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Valorisation and management of water resources using hydrogeological modelling and GIS: Case of Mougheul aquifer

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Abstract: Groundwater level measurement is of fundamental importance in hydrogeology. Besides, the groundwater level of the aquifer can be used for several purposes including a hydrograph plot, together with the construction of a piezometric map which is necessary in order to know the extension of the groundwater, the direction and the velocity of the flow of groundwater, as well as the area of accumulation thereof.

In actual fact, hydrodynamic modelling is a tool to model groundwater flow in the studied area. Nonetheless, this modelling will make it possible to visualise the zones where the water circulates more quickly or more slowly, as well as the zones where there is a recharge or a discharge of the water table.

In light of this, the results showed the direction of water movement from the northeast to the southwest with a weak slope, which suggests a slow speed in the water. Likewise, they alike demonstrated a change in the height of the water in the groundwater from 1,073 m in the northeast to 973 m in the southwest, the fact of which confirms that the areas of its accumulation are in the south of the basin, whilst the feeding areas are in the north of the basin.

Keywords: aquifer, modelling, simulation, Wadi Mougheul watershed, water resource

INTRODUCTION

As a general rule, water is considered a source of life for humans, and is alike considered the primary resource for industry, agriculture and the like. However, in recent years, the world has witnessed a decrease in rainfall and an increase in the rate of evaporation of surface water due to the rise in temperature by reason of climate change (Bekhira, 2014; Bekhira, Habi and Morsli, 2018). Therefore, the world has turned to look for another source of water.

In this respect, groundwater became the only solution for supplying water by digging wells in order to attract water pockets in the ground (El Khamal *et al.*, 2022).

In point of fact, groundwater resources in Algeria are estimated at 7.6 bn m^3, with much greater demand in the north of the country. The aquifer provided in the Sahara Desert supplies 96% of the south's water demand (Gasmi, 2023).

With regards to the water resources they are located in two main overlapping hydrographic basins, the ultimate compound and the continental overthrust, which constitute the transboundary aquifer system north of Western Sahara. The last compound basin (100 to 400 m deep) and the continental basin (1,000 to 1,500 m deep) have huge reserves ranging from 30,000 to 40,000 bn m^3 (Mebarki, 2012; Azlaoui, 2018).

Similar to Algeria, in recent years, the world has experienced significant climate change, among which drought especially in arid areas where the surface water level is in a dry state, which led to the drying up of the dam Djorf Torba, which is among the major water resources in the region (Bekhira, Habi and Morsli, 2019a).

For that, it is necessary to search other sources of water, or rather to valorise it if founded.

Indeed groundwater is one of the possible solutions since the Bechar region, and in particular the Mougheul region, contains a very important aquifer that must be studied (Rabah *et al*., 2016). The Mougheul region located in the Bechar region in southwest Algeria, is considered among the areas which have experienced a shortage of rain over the last 10 years. It has been affected by the climate changes observed around the world, which have negatively affected water resources in the region, either surface or underground waters from which it is nourished (recharged) by precipitation waters. The aquifer of the Mougheul region is considered one of the most important aquifer, being of great importance in the region and in the southwest.

In order to reduce the depletion of groundwater due to its indiscriminate and ill-considered use, especially in arid areas, we conducted this study for the purpose of providing and developing a method for studying the same in an accurate manner.

Many similar studies were carried out on the Bechar region in general and on the Mougheul region in particular from ancient times to the present day, such as Aloui, Nabou and Mekkaoui (2018), Kendouci, Mebarki and Kharroubi (2023), but they were all superficial studies based on speculation and field experiments for one specific point, in contrast to our study, which is a comprehensive and in-depth study that relies on simulations according to the studied aquifer model of Wadi Mougheul; that is, this study shows the results for several points to be analysed in the Wadi Mougheul watershed.

