary and Cretaceous aquifers have been studied. The integration of geochemical and geophysical data allows for a nuanced assessment of fault structures and groundwater hydrodynamics. Advanced techniques, like horizontal gradient and upward extension unveils structural features and density contrasts with precision. This study extends to a spatiotemporal analysis of aquifer hydrodynamics and groundwater mineralization. The Gabès aquifer system exhibits four groundwater facies: Ca–Mg–SO_4, Na–Cl–NO_3, Ca–Mg–HCO_3, and Na–K–HCO_3. Results reveal relative isotopic depletion, suggesting recharge under colder climates and at higher altitudes. However, the study underscores the impact of climate change, with increasing temperature and dwindling precipitation in North Africa, since the mid-20th century. This research is a relevant contribution to sustainable water management by emphasizing the impact of climate change scenarios and groundwater resources management. The detailed exploration of hydrogeological characteristics and aquifer dynamics in the Gabès region is pivotal on effective management of groundwater resources strategies in semi-arid environments.

Keys words: Hydrogeology · geophysics data · Hydrochemical · Gabès region · Tunisia

1 Introduction

The Gabès region, southeastern Tunisia, corresponds to a semi-arid climate region, and has been a focal point of numerous hydrological and hydrogeological studies [2, 10,12,16]. Past research primarily explored aquifer systems and mineral water potential, often overlooking the present hydrogeological conditions shaped by climate change scenarios and growing water demands.

This study considers a comprehensive approach integrating geochemical and isotopic tools to unravel mineralization processes and aquifer hydrodynamics on Gabès aquifer system [3,9,11,18,20]. Geophysical tools like geoelectrical resistivity contribute to a detailed subsurface characterization [1,2,5,8,17,19].

Given the complexity of these factors, a robust management framework will be proposed, considering a thorough groundwater degradation assessment, hydrogeophysical simulation models, and the application of multi-criteria decision analysis. Through the integration of these components, the main aim of this research is to present a holistic conceptual model for groundwater hydrodynamics and groundwater mineralization [4,5,10].

This study will address current challenges and provide insights for the development of sustainable groundwater resources management strategies in the Gabès region.

2 Study area

The hydrogeological environment of the Gabès region in southeast Tunisia (Fig. 1) is typified by a dual climate, with Mediterranean conditions near the coast and desert conditions in the western expanse [1,3,5,10]. Because the area lacks permanent rivers, it sometimes experiences strong storms that channel extra water via wadis such as wad El Akarit, wad Jir, and wad El Hamma [6,13]. Positioned geologically near the eastern edge of the Tunisian meridional Atlas, the study region forms a tectonic transition zone between the Dahar plateau and the Jeffara platform via the unfolding of cretaceous and quaternary strata. Unique characteristics of

* *Corresponding author: imantunes@dct.uminho.pt*

the landscape include multidirectional faults like the NW–SE Gafsa fault and the E–W normal Chotts fault, as well as salt depressions like Fejij chotts [1,10,13].

The hydrogeological system comprises interconnected aquifers nestled within Mio-Pliocene deposits, Senonian units, and cretaceous formations.

