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The influence of the aquifer geometry on the groundwater flows (Timgad Basin, North-East Algeria)

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Abstract

The basin of Timgad belongs to the North-Eastern Algerian Saharan Atlas; it is located at the northern extension of the Aures Mountains. The basin is an asymmetrical syncline oriented East-West covering an area of 1000 Km2. The climate is semi-arid (cold winter and hot summer) with average annual rainfall not exceeding 400 mm. Recently, the increasing agricultural activities led to an excessive exploitation of groundwater resources. In order to meet this rising water supply demands, implementing a water resources management policy is a priority which should be based on a basin hydrogeological study. Effectively, the geological and geophysical studies have confirmed the presence of permeable Miocene and Cretaceous formations (sandstone and carbonate); relatively resistant affected by fractures network, which are probably forming a confined aquifers. Indeed, recent wells drilled in the basin center and their boundaries; show that the aquifers are artesian. The sandstone aquifer of the Miocene is the most important, it is characterized by significant thickness which can exceed 200m, its extension as well as its particular corrugated geometry, characterized by a wavy shape, which forming a series of shale-marl filling depressions, influences the groundwater flow, actually, the piezometric surface illustrates groundwater convergent flow oriented to the east, towards Bou el freis, likewise the sandstone aquifer is marked by the presence of a West-East drainage axis which separates the basin northern part characterized by a low reservoirs hydraulic capacity from the southern part distinguished by the groundwater relative abundance. Groundwater is generally easily extracted, except the northern part of the basin where the top shale-marl layer is thickens to over 1000m.

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Introduction

The geometric configuration reconstruction of the aquifer system represents an important stage to understand their hydrogeological processes (Cudennec *et al.*, 2007). The reconstituted geological structures allow to understand the relationships between the hydrogeological units in order to estimate groundwater flow. Located in northeastern of Algeria, The Timgad Basin occupies two provinces (Batna and Khenchela), with more than 79500 inhabitants (ONS, 2008). As the area is semi-arid (average annual rainfall not exceeding 400mm), water resources are mainly from groundwater which is exploitated by a large number of wells and springs. These are more distributed in southern part of the basin where they are relied upon for many activities.

Today, satisfying water supply needs in the Timgad Basin is a big issue due to the scarcity of water resources and increasing demand in all sectors, but mainly agriculture. The sustainable management of underground water resources is necessary and this starts with an understanding water reservoirs. This study has as objective to evaluate groundwater scarcity causes in northern part of the basin; this will be done by combining the geological and geophysical data for the hydrogeological structures identification and description, as well as to assess their impact on the groundwater flow.

Materials and methods

Geological and geophysical studies were used in order to reconstruct the geometric configuration of aquifer systems, we base on the geo-electrical and geological cross sections combined with stratigraphic log correlation for the Timgad basin. The results are presented as hydrogeological cross sections oriented north-south, which are perpendicular to the axis of the Timgad syncline covering the entire basin (west, middle and east)(Fig. 2).

The study includes data from 90wells which are used for water supply and irrigation. These mostly penetrate the Miocene sandstone aquifer with depths between 50m and 300m. For these wells, depth to groundwater was measured by electric probe and used to create the groundwater piezometric surface of Timgad basin.

From measured water level data a piezometric map was constructed. This map was used to determine the aquifers extension, flow direction, hydrodynamic boundary conditions and groundwater storage zones. In addition, the hydraulic gradient was calculated, in different places across the basin by measuring the change in head divided by the perpendicular distance between two consecutive piezometric lines (Castany, 1982).

Geologic Context

The Timgad Basin is part of the autochthonous atlas foreland at the northern end of the Aures mountains (Fig. 1). It is an east-west syncline formed mainly by folded Miocene sedimentary units extended over this large area (Ghandriche, 1991). The Miocene is comprised of three gross lithologic units which in ascending stratigraphic sequence include; 1) Red conglomerates and limestones at the base (Aquitanian-Serravallian); 2) A marl series with interbedded sandstone layers and greenish gypsiferous shale (Tortonian) in the middle and; alternating; 3) Red clays and shaly sands (Messenian) in the top. The Miocene rests unconformably on a Cretaceous marl and carbonate series (Coquand, 1862), and is covered by Quaternary sediments (Guellal & Vila, 1973 Ghandriche, 1991).

