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Hydrogeological Modeling of the Sandstone Aquifer of Mostaganem Plateau (North-West Algerian) and Perspectives on the Evolution of Withdrawals

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Abstract

overexploitation of the Mostaganem aquifer has considerably reduced its groundwater resources. Based on this fact, the objective of our work is to study the modifications, the evolution, and the impact of the withdrawals of the aquifer in two aspects: magnitude and causes; by modeling groundwater with the Visual Modflow program. The setting was carried out in a steady state, which was calibrated and validated on Gauchez's piezometric maps, then in a transient state.

To predict the possible drop in groundwater levels for the upcoming years, three prospective scenarios were considered. In scenario 1, operating flows of drinking water supply and irrigation will remain constant from 2010 to 2035, the only variable is time, We notice that over 25 years the groundwater level of the slick for scenario-1 will continue to decline, especially in the central part where we note a fall of 5m and 7.5m. In scenario 2, half of the boreholes intended for the supply of drinking water on the Mostaganem plateau are at a standstill as of 2014, the launch of the Mostaganem, Arzew, Oran (MAO) project commissioning of the Chelif Dam is launched and the flow rates for irrigation are kept constant, after simulation, in the central part of the Mostaganem Plateau, we note a marked improvement in the drawdowns, which pass from 2.5 meters and 5 meters has drawdowns from 1 meter to 2.5 meters As, for scenario 3, an increase in the population of 2.51% is observed each year. In addition, the flows of drinking water supply and irrigation will be multiplied by 2.51% from 2010 to 2035, The drawdowns for scenario-3 (Figure 20), give worrying values, especially in the south of the Mostaganem plateau.

In the three scenarios, there is a continuous depletion of the groundwater resource due to significant withdrawals compared to the recharge of the aquifer. These simulations suggest that current sampling rates cannot be sustained over the long term.

Keywords: *Mostaganem aquifer, Over-exploitation, Groundwater levels, Hydrogeological modeling, Visual Modflow, Simulation scenarios.*

1. Introduction

Water is a key component of global socioeconomic development (Soular et. al., 2020). Groundwater, the world's largest freshwater reservoir, supports the survival and sustainability of human life worldwide. It is the main source of drinking water supply (DWS) at 50%, and irrigation at 70% (Seibert et al., 2010; Smith et al., 2016; Gleeson et al., 2016; Dieter et. al., 2018). The dependence of human activities on the availability of groundwater has increased with time and development. (Thakur Praveen, 2020). Moreover, it accounts for almost half of the world's drinking water (Unesco, 2009). Its unique characteristics, such as its subterranean nature, make it a difficult resource to manage, thus contributing to the increase of pressure on this resource. (Les Landes, 2015).

The Mostaganem Plateau is characterized by scarcity or even the absence of surface water. The main source of drinking water supply for human, agricultural, and industrial consumption is groundwater. This resource is limited and has experienced qualitative and quantitative degradation in recent decades due to anthropogenic (over-exploitation and pollution) and natural constraints (type of climate and global warming) (Bahir and Ouhamdouch, 2020; Boufekane and Saighi, 2019).

For several years, the Plateau aquifer has experienced a significant decline in the groundwater level of its main aquifer, consisting of Calabrian sandstones. This is due to a large demographic increase and an extension of irrigated perimeters leading to strong demand for water (Bentahar and Mesbah, 2007).

The water level decline of the aquifer implies the digging of even deeper boreholes. (ANRH, Sogreah consultants, 2006). In this context, hydrogeological studies have been carried out on the Mostaganem Plateau: (Perrodon, 1957), (Bonnet, 1967), (CGG, 1968), (Gauchez, 1981), the explanatory notice of the hydrogeological map of the Mostaganem Plateau at scale 1/10 000th (1978), (Gauchez.1981), (Baiche, 1994), (Saibi, 2000), (Sogreah, 2006), (Bentahar, 2007).

Several new approaches that were established to address groundwater depletion worldwide to enrich the future

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trajectory have been adopted (Bhat & al., 2019; Kaur & al., 2020). In the early 2000s, faced with the challenges of water management marked by water stress, the Algerian public authorities, initiated a series of major hydraulic infrastructure construction projects. In Algeria, 50% of the drinking water supply comes from underground resources and 33% comes from surface water. The average supply of a citizen is 180 liters/day (Algerian water supply, ADE, 2019). Among these new approaches, Algeria has opted for the desalination of seawater. The country has 21 desalination stations according to the Ministry of Water Resources (MRE, 2019), which allows supplying 6 million inhabitants with drinking water, with a volume of 1.34 million m^3/day (ADE, 2019). The only and best solution to guarantee the supply of drinking water in the long term is to move towards the use of unconventional waters, including seawater desalination since most of the population lives near and along the coastline. (Berraki, 2021).

To decrease the exploitation of the Plateau aquifer, two measures were opted for by the Ministry of Water Resources. The construction of a desalination station was commissioned in 2010, providing 200,000m^3/day of drinking water (ADE, 2019). The large MAO project consists of a water-dam-transfer structuring project from the Chelif dam (50 million meters cubic of retention) and a treatment station with a capacity of 600,000 m^3/day, and a pumping station, which supplies Mostaganem, Arzew, and Oran with drinking water. It allows the transfer of 45 million m^3/year for the benefit of the wilaya of Mostaganem. (ANBT, 2010).

Following this program, half of the boreholes intended for the supply of drinking water on the Mostaganem plateau are at a standstill as of 2014, according to the Mostaganem water supply department (DHW, 2015). Even with these important decisions, the level of the aquifer remains at risk; this is due to the large number of boreholes intended for irrigation that was not deemed useful to stop or reduce pumping, and the very large number of illegal boreholes for personal use. Despite the construction of new dams and the use of desalination, Algeria will record a water deficit of 1 billion m^3 by the year 2025 (Remini, 2010.)

Therefore, to better understand the role of current and future water use in different sectors (irrigation, drinking, and industry), the impact of climate change (Döll, 2009), population growth, and the policy interventions on groundwater availability in a quantitative manner, it is necessary to use advanced methods, such as geospatial technology and three-dimensional numerical modeling of groundwater.

The objective of this work is to study the functioning and evolution of groundwater, and the impact of abstractions on the sandstone aquifer of Calabrian, by implementing a management model using the Visual Modflow program.

This modeling will make it possible to advance the understanding of the modeled system operation and to predict future situations of the system according to different solicitations (predictive mode; changing input variables) or even to evaluate the system response to different usage scenarios (management mode; variations in boundary parameters and conditions). (Villeneuve and al., 1998).

The proposed conceptual model for the Mostaganem Plateau Aquifer System takes into account precipitation infiltration, saturated zone flows, drinking water abstraction (DWA), irrigation, and industry needs.

To characterize and understand the structure of the Plateau Calabrian aquifer, we used multi-source data (geological, topographical, geophysical, hydrodynamic), and we created a GIS database built under ArcGIS, which will be used for the implementation of the model.

2. Study area

The Plateau of Mostaganem is in northwest Algeria, in the Wilaya of Mostaganem, 363 km west of the capital Algiers. Bounded in the north by the lower Chelif Plain and the Dahra mountains, in the west by the Mediterranean Sea, in the south by the Bordjias Plain, and in the west by the Mina Plain (Figure 1). The study region is located between coordinates the coordinates are X1= 246 000 m, X2= 304 000 m, and Y1= 274 00 m Y2= 304 000 m (Projected Coordinate System: North_Algeria

Projection: Lambert_Conformal_Conic).

To determine the elevation of our study area, Four Shuttle Radar Topography images with a 30-meter resolution are obtained from the SRTM (2011). Its satellite images are downloaded from the UGSS (2014) in Geotif format.

The study area consists of 11 municipalities: Mostaganem (main city), Ain Tedles, Bouguirat, Sirat, Souaflia, Mesra, Ain Sidi Sheriff, Mansourah, Touahria, and Sayada. And represents 0.029% of the total area of Algeria. (National Statistics Office, NSO, 2008).