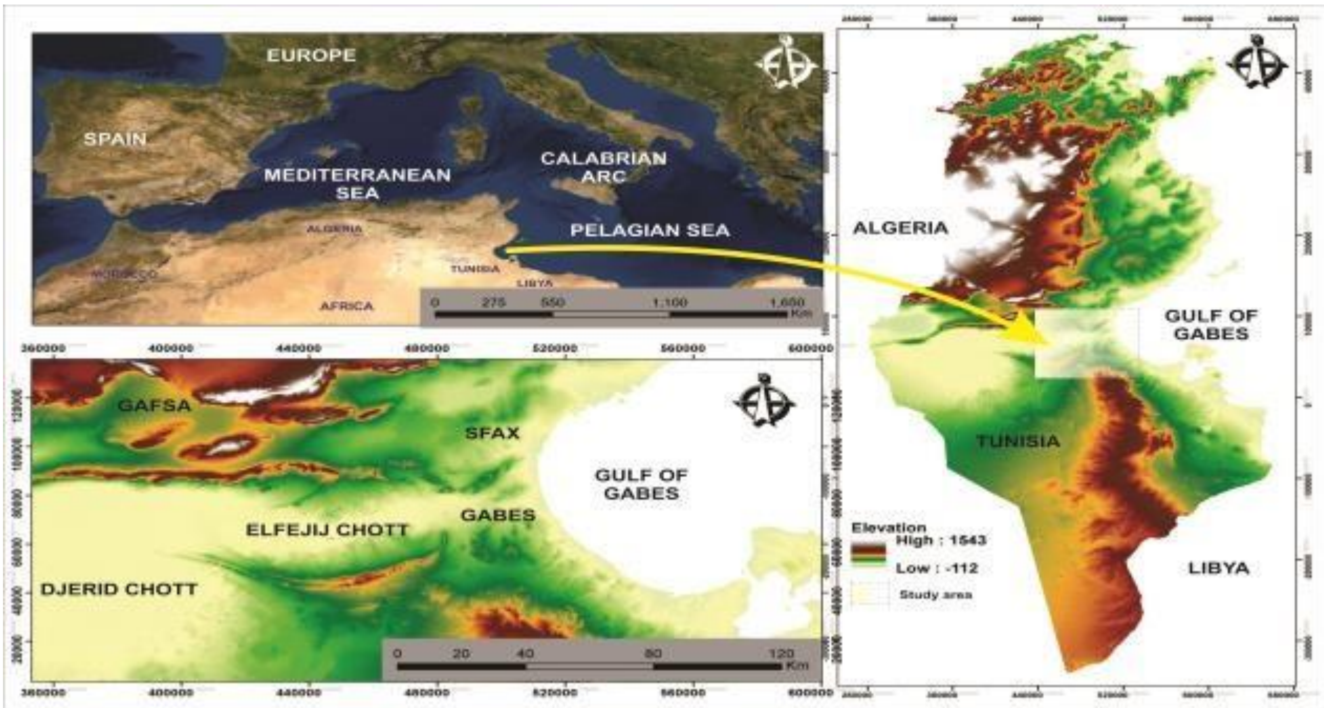

Fig. 1. Geographical setting of the study area and elevation variability

Groundwater overexploitation has led to a discernible decline in the piezometric level, particularly in the continental western part [9,7]. So, sustainable groundwater resource management practices will be crucial to support the water needs of industrial, agricultural, and human activities from the region

3 Methodology

In the intricate exploration of aquifer systems from the Gabès region, this study employed a multi-faceted methodology encompassing geological, geophysical, and hydro-geochemical techniques (Fig. 2). The Vertical Electrical Sounding (VES) method, a pivotal component of electrical prospecting is applied. This involved the injection of a current between electrodes A and B, with simultaneous measurement of potential difference (ΔV), between electrodes M and N. The calculation of apparent resistivity (ρa) resulted from the formula (1):

$$\rho a = k(\Delta V/I) \quad (1)$$

where the geometric coefficient (k) played a crucial role. Building upon extensive VES campaigns previously conducted in the Gabès-South area by the Regional Commissariat for Agricultural Development in Gabès CRDA of Gabès (2018), this study reinterpreted 100 Schlumberger-type VES, covering AB lengths, ranging from 800 to 2000 meters, and spanning the entire region.

Simultaneously, a groundwater sampling campaign was developed, collecting 44 samples from various aquifer systems within the study area. On-site titration methods were employed to determine bicarbonate, carbon dioxide, and carbonate water concentration. Titration was used to measure the dissolved CO2 and water alkalinity, and in-situ measurements included temperature, electrical conductivity (EC), pH, and total dissolved solids (TDS). The High Institute of Water and Science Techniques of Gabes (ISSTEG) laboratory performed studies of cations and anion in groundwater.

The acquired data were processed and spatially visualized using Arc-GIS 9.3, ensuring a high accuracy of 95% ionic balance within ± 8%. Groundwater stable isotope analyses (^{18}O and ^{2}H) were carried out at ISSTEG laboratory, reporting results in δ notation with uncertainties of ±0.1 ‰ for $\delta^{18}O$ and ±1.0 ‰ for $\delta^{2}H$. The synergy of geological, geophysical, hydro-geochemical, and isotopic analyses from aquifer systems provides valuable insights for sustainable water resource management, contributing to a holistic comprehension of the region's hydrogeological dynamics.