Structurally, the Timgad Basin is influenced mainly by the atlas phase of mountain building which defined its folded structures. This was reactivated by the post-Miocene phase of tectonics. In addition to the structure this also created a network of fractures oriented mostly NW-SE and NE-SW affecting both the Miocene and Cretaceous formations (Vila, 1980, Ghandriche, 1991). As the Miocene was deposited on an erosion surface a succession of depressions ,sometimes very deep, were infilled with sediment (Dj. Tagratine, Kef Lakhal), (Laffitte, 1939, Marmi, 1995).

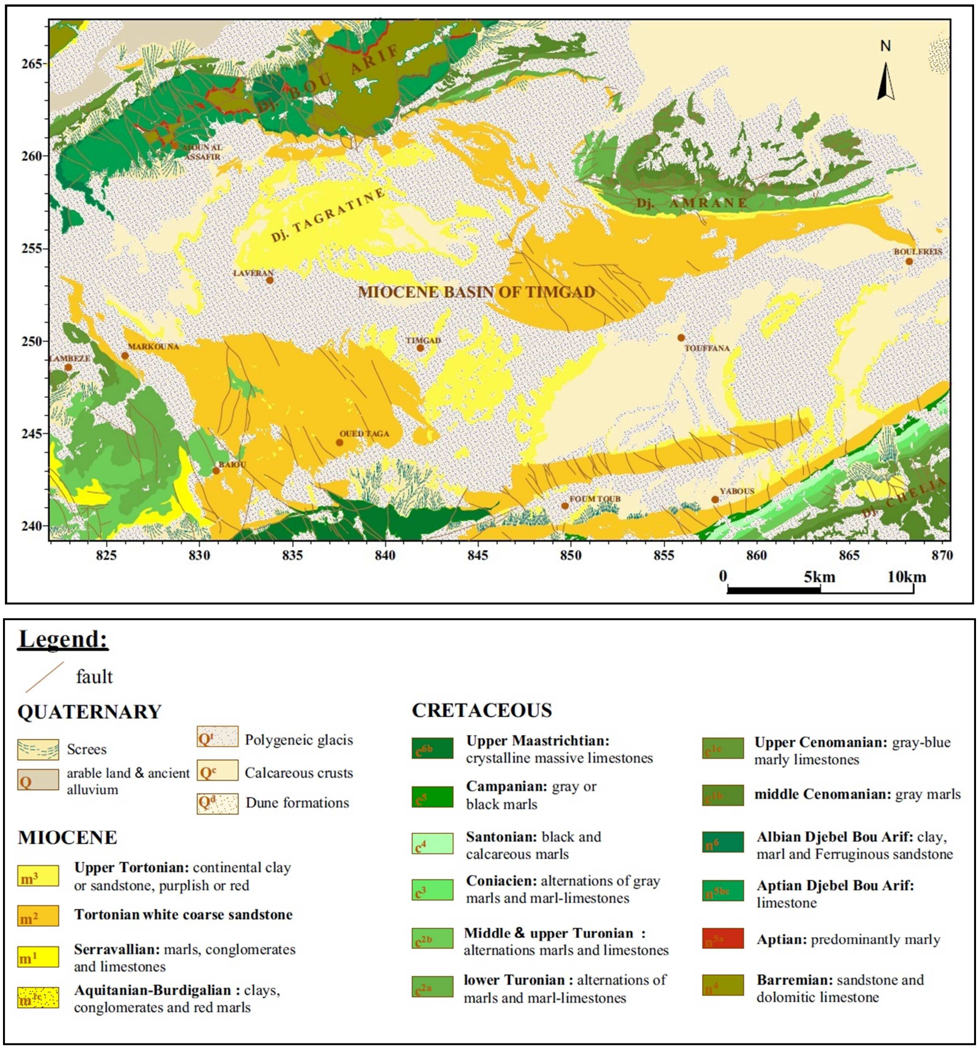

Fig. 1. Geologic map of the studied area Map assembly was made on the support of geological maps of Tazoult, Touffana, Ain el ksar, and Boulhelet, According to Vila & Guellal, 1973.