More to the point, hydrogeological modelling of groundwater has become an imperative necessity today for geological sciences and other sciences to study, evaluate and predict its movement and areas of accumulation, mainly in dry areas, to preserve it by preventing its depletion and pollution (Namitha *et al*., 2019; N'Kaya *et al*., 2020; Itoua-Tsele, Tathy and Malonza, 2021). Similarly, modelling provides the researcher with the ability to simulate several scenarios (El Kayssi, Kacimi and Hilali, 2019). Nevertheless, it is possible to analyse the phenomenon on a large scale, as it shortens time because it closely deals with the phenomenon via a computer without travelling to the concerned location. Further, it is characterised by high accuracy, as it relies on real input data such as hydrological data (precipitation, evaporation, flow, morphology of the precipitation basin) (Elewa *et al*., 2024). In virtue of our work, the meteorological and geological conditions (ground layers, soil quality, topography of the Earth's surface, well locations) were obtained from the weather and geological station, which were attained by processing industrial satellite images and remote sensing technology by use of the ArcGIS program. In this respect, the hydrogeological modelling of groundwater is performed using Modflow 6 and the model muse program for the Wadi Mougheul precipitation basin in the Mougheul region located in the Bechar region, southwest of Algeria. In light of this, all available data were entered and the boundary conditions were determined, a fact of which enabled the extraction of the final model of the precipitation basin. Likewise, the results have alike demonstrated high accuracy compared to the level map that was relied upon in order to stabilise the model, in addition to its reliance on simulating the scenario of the phenomenon.

MATERIALS AND METHODS

AREA STUDY

Geographic context

The town of Mougheul, situated in the Northeast of the Bechar region, is 52 km away from the city of Bechar, which is bounded by (Fig. 1):

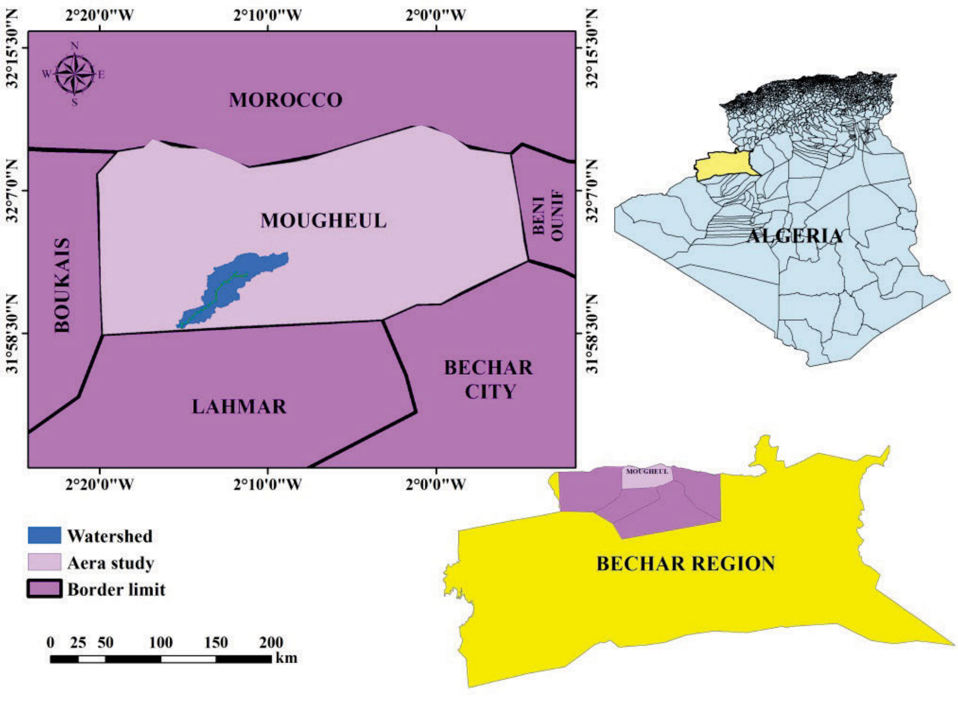

Fig. 1. Geographical location map of the Bechar region; source: own elaboration

– Morocco in the north;
– town of Lahmar and the city of Bechar in the south;
– town of Boukais in the west;
– town of Beni Ounif in the east.

Definitely, Mougheul town located in the Bechar region in the southwest of Algeria, is considered amongst the regions which have experienced a shortage of rain over the last 10 years, and have been affected by the climate changes observed around the world (Rezzoug, 2019), having then negatively affected water resources in the region, either surface or groundwater from which it is nourished (recharged) by precipitation waters, the aquifer of the Mougheul town is considered one of the most important aquifer in the region and in the southwest of Algeria, as well.

Climatic context

In fact, the area studied is subject to a desert climate (pre-Saharan upstream of the watersheds) characterised by excessive dryness of the very low layers of the atmosphere and low rainfall (Fig. 2).

Nevertheless, the purpose of studying the climatic features was to identify the numerous climatic parameters related to the research topic and to demonstrate how the climate affects the study area.