During the French colonization, vine cultivation was introduced on the Plateau. After the independence of the country, it was replaced by irrigated markets for gardening, citrus fruit, and cereal crops (Marc Cote, 1996).

The Plateau of Mostaganem is a first-rate agricultural and tourist area, it is tabular with an area of 700 km^2. This plateau drops steadily towards the west towards the plain of Habra and the Gulf of Arzew. (Gauchez, 1981). It has a series of parallel wrinkles and depressions-oriented southwest and northeast. (Baiche, 1994).

The altitude of the Plateau is situated between 110 m (in the west) and 470 m (in the east) with an average of 200 m which decreases gradually to 100 m at the level of the Macta. (Bentahar, 2007).

In the north, the plateau regularly overlooks the lower Chelif Valley, showing a series of cliffs whose heights vary from 150 m to 200 m. To the northeast, it comes up against the Cretaceous spur of the Djebel Diss (Dahra) which culminates at an altitude of 400 m. To the South-East, it is bordered by a line of relief materialized by the strong buttresses of Akboube and Ennaro which separates it from the plain of Relizane. (Bellal S, & al., 2019).

The hydrography of the Mostaganem plateau is very modest. It is limited to two small permanent rivers (wadis).

The first, the Sefra wadi, 11 km long, originates in the region of the "seven wells", and becomes perennial at the entrance of the town of Mostaganem where it receives the overflow of sources captured from Kheir eddine (ex Pélissier), before flowing into the sea. The second, the Kheire Wadi 6 km long, is a tributary of the Chelif. It is fed by the sources of Ain Soltane and Ain Hallouf (Gauchez,1981).

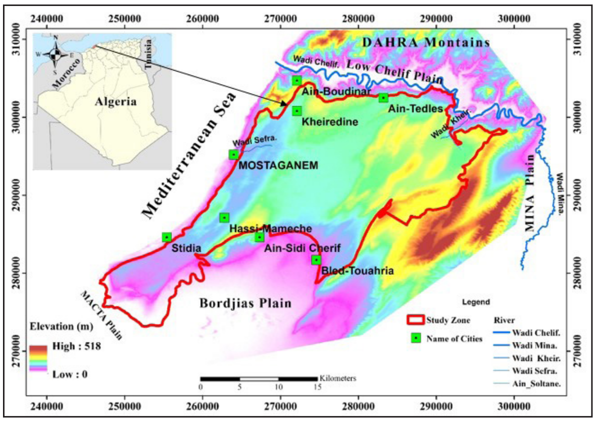


Figure 1. The geographical location of the Mostaganem Plateau.

2.1 Geological and Hydrogeological Characteristics

At the level of the Mostaganem plateau (Figure 2), there are two types of formations:

- Allochthonous formations are the oldest, we can define the Trias which consists of white gypsum located South of the Mostaganem plateau. The tablecloths are in the north of Mostaganem (Karouba, Djebel Diss), where appears a whole set of land belonging to the tablecloths of the Numidian age, extends into the region of Mina. diapirism occurs east of Ain Nouissy.

- Indigenous formations are predominant, they include: the Lower Miocene corresponds to a blue marl level; the upper Miocene is characterized by blue marl interposed by levels of sandstone with calcareous-clay cement, cinerites 0.20 m thick, (Perrodon, 1957). These blue marls are very well exposed at the level of the Akboube State Forest, where they extend widely on the axis of this anticline under quaternary deposits. The Pliocene is almost everywhere on the borders of the Mostaganem plateau. It consists of ancient marl or sandy horizon of 200 to 500 m thick, and the Astian formed of limestone sandstone with a maximum thickness of 100 m. The Quaternary is represented by the transgressive and discordant Calabrian on the deposits of the Mio-Pliocene. It is formed by limestone sandstones. The Calabrian covers the whole plateau of Mostaganem.

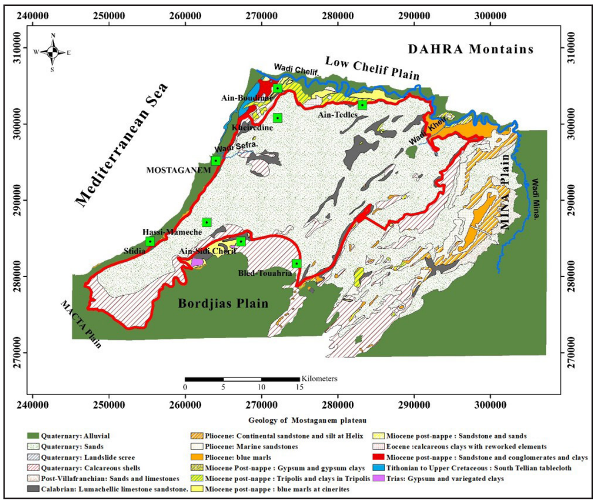


Figure 2. Geological map of the Mostaganem Plateau.

2.2 Climatology characteristics

The Mostaganem plateau is characterized by a semi-arid to temperate winter climate and rainfall ranging between 350 mm and 600mm (1962-2017). Eight metrological stations were selected for this study. Rainfall data were provided by the National Water Resources Agency (ANRH) of Algiers. Temperature data are obtained from the National Meteorological Office (ONM), Dar El Beida, Algiers. A meteorological station is located near the Mostaganem city, and seven rainfall stations (cultivated dunes, Ain Tadles, Hassi-Mameche, Khierdine, Ferme Assorain, Oued-Keir, Fornaka), are distributed through the entire Plateau (Figure 3). The Mostaganem station (04-06-12) and the Ferme Assorain station (11-16-17) present the longest and most complete series of monthly rains (1968-2017). The duration of observations varies from 49 years for the Mostaganem station (04-06-12) to 33 years for the Hassi Mameche station (04-06-03). The data contains gaps in observations, which required their filling by the method of least squares (Table 1).

Table 1. Climate data available at Mostaganem Plateau.

Station Name	Code	X	Y	Data type	Frequency	Period	Deficiency rate (%)	Annual average[1]	Standard deviation
Mostaganem	04-06-12	264800	296250	Evapotranspiration	Monthly	1968-2017.		422	
				Temperature	Monthly	1962-2010	0	18	0.68
				Rain	Monthly	1906-1926 1935-1938 1942-1961 1968-2017	0 0 0 0.5	388	
Cultivated dunes	04 06 11	274000	288300	Rain	Monthly	1970-2010	3.12	336	
Ain Tadles	04 06 06	283100	302600	Rain	Monthly	1942-1961 1968-2009	3.04		
Hassi-Mameche	04 06 03	263050	287600	Rain	Monthly	1928-1961	8.83		
Khierdine	04 06 02	272100	300750	Rain	Monthly	1969-2009	1.66	358	
Assorain Farm	11 16 17	281250	291850	Rain	Monthly	1968-2009	1.82	337	
Oued-Keir	01-36-06	291500	297600	Rain	Monthly	1970-2009	2.99	346	
Fornara	11 16 06	250800	278500	Rain	Monthly	1967-2009	1.59	268	

Units: Rain and Evapotranspiration in mm; Temperature in °C.

Precipitation on the Mostaganem plateau varies in time and space; we note an irregularity of rainfall from one year to another and from one station to another (Figure. 3). Thus, the height of precipitation is greater in the northern part of the plateau (04-06-12 = 592 mm for 1971, 04-06-02 = 556 mm for 1979, 04-06-06 = 575 mm for 1971) than in the southern part (11-16-06 = 486 mm for 1969, 04-06-11 = 402 mm for the year 1971,11-16-17 = 494mm for 1971). Over 49 years, the rainy months extend from September to April, and the driest months from July to August.