4 Results

Plotting groundwater samples from the study area shows the presence of several water types on a Piper diagram (Fig. 3A). The first is of the chlorinated calcium-magnesium kind, whereas the second is of the chlorinated sodium variety (Table 1). Certain samples exhibit a form of water that mixes (Fig. 3A). In the western section of the study area, the hydrochemical zonation of the groundwater aquifer systems from the Gabès region corresponds with the flow path of groundwater and differentiates the thermal deep aquifer of the continental Interlayer aquifer (CI) from other aquifer systems, like the Djeffara aquifer and the shallow aquifer of Neogene. Additionally, the groundwater samples show a mixing water across the main aquifer systems, as indicated by the Langelier-Ludwig diagram (Fig. 3A)

Table 1: Descriptive statistics of groundwater composition from Gabès aquifer system

Parameter	Ca2+	Mg2+	Na+	K+	SO42-	Cl-	HCO3	F-	PO4
Maximum	261	131	1443	78	1456	1902	186	2	6
Minimum	91	42	201	6	454	244	133	0	0

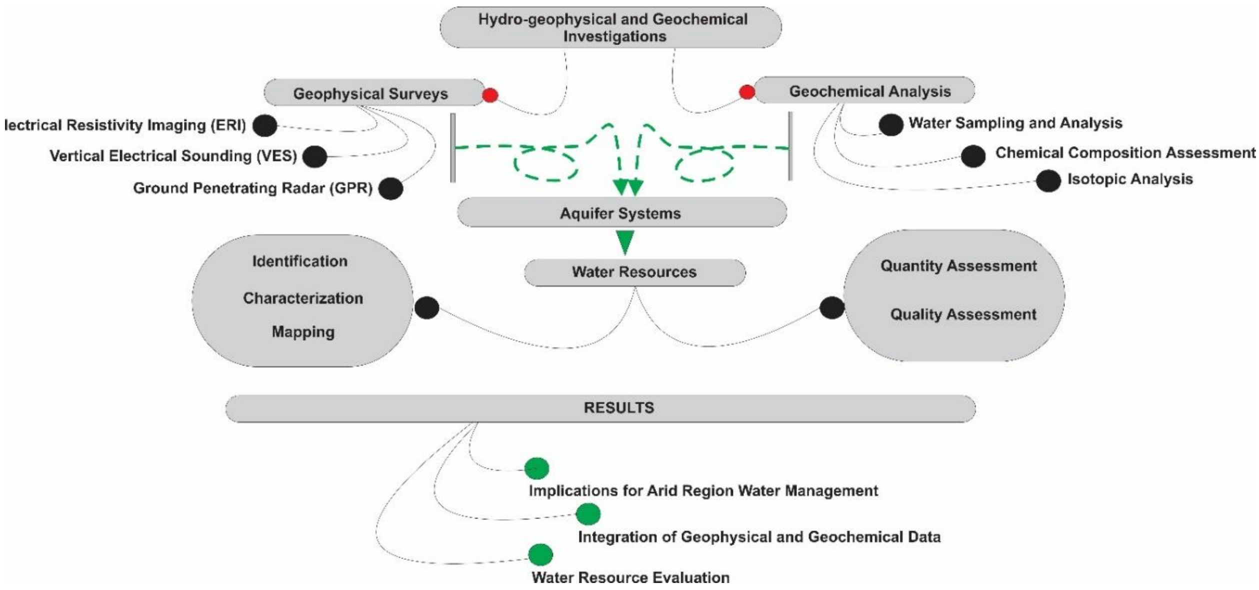

Fig. 2. Flowchart methodology

Moreover, the Continental Interlayer (CI) thermal aquifer's groundwater mostly controls the Djeffara aquifer's recharge because of the study area's vertical fault ramification, particularly in the El Hamma region [5,8]. As per Figure 3B, the Gibbs diagram indicates that the primary factors affecting groundwater aquifer systems are evaporation and rock weathering processes. Studies on evaporation indicate that temperature variations in groundwater can hasten the decomposition of minerals and cause the water's salinity to rise quickly [7, 8]. The two significant aquifer systems in the Gabès area (CI and Djeffara) provided the groundwater isotopic composition data. Consequently, our studies will further pertinent information on the mechanics of aquifer recharging. The regional meteoric water line of Sfax (RMWLS) will be used to compute precipitation isotope values since isotopic rainfall data are scarce in the study location [2,7,8]. On a standard diagram (Fig. 3C), the variation graphs for the groundwater isotopes δ18O and δ2H are displayed. The δ18O readings of the CI thermal water range from 8 to 6, while the δ2H values range from -70 to -51. The dominant wind direction and the geographic distribution of precipitation have an impact on natural recharge, particularly in the Dahar mountains and along the coastal plain where the exposed Neogene aquifer is close to the surface. As a result, the groundwater aquifer became lighter as it moved westward toward the Gabès region. The link between δ18O and chloride groundwater concentrations might explain different mineralization processes, with two separate groups (Fig. 3C). The first groundwater group (Fig. 3C) shows the dominance of evaporation processes with δ18O values ranging from -7.84 to -3.42 and chloride concentrations between 6 and 13 meq/L. The western portion of the Gabès area, which is connected to the CI aquifer system, correlates with this group. A dissolving process is mostly linked to the second groundwater group, whose δ18O values range from -7.5 to -4.6, their chloride concentrations are often higher than 15 meq/L, and their δ2H excess varies from -58.70 to -40.76. The CI and the Djeffara aquifer systems are representative of this groundwater group (Fig. 3 A, C). Additionally, the Cl- and TDS versus δ18O plots (Fig. 3) verify the existence of distinct groundwater groups as well as the impact of dissolving and mixing processes. Furthermore, several groundwater groups with increasing mineralization below the recharge reference point are shown in a scatter plot of δ2H against EC. This study suggests that the dissolution of the hosted rocks and the mixing of various water sources are the primary causes of the scattered isotopic data