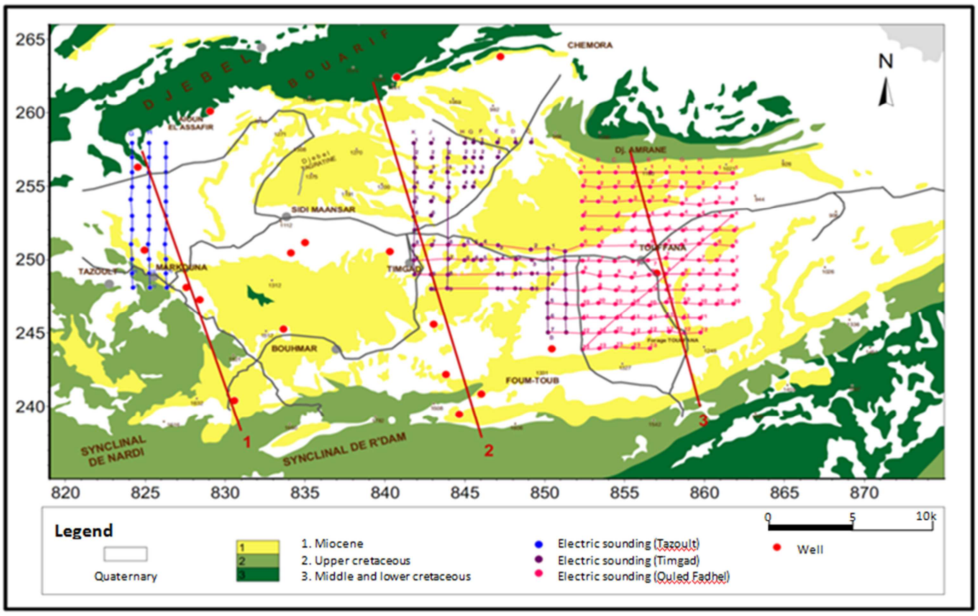

Fig. 2 Position map of electric soundings, wells and hydrogeological cross sections.

Geophysic context

Understanding lithological and structural variations of the existing geological formations is crucial for future water well implementation. A geophysical study using a surface electrical array was peformed in Timgad basin in the regions of Tazoult, Timgad and Ouled Fadhel (ENAGEO, 1993). For that study, 233 vertical electric soundings were made with AB = 4000m (A and B being the current emitting electrodes). The study showed the presence of low resistivity deposits, which are inferred to be Miocene marls and clays. This deposit thickens from the syncline boundary towards the center of the syncline. The conductive interval covers a relatively resistant level composed mainly by Miocene sandstones and partially by Cretaceous limestones which also outcrop on the basin edges, (Fig. 2).

Resultants and discussion

Interpretation of hydrogeological sections

A varied and contrasting lithology is shown by the hydrogeological sections on Fig. 3. These sections are characterized as folded structures with dips converge towards the center of the basin, favoring the groundwater recharge and storage, (ENAGEO, 1993). The major aquifers in this system are described in descending stratigraphic order below.

The sandstone aquifer of the Miocene

The base aquifer is an autochthonous detrital formation of the Tortonian age which extends throughout the basin. This is comprised mainly white sandstone with alternating greenish silty shale. This formation lies unconformabily on the Upper Cretaceous at the northern end of the Djebel Chelia anticline. The sandstone formation has a wavy shape with numerous erosional depressions filled by mio-Quaternary shale and marl deposits. Accordingly, thickness is varied but increases up to 1000m mainly in the center of the basin (syncline of Tagratine and the region of Ouled fadhel).

Known for its artesian wells, this aquifer is the most exploited. In addition, it is characterized by significant thickness which can exceed 200m, its extension as well as its particular corrugated geometry.

The limestone aquifer of the Upper Cretaceous

A massive crystalline limestone of the Maestrichtian age is exposed on the surface on the southern basin boundary (R'dam and Chelia massive). This formation is up to 300 meters thick. The limestones aquifer is little exploited comparedto the overlying sandstone aquifer. However, it is used in southern boundaries of the study area near the regions of Oued Taga, Foum Tob and Yabous.

The limestone aquifer of the Lower Cretaceous

Aptian limestone is exposed on the surface in the central part of the Bou Arif anticline, located at the northern basin boundary. The base of the Aptian is composed of basal marl banks up to with beige greenish and gray colors and is approximately 70m thick. Above this, lies a limestone formation which is about 300m thick which has aquifer potential. The exploitation of this aquifer is very limited given its depth plunge under the more recent formations and is restricted to the southern slope of Dj. Bou Arif (Ain Abderrahmane region and Aioun el Assafir region).