With the intention of doing so, it was determined to give special consideration to the Wadi Mougheul watershed's climate, with a focus on rainfall being the most crucial factor. The hydrological behaviour of the groundwater and the watercourses is significantly influenced by the climate of the watershed.

In fact, keeping in mind that precipitation, particularly rainfall, is a crucial component of groundwater recharge has shown to be of critical nature (Bekhira, Habi and Morsli, 2019b).

The climate of Mougheul is monitored by a weather station located on the border of the region at a latitude of 32.0209 N and a longitude of 2.2197 W, at an altitude of 932.8 m (ANRH, 2016a).

Above and beyond, we take into consideration the first layer of model top for the spatially distributed recharge over the study area in mm·y^{-1} as one of the average rainfall for the purpose of the study.

Hydrological context

This study was conducted in a representative watershed named Wadi Mougheul in Mougheul district, an arid area in the northeast of Bechar region (Fig. 1).

The drainage area is approximately 28.16 km^2, which includes all landform zones, highlands, midlands and lowlands.

The Wadi Mougheul, which is about 8.6 km long, originates at an altitude of 1,100 m a.s.l., and the river bed descends to an altitude of 950 m a.s.l. (Fig. 3).

Geological context

Unquestionably, the existence of groundwater is conditioned by a geological criterion, which includes lithological and structural conditions, thus ensuring a decisive role in the existence or not of the groundwater (Azlaoui, 2018).

Likewise, geology makes it possible to quantify groundwater reservoirs and to know their types of groundwater, as well as their boundary conditions according to the distribution of geological facies. Moreover, the description of the geological map of the region of Mougheul includes geological terrains belonging to different geological eras (Fig. 4).

The Mougheul region is characterised by a strong Jurassic calcareous dolomitic layer as well as folded Paleozoic bedrock.

The Mougheul region has five formations, the formations of Hassi Laâma, Oued Mennat and Koudiat El Haïdoura are permeable – their thicknesses, their structures and their outcrop surfaces constitute a favourable geological configuration for the storage and circulation of groundwater – unlike the formations of Oued El Abiod and Aïn Ben Serhane which are impermeable formations (Fig. 5) (Mekkaoui, 2000; Nasri *et al.*, 2018).