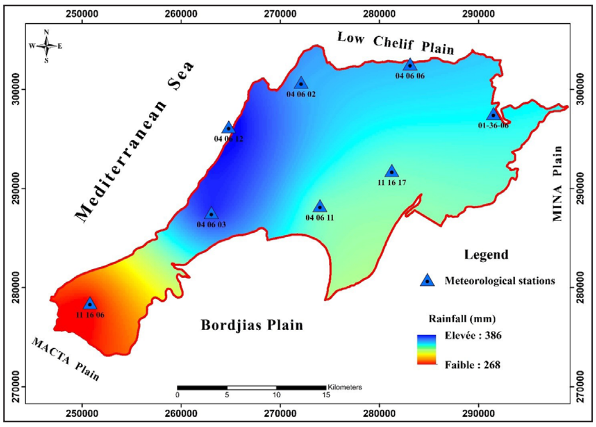


Figure 3. Annual rainfall distribution through rainfall stations on the Mostaganem Plateau over the period 1968-2017.

The year 1981 is the driest in the entire Mostaganem Plateau with minimum precipitation of 85 mm at station 11-06-06 located in the south of the study area.

Evapotranspiration (ET) is the amount of water transferred to the atmosphere by evaporation at ground level and the level of precipitation interception and by transpiration of plants. Potential evapotranspiration (ETP) is the amount of water that would evaporate or transpire from a watershed if the water available for evapotranspiration was not a limiting factor (Laborde, 2003). Evapotranspiration is measured by the Thornthwaite method:

$$\mathbf{ETP = 1.6\ (10T/I)^a} \quad (1)$$

With:

ETP: potential evapotranspiration in mm

T: average monthly temperature of the month in °C

$I = \sum_{i=1}^{12} i$: The annual heat indexes

a= $0.492+1.79\times10^{-2}\times I-7.71\times10^{-5}\times I^2+6.75\times10^{-7}\times I^3$

Were

i = $(T/5)^{1.514}$ monthly heat index

The mean ETP values (Figure 4) range from 23.18mm in January to 152.25mm in July.

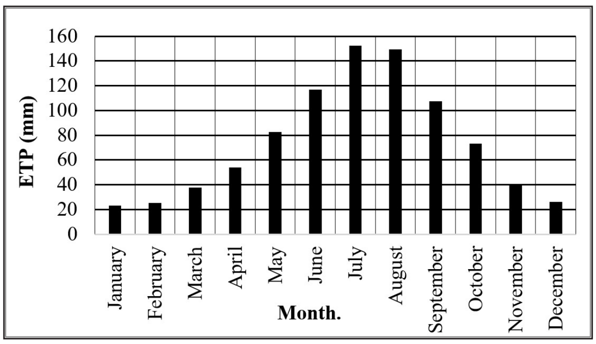


Figure 4. Change in monthly ETP averages at the Mostaganem plateau (1968-2017).

Real Evapotranspiration (ETR) is the amount of water evaporated or transpired by soil, plants, and open water in a watershed (Laborde, 2003). The ETR is calculated by the empirical formula based on the Turc method.

$$\boldsymbol{ETR = \frac{P}{0.9} + \frac{P^2}{L^2}} \quad (2)$$

ETR = actual annual evapotranspiration in mm

P = annual precipitation in mm

L = the evaporating power.

L^2 = $(300+25T+0.05T^3)^2$.

T = average annual temperature in °C.

Precipitation and Temperatures (Figure 5), used in our calculation will be those relating to the Mostaganem 04-06-12 station (period 1969-2017).

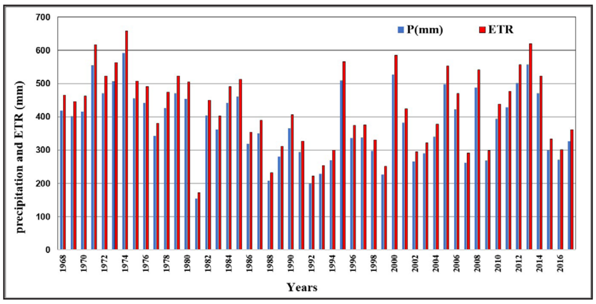


Figure 5. Interannual variation of the ETR at the level of the Mostaganem Plateau.
(Period 1968-2017)

At the station of Mostaganem (Figure 5) period 1968-2017, the maximums rainfall, recorded during the year 1974 with 657mm. The minimum is observed during 1981 with 171mm.

The **Thornthwaite** method was adopted to estimate the different terms of the hydrological balance equation that was established over 49 years (1968-2017), whose formula is written as follows:g

$$\boldsymbol{P = ETR + R + I} \quad (3)$$

With:

P: average annual precipitation (mm)

ETR: actual annual evapotranspiration (mm)

A: average annual runoff (mm)

I: average annual infiltration (m)

The study of the flow deficit at the scale of the study area resulted in an evaluation of the real evapotranspiration (ETR) estimated by the Turk method at 422 mm. The infiltrated water layer determined by the Sogeta-Sogreah method was estimated at 19 mm. Runoff reaches 23mm (1968-2017).

2.3 Hydrogeological characteristics

The Mostaganem Plateau has an impermeable marly substrate, topped with sandy-past sandstone or sandy-clay sandstone that contains the main aquifer (Figure 6). The sand overcomes all this, with facies and thickness varying according to their location, where it is possible to show the presence of a sandy limestone crust associated or not with red soil. Calabrian is the main aquifer with varying thicknesses. Thus, it can reach a power of 100 to 120 m in topographical depressions while on the bulges of the base, the formation will be 20 to 30 m. In general, the thickness of this series decreases from ENE to WSW. The Miocene and Lower

Pliocene formations constitute the impermeable substratum of the main aquifer. The Miocene is essentially represented by blue marl, sometimes including gypsum levels. The Quaternary is transgressive and discordant in earlier series.

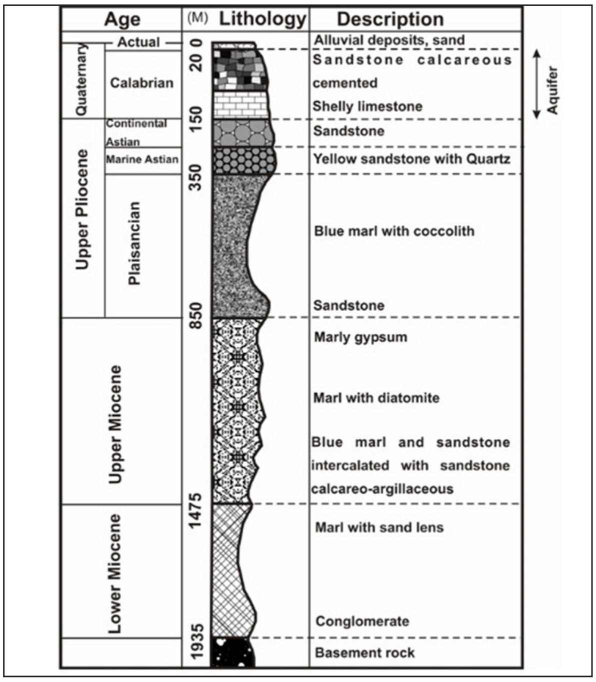


Figure 6. Well log stratigraphy at Mostaganem plateau (Saibi, 2008).

The sandstone aquifer of Calabrian has been the subject of several piezometric companies: during the year 1970 by the Office of Hydraulic Inventory and Research of the ANRH of Algiers, and a piezometric campaign of June 1990 by (Baiche, 1994) in the framework of a Magister supported at the University of Oran. The ANRH of ORAN carried out the last piezometric surveys, on one hand, during the years 1995 and 1996-1997, which covered 12 piezometers, and on the other hand, during the hydrological years 1998-1999, 1999-2000, 2010, 2011, 2012 and which covered 17 piezometers and whose main role is to control the Mostaganem Plateau aquifer.

The variations in the groundwater level during periods of high and low water are small (Figure 7). They are 1 to 2m in areas where the aquifer is less than 10m deep and 0.5m on the rest of the Plateau. The aquifer is fed exclusively by the infiltration of precipitation water. Sources account for 85% of the flow of natural outfalls. They are located on the periphery of the Plateau where the impermeable substrate collapses. The piezometric surface emphasizes the general conformity of the layer with the surface of the ground. (DEMRH, 1971).