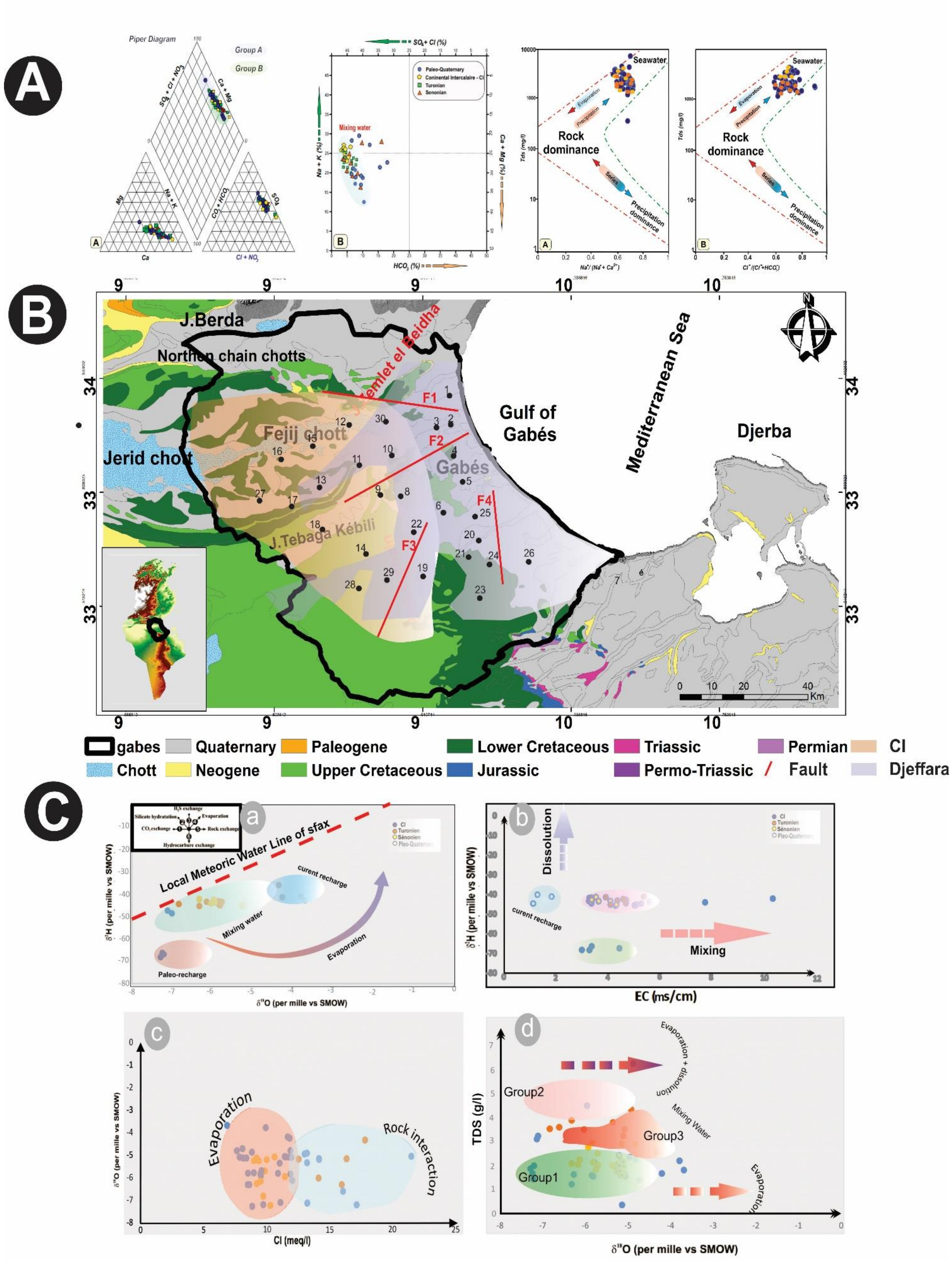

Fig. 3. **A.** Classification of groundwater samples, **B.** Conceptual model of the different recharge mechanisms, **C.** Isotopic scatter plots from Gabès region

This research was conducted in the Mio-Plio-Quaternary (MPQ) and Cretaceous environments in the Gabès area. The Cretaceous series had unique groundwater chemical properties and hydric potentials, which were emphasized by particular formations acting as aquifer networks. This is in complete harmony with the priceless contributions made by renowned scholars [11,10,8,14], which have greatly expanded our understanding of the region's geological characteristics.

In some areas, shallow wells provide access to the MPQ's sandy and/or sandstone series, which makes up the majority of the surface aquifer. This aquifer is notable for having a high hydric potential, being thick (> 80 m), and being low salinity (TDS <5 g/L). The relevance of high resistivities correlating to low groundwater salinity and vice versa is shown by the association between the apparent isoresistivity and groundwater salinity spatial distribution, notably at AB/2 = 300 m depth.

As groundwater wells produce strong, distinct flow patterns, the shift to the semi-deep aquifer system, the Lower Senonian (SIC) carbonate series, takes dominance. These limestone formations play a crucial role; they are found in grabens and are well positioned near the horsts of Teboulbou and Ragouba. The fault network in the