The basin hydrogeological cross-sections show the footprint of the post-Miocene tectonic phase. This tectonic phase induced a large rift valley. The junction between the normal faults located at the section centers clearly shows the rift extension and highlights the contact between the sandstone aquifer and the marl-clay filling of the rift, which forms an effective aquitard (constitutes water confining layer).

Communication between aquifers

In cross-section, the impact of the Atlas tectonic phase can clearly be seen with respect to the folded structure. Additionally, the scour-and-fill character of Miocene on the Cretaceous surface is also apparent. The sections (1, 2) show that the Maastrichtian limestones outcrop with a slight dip on the south-west end of the basin (Dj Chelia and R'dam), where they come into contact with the Tortonian sandstone (Miocene).Whereas, the Aptian limestones are strongly inclined on the northern boundary. Indeed, they have contact with Miocene sandstone only near the surface (Fig. 4).

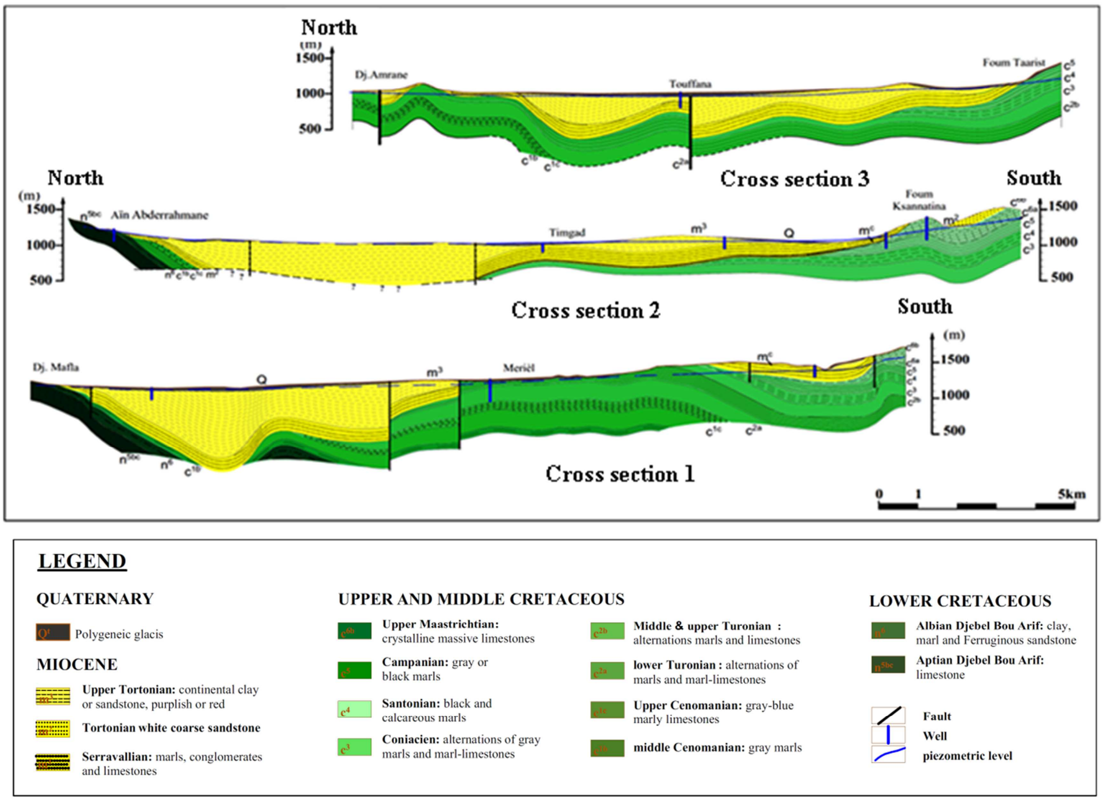

Fig. 3. Hydrogeological cross sections of the basin of Timgad.