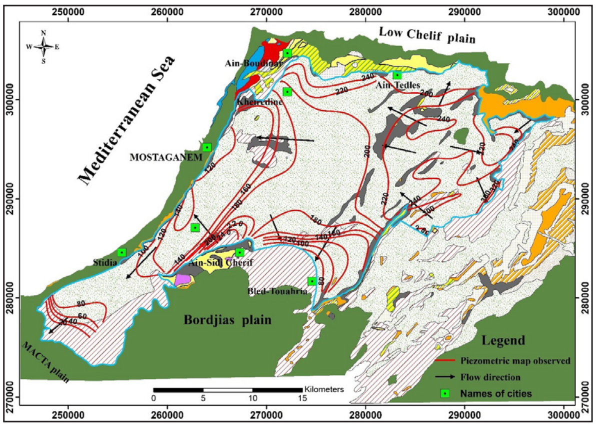


Figure 7. Piezometric map of the Mostaganem Plateau 1970.

3. Materials and Methods

3.1 Model implementation

For modeling an aquifer system, the first step is to assign boundary conditions and calculation parameters (EL Arbi Toto et. al., 2009). This phase was accomplished through the literature review of available data.

The software used is Visual Modflow 2011.1, which simulates groundwater flows and contaminant transport in both steady and transient conditions. The Visual Modflow includes several modules: Modflow-2000: developed by USGS (Pallok, 1989) to simulate underground flows. Modpath: a program used to simulate particle flow lines downstream or upstream of a reference point. MT3D: program modeling the transport of solutions or contaminants in the aquifer.

Conceptual modeling using the Modflow 2000 code, which resolves the partial derivative diffusivity equation of groundwater flow in a porous media by the finite difference method,

$$\frac{\partial}{\partial_x}\left(k_{xx}\frac{\partial h}{\partial_x}\right)+\frac{\partial}{\partial_y}\left(k_{yy}\frac{\partial h}{\partial_y}\right)+\frac{\partial}{\partial_z}\left(k_{zz}\frac{\partial h}{\partial_z}\right)div(k\ grad\ h)-w=s_s\frac{\partial h}{\partial t} \quad (4)$$

With k the hydraulic conductivity (L/T), h the hydraulic load (L), $_{Ss}$ the specific storage coefficient (L^{-1}), W the volumetric flow per unit volume representing the term well or source (T^{-1}), and the time (T).

Modeling is initiated by trial and error to obtain the best set of calculated piezometric concerning the observed values.

3.2 Delimitation of the study area extension

The modeled study area corresponds to the Calabrian sandstone aquifer of the Mostaganem Plateau, with an area of 700 km^2, and the coordinates are X1= 246 000 m, X2= 304 000 m, and Y1= 274 00 m Y2= 304 000 m. The first step in building the model consists of defining the number of layers and defining the mesh of the study area (Figure 8).

The discretization of the space in regular square meshes presents a great facility both in the use and in the implementation of the models. (Ledoux E, 2003). The study area was discretized in a single layer regularly in a square mesh of 500×500m aside, for a total of 2520 active meshes.

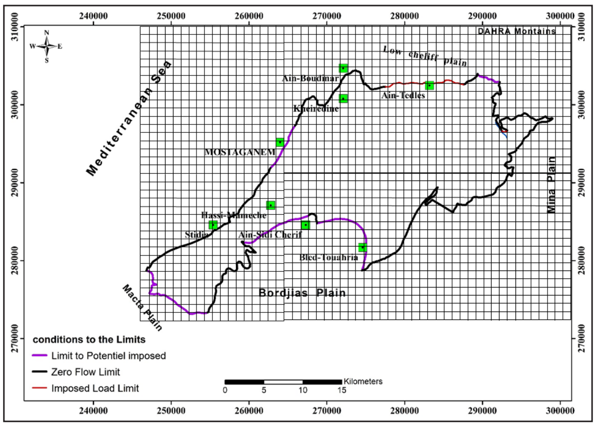


Figure 8. Discretization of the Calabrian aquifer of the Mostaganem Plateau.

3.3 Boundary conditions

The relationship between the modeled domain and the external environment is described through three types of boundary conditions. The first is the imposed load condition (Dirichlet condition): the piezometric height is known along the boundary. The second is the Required flow condition (Neumann condition): when the exchanged flow rates are known. the tightness limits (tight limits) or limits through which the flow rate is negligible are considered zero flow limits. The third concerns the Mixed load and flow condition (Fourier or Cauchy condition): the flows are dependent on the piezometric height. This is the case for rivers draining or feeding the aquifer. These types of boundary conditions can simulate flows between the groundwater and surface waters (Dassargues, 1995).

The boundary conditions concern the rules for the exchange of flows between the modeled domain and the external environment (Ledoux, 2003):

- in the North limit with no flux, (Figure 9) constituted by the marls and clays of the Miocene of Djebel Bel Hacel.
- in the North-East, an imposed load limit.
- in the East and South-East, zero-flow limits.
- in the South, a limit to be imposed is the exit of the piezometry towards the plain of the Bordjias;
- in the South-West, there is also an imposed load limit, which is the exit of the aquifer towards the plain of the Bordjias.
- The western limits are a zero-flow limit except for the area of the city of Mostaganem, where an imposed charge flow was been imposed.

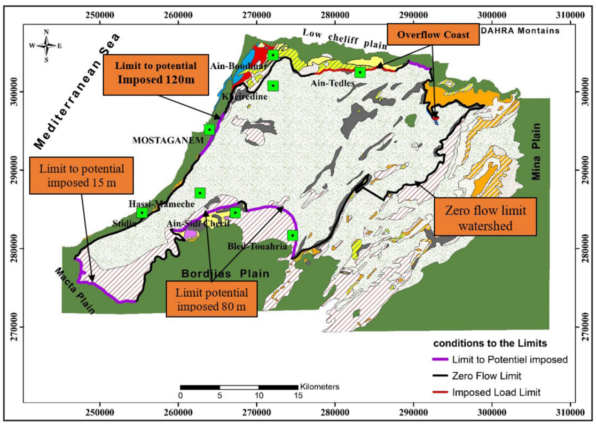


Figure 9. Map representing the boundary conditions of the Calabrian aquifer of the Mostaganem Plateau.

3.4 Results and discussion

3.4.1 Simulation and calibration in steady-state

A steady state is a condition that characterizes an aquifer before a variation is introduced. (Bandani E & al., 2011). The steady-state piezometry of the Mostaganem Plateau aquifer is established using data from the 1970 piezometric campaign (Gauchez, 1971), minimizing the gap between calculated and observed piezometry. The parameters used are the permeability, the recharge, and the thickness of the aquifer.

Adjustments were made to the permeability to best match the simulated piezometric map to that observed one (Table 2).

Table 2. Permeability Adjusting in steady state.

Borehole N°	Initial K (m/s)	K modified (m/s)
F111	0.125×10^{-4}	1×10^{-4}
F56	0.125×10^{-4}	1×10^{-4}
F41	0.125×10^{-4}	6×10^{-4}
F42	1.5×10^{-4}	6×10^{-4}
F43	0.125×10^{-4}	6×10^{-4}
F85	3×10^{-4}	6×10^{-4}
F92	3×10^{-4}	4.5×10^{-4}
F20	3×10^{-4}	6×10^{-4}
F21	4×10^{-4}	4.5×10^{-4}
F65	6×10^{-4}	6×10^{-4}

At the end of the calibration, a map of the spatial distribution of the permeabilities was drawn up across the Calabrian aquifer (Figure 10). Five zones of permeability are shown, the values are between 1×10^{-4} and 1.5×10^{-4} on most of the central part of the Plateau and the extreme southwest of the Plateau. South of Ain Tedles is a V-shaped zone (boreholes F41, F42, F43) whose tip points towards the center of the Plateau and whose permeability value is the highest of the order of 6×10^{-4} to 7.5×10^{-4}, another zone lying to the east of the city of Mostaganem (boreholes F66, F67), and at the eastern end (borehole F85) of the Plateau. These values are explained by the presence of lumachellic sandstones and limestones. These zones of low permeability values are progressively surrounded by ranges of intermediate permeability values in the range of 4.5×10^{-4} to 6×10^{-4} and then values in the range of 3×10^{-4} to 4.5×10^{-4}.