research region reveals the structural complexity. It consists of three major faults that are oriented NE-SW and NW-SE (F1, F2, F3; Fig. 3B). Together with horsts (Zemlet El Beida, El Hammamet, Teboulbou, and Ragouba) and grabens (El Mida, Tarfaia-Oudref, Oudref-Gabes, Chenchou, and El Hamma), this complex network of faults shapes the structural landscape. It also has a major impact on the sedimentation of the area and the hydrodynamics of aquifer systems in the siliciclastic series MPQ, carbonates of the Lower Senonian, or sandstone of the CI. Faults and grabens disrupt the typical lateral flow of groundwater from west to east, while vertical water movements across faults mix water from several aquifer systems [8,14]. These illuminating results led to the creation of a painstakingly constructed summary map that presents an updated structural scheme for the North Gabès-El Hamma area (Fig. 3.B). This map (Fig. 3.B) serves as a reference, showing regions that are suitable for the exploitation of different aquifer systems. Given that the Mio-Plio-Quaternary (MPQ) is distinguished by its reduced hydrological significance, its utilization is considered advantageous in some areas. On the other hand, because of their extraordinary karstification and larger thickness, the Lower Senonian Limestones (SIC) are known to have a significant hydrogeological potential, especially in graben regions (El Mida, El Hamma, Chenchou, and Oudref-Gabès) and horst areas (Teboulbou and Ragouba).