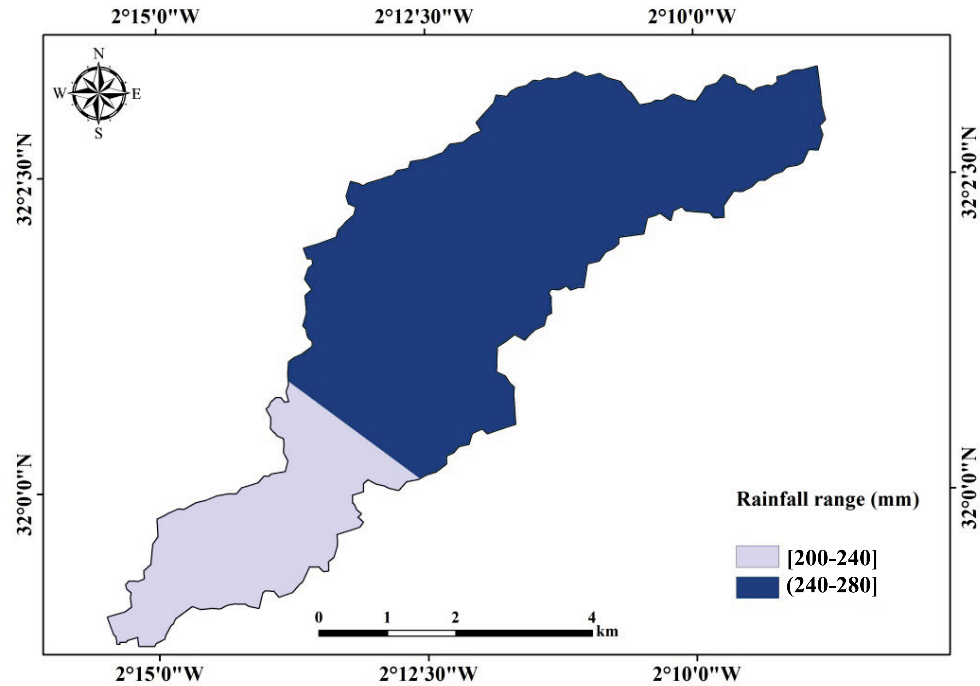

Fig. 2. Rainfall map of the Mougheul region; source: own elaboration

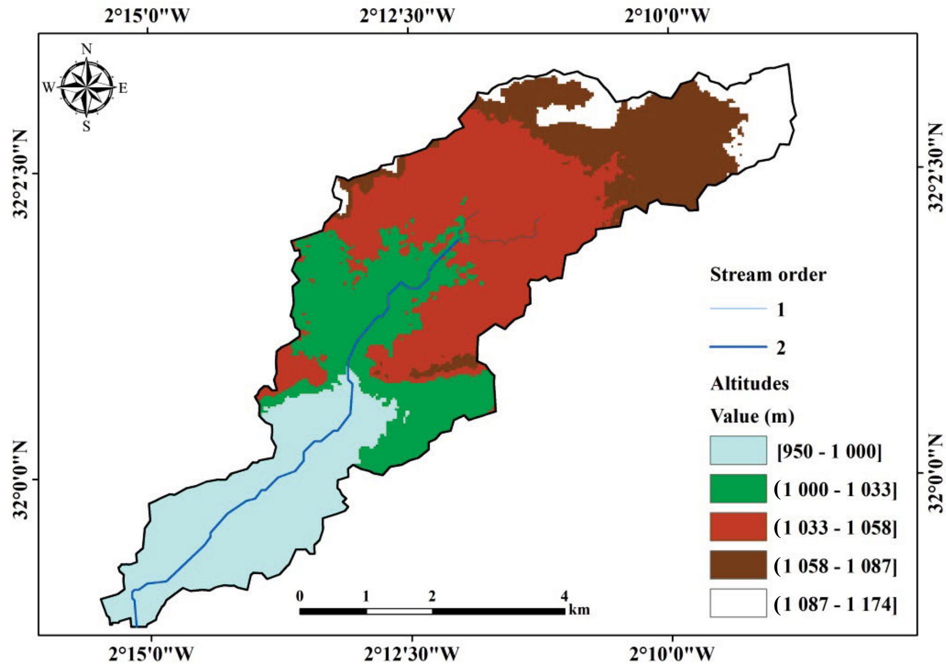

Fig. 3. Pedological map of the Mougheul region; source: own elaboration

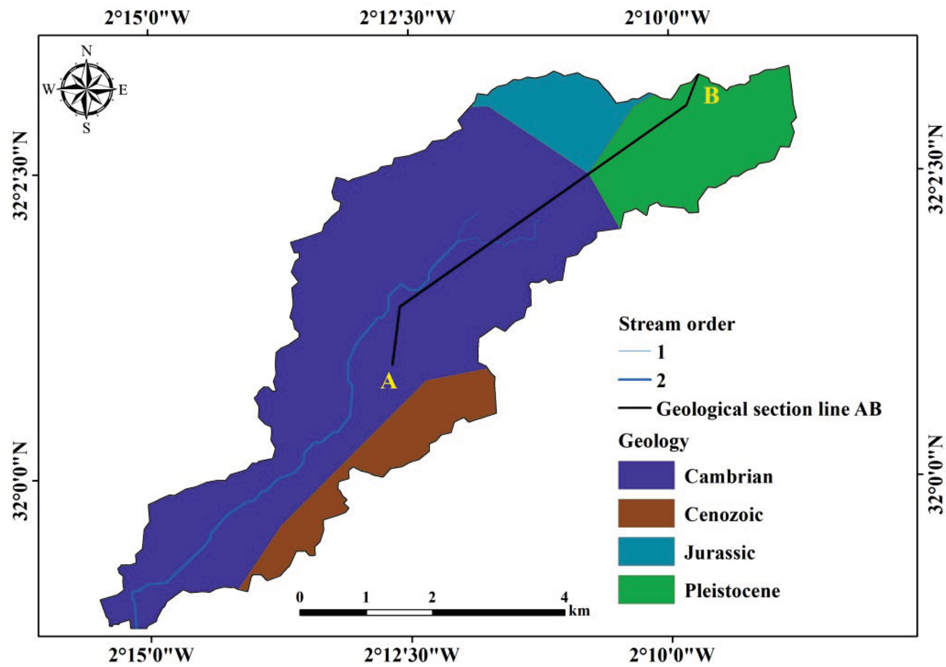

Fig. 4. Geological map of the Mougheul region; source: own elaboration

Details of the soil geology and its hydraulic conductivity are given in Table 1.

Hydrogeological context

The aquifer of Cambrian to Silurian sedimentary is the fundamental component of the hydrogeological unit of the Wadi Mougheul watershed (Fig. 6).