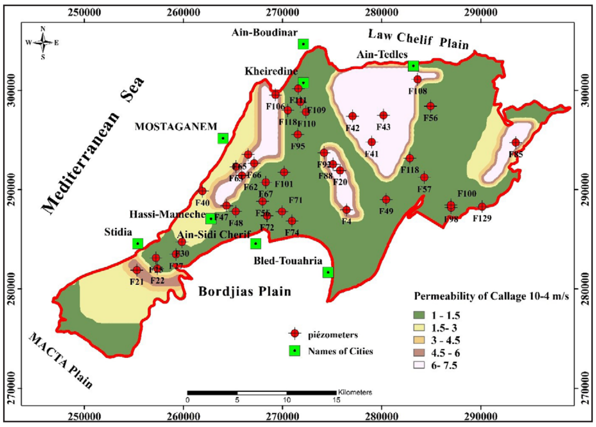


Figure 10. Spatial distribution of the permeability of callage after calibration in steady-state 1970.

The recharge of the aquifer is constituted by the flow calculated in the form of effective rainfall infiltration rates determined by the hydrological balance sheets and by the flows imposed on the lateral limits of the modeled domain (Kessasra, 2015). The average infiltration is calculated from the rain and temperature archives recorded in the stations distributed on the Mostaganem Plateau.

The thickness of the aquifer is calculated using the drilling logs over the Mostaganem Plateau. The study is complemented by geophysical analysis and geological sections. A thickness distribution map was made using all of its data (Figure 11). The maximum thickness of the aquifer is 125 m in the eastern part of the plateau, while the entire central part is between 50 and 75 meters thick, up to 100 meters thick, and it is in this part of the Plateau where most of the drilling is concentrated, especially those intended for the supply of drinking water.

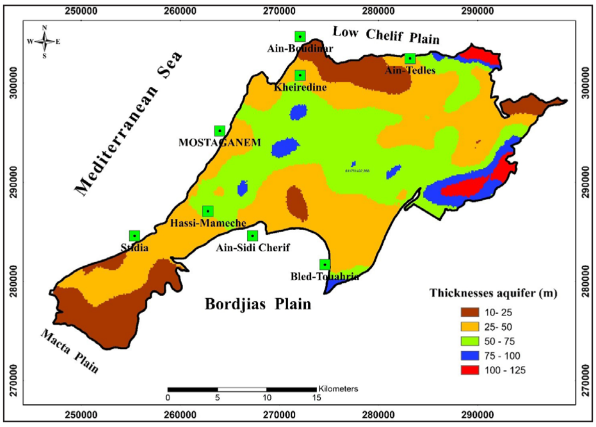


Figure 11. Spatial distribution of the thicknesses of the Mostaganem Plateau aquifer.

The simulated head is well correlated with the observed head (Figure 12), with a correlation coefficient of 0.99. Statistical analysis of the calibration results of the model mentioned in Table 3 gives acceptable values. The residue is between 0.56 m and 18.85 m. The average absolute value of the residues is 0.978 m for a groundwater level between 84.3 m and 285 m. The square root of the quadratic mean error (RMS) is 6,264 m.

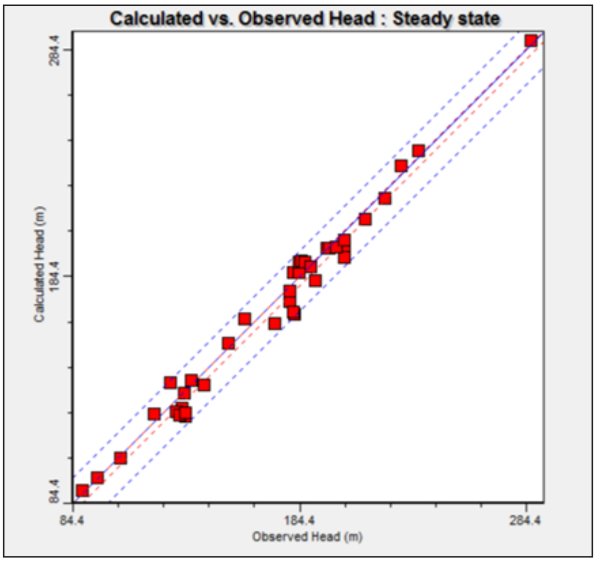


Figure 12. Comparison of calculated and observed heads in steady state.

Table 3. Statistical indices of the results of the model calibration.

Number of points	38
Minimum residue	-0.338
Maximum Residue	-14.105
Average absolute error (m)	0 978
RMS (m)	6 264
Standard RMS %	3 163
Correlation coefficient	0.99

The setting in steady-state, as shown in (Figure 13), is considered optimal. It is satisfactory because the calculated hydraulic loads correspond overall to the piezometric measurements made in the Calabrian sandstone aquifer of the Plateau de Mostaganem. The shape of the isopiezes appears to be like the measured isopiezes, the same piezometric tendencies have been largely reproduced throughout the Plateau. However, isopiezes seem to be shifted in the South-West probably due to a poor estimation of the permeability set due to the lack of measurements in this Plateau area and the lack of pumping tests carried out.

On the Mostaganem plateau, the simulated piezometry has a flow direction identical to that observed, it is done from the central part towards the south, the east, and the west. In the east part, the flow has a divergent aspect, it is done towards the east and the west. In the southern part of the plateau, the groundwater level passes from 180m to 100m and the flow goes south, towards the plain of the Bordjias. In the southwest, the groundwater level goes from 80m to 20m, and the flow is towards the plain of the Macta. In the western part of the plateau, the general flow direction goes from the city of Mostaganem where the groundwater level passes from 180m to 120m.

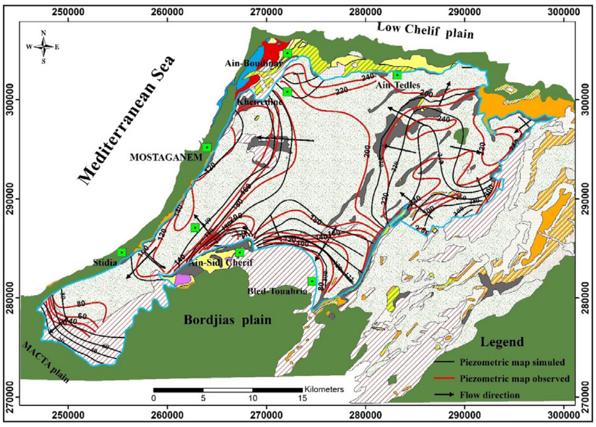


Figure 13. Simulated and observed groundwater head maps of the Calabrian aquifer of Mostaganem Plateau for the steady state of 1970.

3.4.2 Transient state

The calibration of the model in a transient state was developed considering the arrangement of piezometric chronicles and samples in the aquifer. The transient state extends from 1st September 2010 to 31 December 2010. The simulated piezometry in 2010 is presented in (Figure 14), it is calculated from the piezometry observed by the ANRH (National Water Resources Agency). A new parameter is included in the setting, namely the storage coefficient.

3.5 Results and Discussion

The general appearance of the simulated piezometry between 1970 and 2010 is similar, especially in its western part towards the city of Mostaganem. Piezometry is also similar between the two simulation periods in the southwestern part of the Mostaganem Plateau south of the town of Stidia, where the flow goes south towards the Macta Plain, and near the towns of Blad Touahria and Ain Sidi sheriff. The general shape of the piezometry is also similar between the two simulation periods. The flow is towards the plain of the Bordjias. The difference between these two maps (1970 and 2010) is observed in the eastern part of the Mostaganem Plateau where the 240m isopieze curve becomes concentric on the 2010 map.