5 Conclusions

In the Gabès region, the presented study delved into the characterization of two aquifer systems: the Mio-Plio-Quaternary (MPQ) aquifer, characterized by a shallow sandy-clayey composition with relatively lower hydrological potential, and the deeper Lower Senonian aquifer, composed of Senonian limestones boasting higher hydrological potential. The primary objective was to assess the viability of these aquifer systems, drawing upon a synthesis of geological data, groundwater characterization, oil drilling records, and 100 Vertical Electrical Soundings (VES) to provide a detailed characterization as a contribute to groundwater management.

Stratigraphically, the region contains Lower Cretaceous to Quaternary formations, containing hydrogeological and petroleum wells. Structurally, the Gabès region exhibits a complex fault system, predominantly oriented NE-SW and NW-SE, resulting in higher altitude zones (horsts) and lower ones (grabens). Other faults have been defined on the study area and a better characterization and enriching the knowledge of the region's structural intricacies.

This investigation consolidates the existing knowledge about the hydrogeology of Gabès region and introduces novel insights into the lateral and vertical extents of the aquifer systems, offering valuable guidance for effective groundwater exploitation and management. However, recognizing the need for ongoing detailed characterization, further investigations are essential. Indeed, Future considerations should include reinterpreting seismic profiles and extending VES coverage to places that have not been studied.

References

1. N. Abaab, A. Zanella, D. Akrout, R. Mourgues, M. Montacer, *Timing and distribution of bedding-parallel veins, in evaporitic rocks, Bouhedma Formation, Northern Chotts, Tunisia*, J. Struct. Geol. **153**,104461(2021)
2. S. Abdeljaouad, F. Zargouni, *Mise en évidence d'une tectonique intracrétacé dans le secteur de J. Zemlet El Beïda (chaîne des Chotts)*, Acte de 1er Congr. Nat. Sc. Terre, Tunis, t. **I**, 285 (1981)
3. B. Abdelkarim, I. Antunes, R. Missaoui, N. Abaab, B. Agoubi, *Assessment and modeling of the spatio-temporal variability of recharge in arid zones: the case of the Oued Zegzaou watershed (Southern Tunisia)*, in 1st Int Virtual Seminar on Geosciences, Constantine, Algeria, 7–9 Mar 2023 (2023)
4. B. Abdelkarim, B. Agoubi, N. Abaab, I. Antunes, *Predicted impacts of global warming and climate change on groundwater resources in a semi-arid region, southeastern Tunisia*, Euro-Mediterranean Journal for Environmental Integration, 1-13 (2023)
5. B. Abdelkarim, I.M.H.R. Antunes, B. Agoubi, *Groundwater recharge mechanism*