On the basis of existing information, we tried to develop an outline of the hydrogeology of this geological formation (ANRH, 2008; ANRH, 2016b).

All the drilling carried out in the region captures this formation with a thickness greater than 80 m.

STUDY METHODS

Piezometric map

In our case, the recognition of the piezometric surface of the water table (Fig. 7), was obtained by the inventory of some implanted wells (14 water wells) (Fig. 8), by objective, firstly in order to calibrate and validate the model, secondly, the study of these piezometric maps allows us to know the form of the flow of the water table, the direction of the general flow, the depth of the piezometric surface, which also represent the hydrodynamic boundary conditions.

The hydrodynamic map was created using tools to model groundwater flow in the study area. However, this map will make

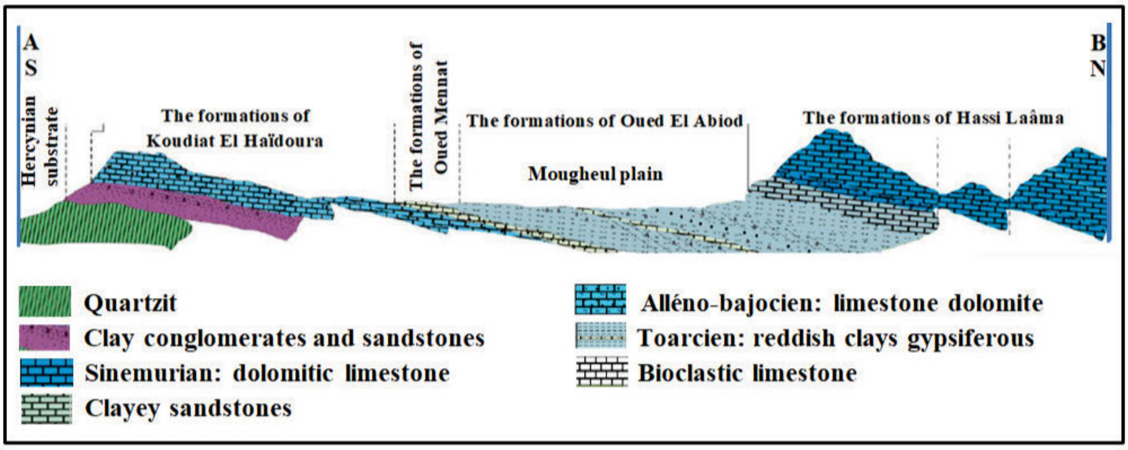

Fig. 5. Schematic geological section AB of the Mougheul region; S = south, N = north; source: Mekkaoui (2000)

Table 1. Geological cross section of study area

Layer No.	Layer type	Hydraulic conductivity ($m \cdot s^{-1}$)
01	gypsiferous red-clay	$5.57 \cdot 10^{-7}$
02	bio-clastic-oolitic limestones	$3.65 \cdot 10^{-5}$
03	dolomite limestones	$1.34 \cdot 10^{-6}$

Source: own study.

decisions in the management of water resources, which will alike help in making informed decisions in the management of groundwater resources.

Hydrogeological modelling

Before starting modelling, preliminary data must be prepared, such as morphological, hydrological, and geological data.

In this study, we used the Modflow 6 and Model Muse programs for the hydrological modelling of the groundwater in the Mougheul district.