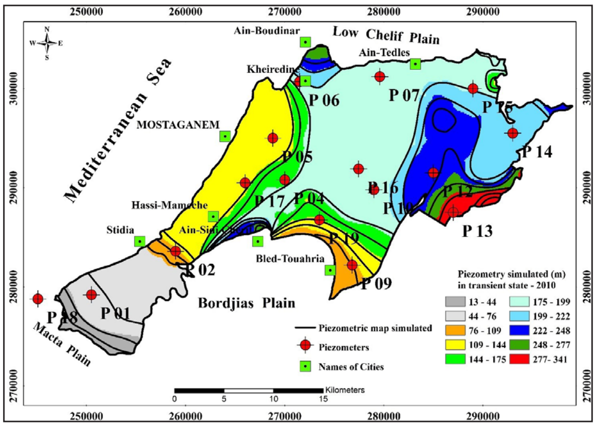


Figure 14. Simulated groundwater head of Calabrian aquifer for transient state period 2010.

The general flow direction observed on the piezometric maps is identical for both simulation periods. We have also monitored the drawdowns of the aquifer by way of drilling (Table 4). We find that over 10 years, the groundwater level has dropped considerably. The largest drop is observed at the P19 borehole in the Blad Touahria region south of the Mostaganem Plateau, at 9m. The other major drawdown is at the level of the P06 piezometer in the Kheir-Eddine region, which is 1.22m. We note that the major drawbacks are in the edge areas of the Mostaganem Plateau where the depth of the aquifer is shallow and where exploitation is intense, especially in the central part of the Plateau.

3.5.1 Aquifer Water Balance

Modflow allows the calculation of detailed water balances in system inputs and outputs of the system on all model elements or by area. These balance aquifers, in the form of scales, make it possible to determine the storage capacity of the aquifer and the share of recharge by the rains and the external borders (Kessasra, 2015).

The transient water balance is shown in Table 5, it highlights the supply and output terms following the hydrogeological functioning of the Mostaganem Plateau aquifer. In terms of inputs, the aquifer is fed by direct infiltration of precipitation, which represents 24% of the groundwater input. The rest of the inflows come from the external and lateral limits of the systems called boundary zone inflows, which represent 28.37%.

The main exit points of the model are represented by the water withdrawals by DWS (drinking water supply), agricultural and industrial catchments that represent 57.6%, and the exits in the southern parts towards the plain of the Borgias and the Macta plain 38%, the sources 3.44%. The storage capacity of the Mostaganem plateau aquifer is an important term, it is 34 570 m^3/day, and the destocking of the aquifer represents 0.82%.

Table 4. Changes in the piezometric levels of the Mostaganem Plateau aquifer (ANRH Relizane-2010)

Piezometer N°	Name	1998	1999	2000	2010
P 07	Mostaganem	237 80	237 80	237 80	235.89
P 19	Blad touahria	157.41	156 97	156 98	147.14
P 01	Douar louiza	73.88	73.65	73.65	73.28
P 04	Douar benattia	172 80	172 80	172-01	170.85
P 05	Sidi fellag	131.83	131.83	131.55	131 95
P 06	Kheir - eddine	160 78	160 78	160.79	162.17
P 12	Ennaro	223.62	223.61	223.61	220.25
P 13	Bled fernaka	273 83	273 83	272.39	270.12
P 14	Ain soltane	198.11	198.11	197.61	194.81
P 15	Sour kelmitou	201.72	201.72	201-08	199.58
P 16	Douar medjahri	171.24	170.36	170.35	169 96
KD2	Kheir-eddine 2	145.03	145 59	145 59	154 53
P2		251.38	251.24	251.24	264 57
BT1	Blad touahria	107.07	107.15	106 92	/

Table 5. Water balance of the Mostaganem Plateau aquifer in the transient state.

Mostaganem Plateau	Inbound (m³/day)	Outflow (m³/day)
Storage	34570	737.85
Border contribution	25558	34321
Pumping	0	51867
Drains	0	3105.2
Refill	29934	0
Total	90062	90031

To predict the possible decrease in the groundwater level for the following years on the Calabrian aquifer of the Mostaganem Plateau, the schematic conceptual model revealed a consistent behavior of the flows to predict the possible decrease in the groundwater level for the following years of the Calabrian aquifer of the Mostaganem Plateau. The schematic conceptual model revealed a coherent behavior of the underground flows. During the summer, the decrease in the recharge of precipitation and the increase in the withdrawals cause a lowering of the piezometric surface over the entire Mostaganem Plateau.

Three scenarios have been constructed to assess the impact of the changes, which would be due to the exploitation of groundwater at the drilling level, to consider rational management of the groundwater.

3.5.2 Description of Scenarios

Scenario 1: the operating flows for DWS and irrigation will be constant from 2010 until 2035. The only variable is time.

Scenario 2: half of the boreholes intended for the supply of drinking water on the Mostaganem plateau are at a standstill as of 2014, the launch of the MAO project, which supplies some municipalities of the Plateau de Mostaganem by the transfer of water from the Chelif Dam. Irrigation flow rates are kept constant from 2010 to 2035.

Scenario 3: An increase in the population of 2.51% is observed each year (according to the National Statistics Office), the flows of drinking water supply and irrigation will be multiplied by 2.51% from 2010 to 2035.

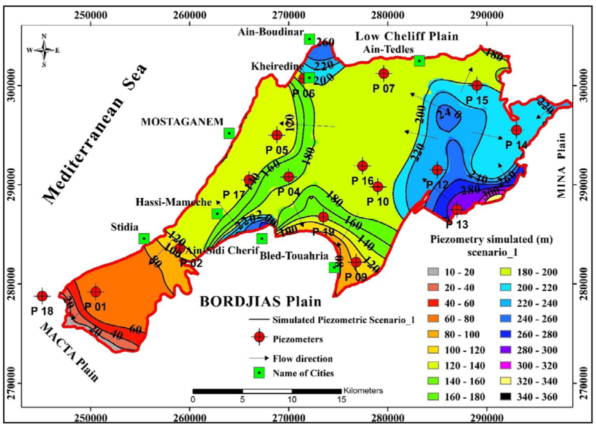


Figure 15. Simulated Piezometric map of Calabrian Aquifer scenario-1.

We notice that over 25 years the groundwater level of the slick for scenario-1 will continue to decline, especially in the central part where we note a fall of 5m and 7.5m. South of the town of Stidia in the southwest part of the Plateau, the lowering of the aquifer is 12.5 m. The maximum value of the blowdown recorded is between 17.5 m and 20 m, and it is mainly at the level of the boreholes which overexploit the aquifer (Figure 15).

The drawdown for scenario-1 is very important: at borehole P01 with 10.25 m in 2035, borehole P15 with a 5.75 m drop, borehole P16 in the central part of the Plateau shows a 2.81 m drop, and borehole P05 with a 1.01 m drop (Figure 16).

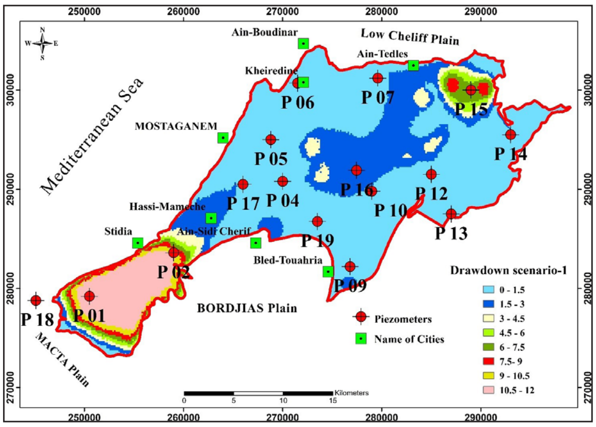


Figure 16. Drawdown map of Calabrian Aquifer Scenario-1.