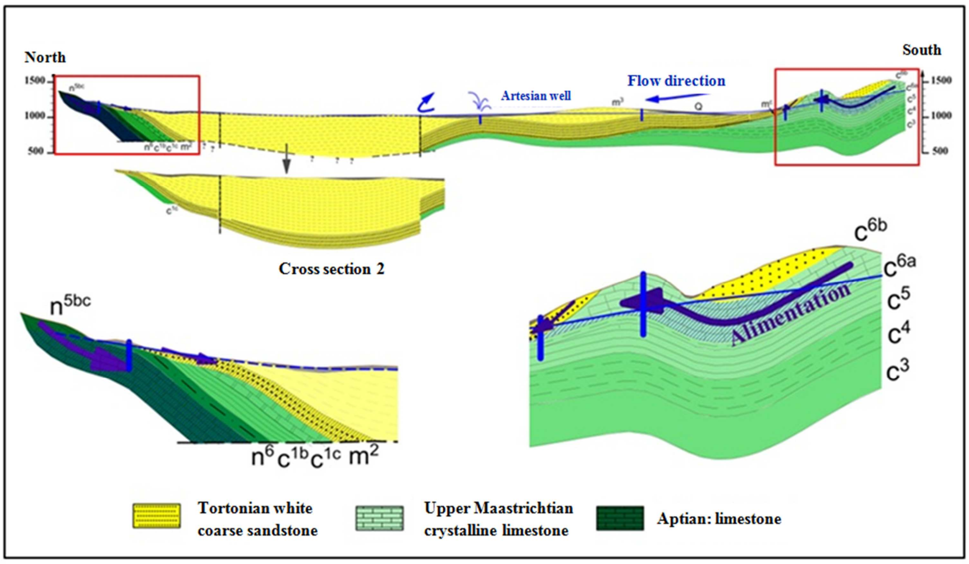

Fig. 4. Morphological and hydrogeological relations between the various aquifers of Timgad basin.

Piezometry

The piezometric map (Fig. 5) shows that the aquifer is recharged mainly from the southern boundary. This recharge boundary is formed by the Aurès massive (Dj. Chelia, Rdam, Nerdi Bouhmar), with a maximum altitude of 2328m (Dj Chelia), annual rainfall up to 770mm (ANRH 2013).

In this area, the Cretaceous carbonate formation is in contact with the Tortonian sandstone aquifer. Here, the carbonate sequence sources the sandstone aquifer creating its favorable aquifer conditions. The Dj.Bou Arif southern side is also a water supply source made mainly a marl-limestones formations of lower Cretaceous (maximum altitude of 1744m, K. Graf) (Fig. 4).

Located at the basins northern part, the rift shale-marl filling forms a water confining layer which influences. First, the groundwater flow direction:

The sealed barrier creates an east oriented flow axis in the basin center. This separates the southern part, characterized by the groundwater abundance where the sandstone formation is close to the surface, from the northern part, characterized by restricted groundwater utilization due to the resource plunging to depths >1000m (Fig. 6). Second, the shale/marl section acts as an aquitard causing the sandstone unit to become confined and leading to artesian conditions in the southern part.

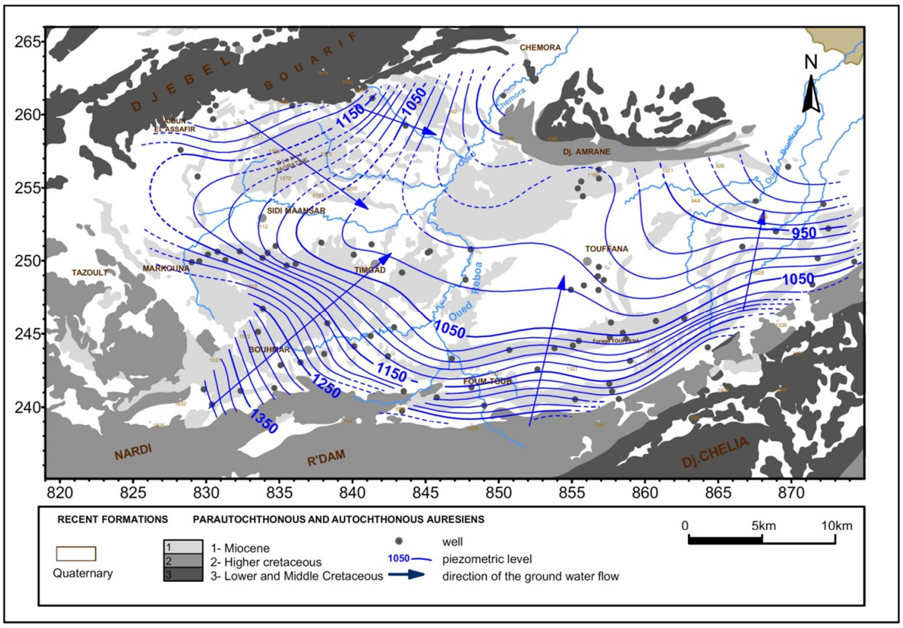

Fig. 5. Piezometric map of the Miocene sandstone aquifer (Timgad basin, April 2015).