in a semi-arid region from southern Tunisia–a hydrogeochemical and isotopic contribution, Sustain Valencia 2022 Conference,69 (2022)
6. B. Abdelkarim, F. Telahigue, B. Agoubi, *Assessing and delineation of groundwater recharge areas in coastal arid area southern Tunisia*, Groundwater for Sustainable Development, **18**, 100760 (2022)
7. B. Abdelkarim, F. Telahigue, N. Abaab, B. Boudabra, B. Agoubi, *AHP and GIS for assessment of groundwater suitability for irrigation purpose in coastal-arid zone: Gabes region, southeastern Tunisia*. Environmental Science and Pollution Research, 1-16 (2022)
8. B. B. Benabdelkarim, N. Durães, B. Abdelkarim, M.R. Azevedo, J. Medina, I. Benhenda, M. Khlifi, S. Kamel, Assessment of groundwater quality used for irrigation in Gabes-Kebili regions southern Tunisia based on geochemical characterization and MCDM method. Water and Environment, 309 (2023)
9. H. Besser, N. Mokadem, B. Redhaounia, R. Hadji, A. Hamad, Y. Hamed, Groundwater mixing and geochemical assessment of low enthalpy resources in the geothermal feld of southwestern Tunisia. Euro-Mediterr J. Environ. Integr. **3**, 16. https://doi.org/10.1007/ s41207-018-0055-z (2018)
10. S. Bouaziz, Study of tectonics in the Saharan platform and Atlas (southern Tunisia): evolution of paleo-fields of constraints and geodynamic implications, PhD Thesis, University of Tunis (1995)
11. K. Boukhalfa, G. Li, W. Ben Ali, M. Soussi, Early Cretaceous spinicaudatans ("conchostracans") from lacustrine strata of the Sidi Aïch Formation in the northern Chotts range, southern Tunisia: Taxonomy, biostratigraphy and stratigraphic implication. Cretaceous Research, 56, 482-490 (2015). http://dx.doi.org/10.1016/j.cretres.2015.06.006
12. A. Gharbi, Z. Ibn Ali, M. Zairi, Groundwater suitability for drinking and agriculture purposes using irrigation water quality index and multivariate analysis: case of Sidi Bouzid aquifer, central Tunisia. Environ. Earth. Sci. **78**: 692–711. https://doi.org/10.1007/ s12665-019-8733-y (2019)
13. M. Gharbi, O. Bellier, A. Masrouhi, N. Espurt, Recent spatial and temporal changes in the stress regime along the southern Tunisian Atlas front and the Gulf of Gabes: new insights from fault kinematics analysis and seismic profiles. ectonophysics **626**, 120–136 (2014) http://dx.doi.org/10.1016/j.tecto.2014.04.00
14. R. Missaoui, B. Abdelkarim, K. Ncibi, M. Gentilucci, S. Brahmi, Y. Ayadi, Y. Hamed, Mapping groundwater recharge potential zones in arid region using remote sensing and GIS perspective, Central Tunisia. Euro-Mediterranean J. Environmental Integration, 1-15 (2023)
15. R. Missaoui, B. Abdelkarim, K. Ncibi, Y. Hamed, A. Choura, L. Essalami, Assessment of groundwater vulnerability to nitrate contamination using an improved model in the Regueb Basin, Central Tunisia. Water, Air, & Soil Pollution, 233(8), 320 (2022)
16. R. Missaoui, K. Ncibi, B. Abdelkarim, A. Bouajila, A. Choura, M. Hamdi, Y. Hamed, Assessment of hydrogeochemical characteristics of groundwater: link of AHP and PCA methods using a GIS approach in a semi-arid region, Central Tunisia. Euro-Mediterranean J. Environmental Integration, 1-16 (2023)
17. Mnasri, H., Nunes, A., Sahnoun, H., Abdelkarim, B., & Mahmoudi, S. (2023). Assessment of soil erosion in southern Tunisia using AHP-GIS modeling. Euro-Mediterranean Journal for Environmental Integration, 1-12.
18. H. Mnassri, H. Sahnoun, B. Abdelkarim, A. Nunes, S. Mahmoudi, Assessment of water erosion hazard using an integrated approach of geographic information systems and analytic hierarchy process: watersheds of oum el ghram and bou said (southeastern tunisia), In: 1st Int Virtual Seminar on Geosciences, Constantine, Algeria, 7–9 Mar 2023 (2023)
19. B. Redhaounia, B.O. Ilondo H. Gabtni, S. Khomsi, M. Bédir, Electrical resistivity tomography (ERT) applied to karst carbonate aquifers: case study from Amdoun, Northwestern Tunisia. Geophys. Pure Appl. https://doi.org/10.1007/s00024-015-1173-z (2015)
20. B. Redhaounia, M. Bédir, H. Gabtni, B.O. Ilondo, M. Dhaoui, A. Chabaane, S. Khomsi, Hydro-geophysical characterization for groundwater resources potential of fractured limestone reservoirs in Amdoun Monts (North-western Tunisia). J. Appl. Geophys. 128, 150–162. https://doi.org/10.1016/j.jappgeo.2016.03.005 (2016)