Nine municipalities in the Mostaganem Plateau were connected in 2014 to the drinking water supply network from the Mostaganem-Arzew-Oran water transfer complex (MAO) and the Sonactel seawater desalination station (DHW Mostaganem). This operation affected the douars belonging to the municipalities: Mostaganem, Ain Tedèlès, Sidi Belattar, Oued El Kheir, Bouguirat, Hassi Mameche, Stidia, and Mesra, with a total population of 37 338.

The project will provide 24/7 drinking water to populations to meet a quota of 150 l/day per capita, whereas previously these populations were supplied by tanks from wells. The annual volume of the MAO transfer is 155 Hm^3 of which 45 Hm^3 for the northern part of the Mostaganem plateau. After the MAO transfer has been put into operation, the 60 AEP boreholes that fed the town of Mostaganem and some neighboring municipalities will be shut down, leaving the plateau aquifer at rest. It is from this state that the 2nd scenario was envisaged.

Scenario-2 simulation results showed a marked improvement in the downturn compared to scenario-1. East of the town of Ain Tedles, which lies northeast of the Mostaganem Plateau, the drawdown varies between 5 and 7.5m and is up to about 12.5m to 15m for Scenario-1. However, we note a clear improvement for Scenario-2, where significant drawdown values have improved to arrive at drawdowns ranging from 2.5m to 5m.

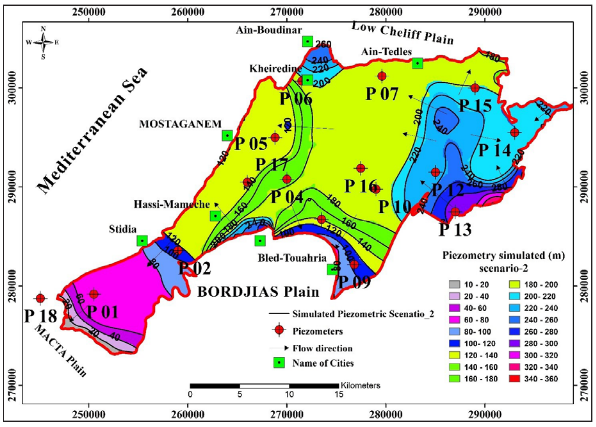


Figure 17. Simulated Piezometric map of Calabrian aquifer scenario-2.

In the central part of the Mostaganem Plateau, we note a marked improvement in the drawdowns, which pass from 2.5 meters and 5 meters have drawdowns from 1 meter to 2.5 meters (Figure 17).

For Scenario-2 (Figure 18), there is a clear improvement compared to Scenario-1, for drilling P3 where there is a stabilization of the groundwater level throughout the simulation period, with a clear improvement in the lowering, the same is true for drilling P16. On the other hand, the lowering of the aquifer is significant in the southern part of the Plateau at drilling P01 with a value of 16.31m and at drilling P06 (Kheireddine-2) with 2.9m.

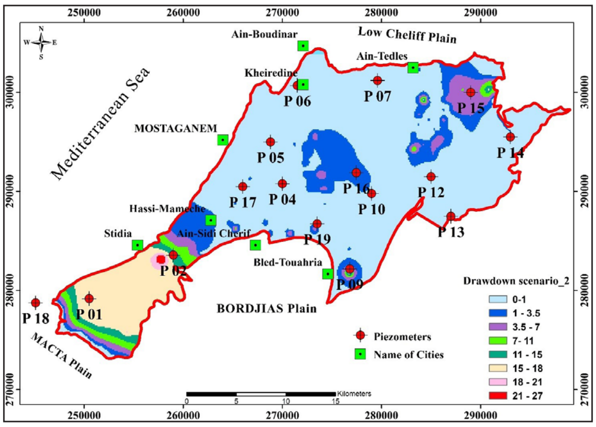


Figure 18. Drawdown map of Calabrian aquifer Scenario-2.

Table 6. Water balance of the Mostaganem Plateau aquifer resulting from scenario-2, (Period 2010-2035).

Mostaganem Plateau	Inbound (m^3/day)	Outflow (m^3/day)
Storage	23651	1190.2
Border contribution	25137	35653
Pumping	0	38723
Drains	0	3110.5
Refill	29934	0
Total	78723	78677

49.20% represents the abstraction at the level of the Plateau aquifer after half of the drilling for DWF has stopped, so we note an improvement in the volume taken (Table 6).

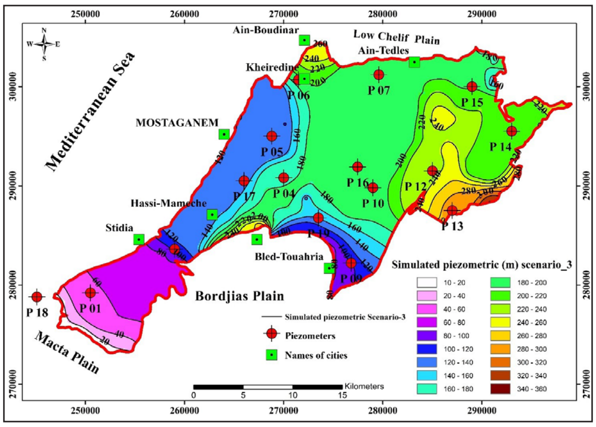


Figure 19. Simulated piezometric map of Calabrian aquifer scenario-3.

The general shape of the piezometry during scenario-3 (Figure 19) is modified in the northeastern part of the Mostaganem Plateau, east of the city Ain-Tedles. The piezometric curves become concentric with the 2010 simulated map where the curves were parallel at this location. On the rest of the Plateau, the general appearance of the piezometry is like the simulated map of 2010 with some less marked deformations.

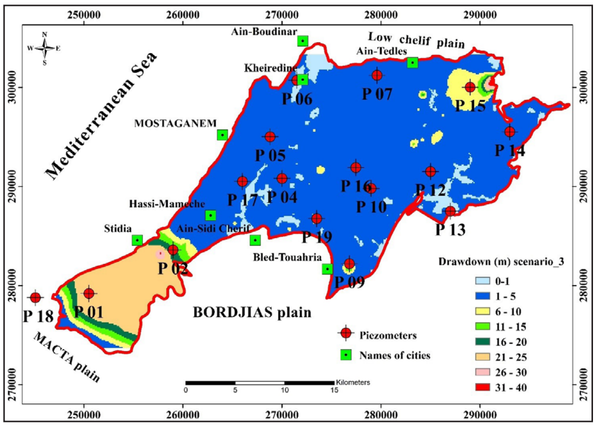


Figure 20. Drawdown map of Calabrian aquifer Scenario-3.

The drawdowns for scenario-3 (Figure 20), give worrying values, especially in the south of the town of Stidia which are of the order between, 21 m to 25 m especially the boreholes P02 and P01. On the rest of the Plateau, the drawdowns reach 5 meters. On the other hand, in the northeast part of the Plateau, the drawbacks vary between 6 and 25 m.