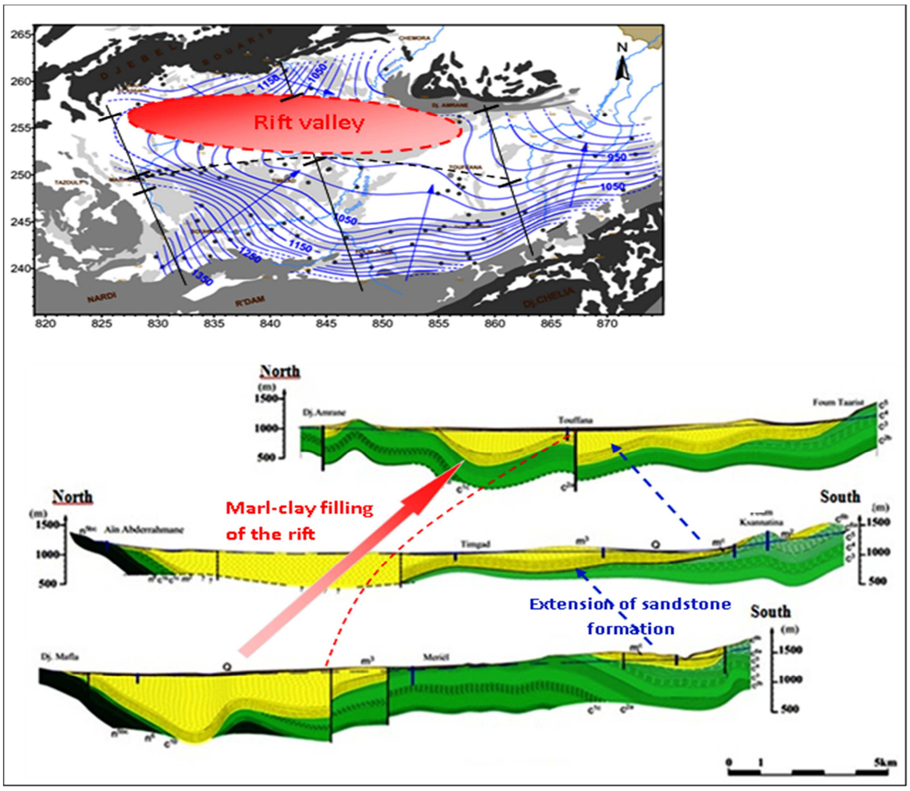

Fig. 6. Explanatory diagram of the geomorphology of the sandstone Miocene aquifer.

Mainly, the groundwater flow axes are oriented towards downstream (eastern basin, Bou el Freis region) from the south and west directions indicating a convergent groundwater flow (Fig. 5). The piezometric map shows a tightening piezometric lines at the basin boundaries (hydraulic gradient i = 2.5% to 5%). Otherwise, the piezometric lines interspacing becomes wider in the center and downstream (hydraulic gradient i = 1.5% to 0.5%).

Conclusion

The Timgad basin contains a various aquifers; the Miocene sandstone aquifer is the most important. It is characterized by many features such as its artesian wells, an important thickness up to 200m, its aerial extent and it's shallow depths. It is supplied essentially by the northern Aures massive, (a Cretaceous formation of a carbonated nature). Mainly, the groundwater flow direction is towards the East of the basin (region of Bou el Freis). A large shale marl rift valley is located in the northern basin part; it forms a sealed barrier that influences the groundwater flow direction and at same time increases the groundwater aquifer pressure. This rising pressure has lead to water artesian conditions in the southern part of the study region that show the importance of this aquifer. The Timgad basin generally offers easy access to groundwater. However, the basin's northern part, where the shale marl filling is thicker (>1000m) water is trapped deeply making exploitation expensive. In addition, regions of the basin could already be feeling the impacts of water production indicated by steepening groundwater gradients. Ultimately, traditional Miocene reservoir may not be sufficient to meet growing demands on its own.

This requires additional investigation; however, other alternatives also need to be examined including the viability of the upper and lower Cretaceous limestone aquifers and make seeking alternate solutions (surface water) to supply arid regions and to support the agricultural sector.

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