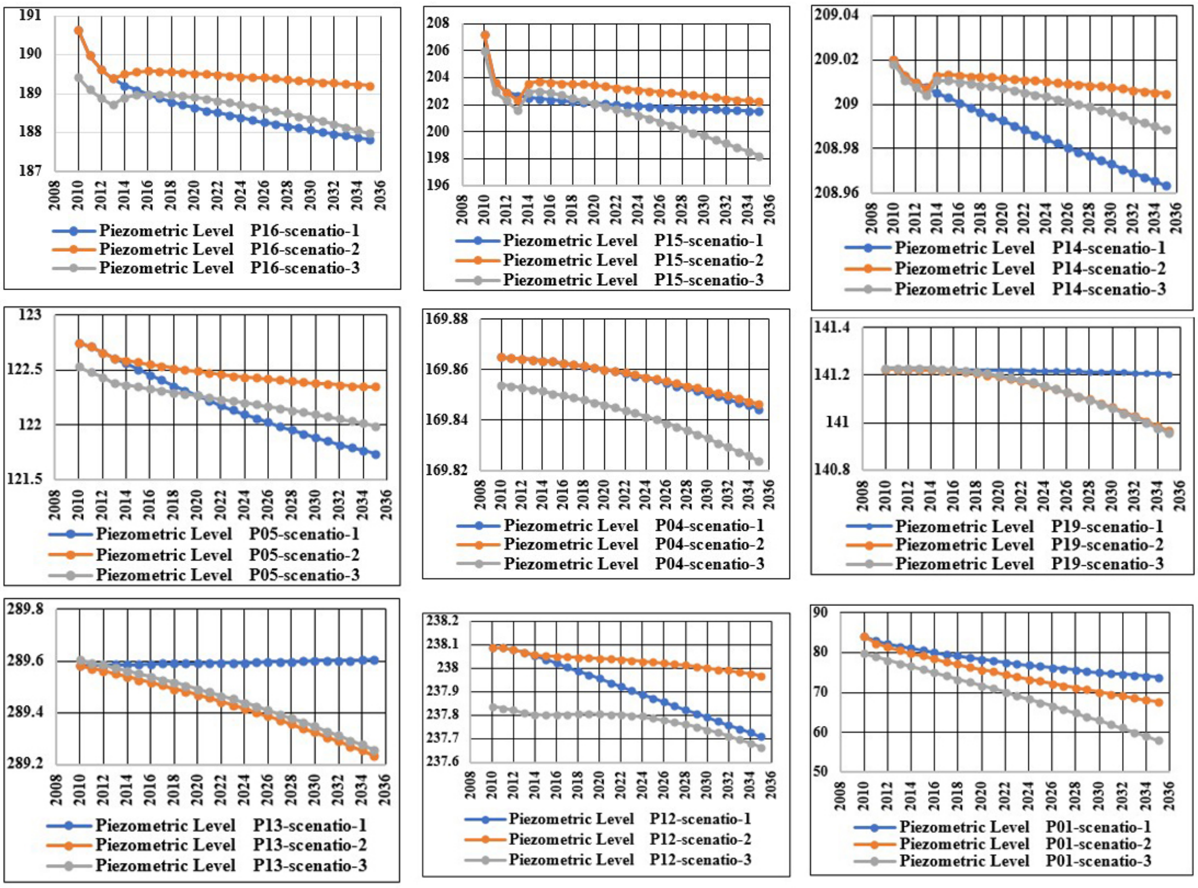
Table 7. Water balance of the Mostaganem Plateau aquifer resulting from scenario-3. (Period 2010-2035)

Mostaganem Plateau	Inbound (m^3/day)	Outflow (m^3/day)
Storage	43293	1126.1
Border contribution	25670	32928
Pumping	0	61773
Drains	0	3040.6
Refill	29934	0
Total	98897	98868

62.50% is the withdrawal from the Plateau aquifer for scenario-3, which indicates a strong increase in the volume was withdrawn (Table 7).

3.5.3 Comparison of the three Scenarios

Figure 21. Comparison with the three scenarios on the Mostaganem plateau.



The three scenarios were combined in a single graph (Figure 21 and Table 8) for each of the boreholes to compare them. We see the first group of boreholes with the same pattern, P16, P15, and P14, the groundwater level of these three boreholes drops during the period 2010 to 2013. In 2014 we notice an improvement in the groundwater level for scenario-2 and 3, while for scenario-1 the groundwater level continues to drop until the end of the simulation. These three boreholes are in the central and eastern parts of the plateau, where the thickness of the aquifer is significant.

The P05 and P04 boreholes are in the western part. After a drop in the groundwater level, drilling P05 shows stabilization of the groundwater level for scenarios-2, while the continuous level decreases for scenarios-1 and 2. The groundwater level curves of scenarios-1 and 2 overlap for P04 and show a slight drop from the beginning to the end of the simulation.

P01 is located southwest of the plateau where the aquifer thickness is small. We notice a decrease in its groundwater level for all three scenarios. The P19 and P13 boreholes have identical graphs with a stable groundwater level during the simulation for scenario-1, while a decrease in piezometric levels is observed for scenarios-2 and 3. The P12 borehole reacts well to scenario-2, whereas we note a decrease in the level during scenarios-1 and 3.

Table 8. Drilling down to the level of the Mostaganem Plateau boreholes for the three scenarios

	P3	P19	P16	P15	P14	P13	P12	P05	P04	P01	KD2	BT1
Scenario-1	0.01	0.02	2.81	5.75	0.06	-0.02	0.37	1.01	0.02	10.25	1.05	0.69
Scenario-2	0,003	260 0	414 1	5,033	0,016	347 0	117 0	408 0	0,018	16,312	2,085	
Scenario-3	0,006	274 0	440 1	695 7	0,030	347 0	173 0	538 0	0,030	840 21	326 1	188 2
	-0.003	255 0	369 -1	945 1	-0.027	370 0	-0.202	-0.471	0,010	11,588	280 0	498 1

(Table 9) shows the results from the transient scenarios through the variations in the groundwater level on the Plateau: at borehole P01 in the south-west, borehole P15 in the far north-east and south of the town of Ain Tedles, and borehole BT1 in the south of the Plateau. Figures.6 and 7 illustrate the piezometric mapping of the different scenarios chosen in this study.

(Figures 19, 20, and 21) show the different drawdowns observed during the three scenarios envisaged for the Mostaganem Plateau aquifer.

Table 9. Variations in simulated groundwater levels of the Calabrian Tablecloth of the Mostaganem Plateau

	P3	F19	F16	P15	P14	F13	P12	P05	P04	P01	BT1
Scenario-1	214.78	141.20	187.82	201.49	208.96	289.60	237.71	121.74	169.84	73.84	108.90
Scenario-2	214.79	140.96	189.21	202.21	209.00	289.23	237.97	122.34	169.85	67.68	107.50
Scenario-3	214.78	140 .6	187.98	198.23	208 99	289.26	237.67	121.99	169.82	57.99	107.38

4. Conclusion

In these difficult water conditions (lowering of the groundwater level, overexploitation of the aquifer), all economic and environmental activities of the Plateau are affected. Drinking water supply (DWF) is disrupted and agricultural production is reduced.

Modeling in hydrogeology advances the understanding of the functioning of the modeled system and predicts future the state of the aquifer according to different solicitations (predictive mode, modification of variations of input variables) or to evaluate the response of the system to different scenarios of use of the system (management mode; variations in boundary parameters and conditions) (Villeneuve & al., 1998).

Transient state modeling may be useful in determining the location of operational boreholes and piezometers for groundwater monitoring. The transient state simulations are used to model time-dependent problems where large volumes of water are released from the aquifer.

The Mostaganem Plateau has discontinuous data over time and a piezometric monitoring network that is well distributed over the entire plateau, but certainly with an insufficient number, which can lead to gaps and uncertainties in forecasts.

For all scenarios, there is a sharp piezometric decline over the whole of the Plateau de Mostaganem, until 2035. The Calabrian aquifer is continuously overexploited, and this has been for many years. This continuous depletion of the underground resource is due to greater withdrawals compared to the total recharge of the aquifer, and consequently, the volume stored continues to decrease. These simulations, therefore, suggest that current sampling rates cannot be maintained in the long term, especially with the current drought that the country and North Africa in general, are experiencing.

Based on the results of these scenarios, it is so important for sustainable management of the Mostaganem Plateau aquifer to set up a follow-up of the withdrawals (DWS, AEA, and AEI), to limit as far as possible the carrying out of new catchments in this aquifer and above all to control and sometimes penalize illegal drilling.

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Ethics declarations

Competing interests

The authors declare that they have no competing interests.

Abbreviations

ADE: Algerian Water
AEA: Agricultural water supply
AEI: Industrial water supply
ANRH: Directorate-General for Water Resources
CGG: General Company of Geophysics
DGRST: Directorate General of Scientific Research and Technological Development
DHW: Direction Wilaya Hydraulic
DWS: Drinking water supply
DWA: Drinking water abstraction
Hm3 : cubic hectometres
ONM: National Meteorological Office Algiers
MAO: Mostaganem, Arzew, Oran.

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