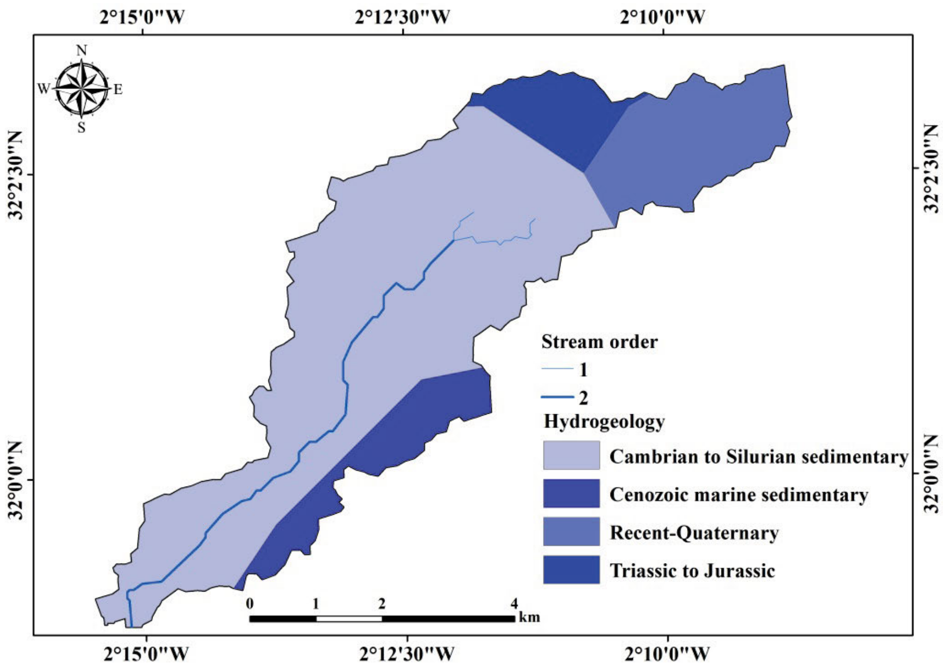

Fig. 6. Hydrogeological map of the Mougheul region; source: own elaboration

it possible to visualise the zones where the water circulates more quickly or more slowly, as well as the zones where there is a recharge or a discharge of the water table.

In summary, the production of a piezometric map using GIS involves the collection and integration of hydrogeological data into a computerised system to allow their processing and visualisation. Further, this map will provide valuable information on the usage of groundwater and will help to make informed

In morphological data, we downloaded the digital model with a resolution of 12 m from the Landsat 8 satellite for free.

The ArcSIG program was used to analyse the data to prepare a digital elevation map, which allows us to extract and define the watershed of Wadi Mougheul for the study area, export the rest of the maps, and import to create the model top in Modflow 6 and Model Muse programs.

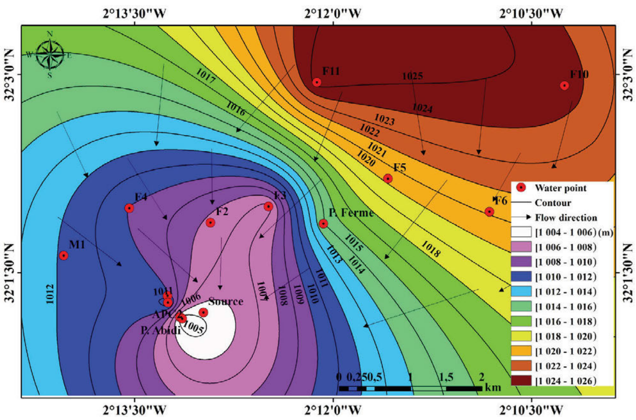

Fig. 7. The piezometric map of the Mougheul groundwater; source: own elaboration

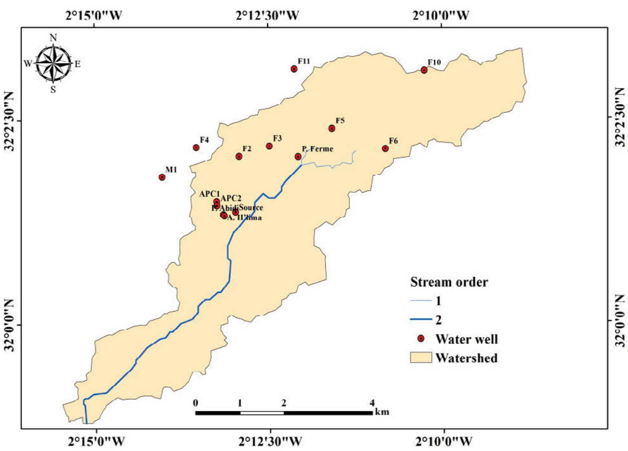

Fig. 8. Representative map of wells in the watershed of Wadi Mougheul; source: own elaboration

After extracting the digital model, we performed extraction thereof in American standard code for information interchange (ASCII) format to the Modflow 6 program for the first layer of the model (model top) (Fig. 9).

Further, we create the drainage system of the watershed of Wadi Mougheul and export the same in shapefile format so as to be used in the Modflow 6 program.

In hydrological data, we need the annual precipitation rate as a spatially distributed recharge for the study area, which is estimated at $7.61 \cdot 10^{-9}$ $m \cdot s^{-1}$.

Similarly, we need the flow rate of Wadi Mougheul as a spatially distributed recharge for the study area, which is estimated at 0.001 $m^3 \cdot s^{-1}$.

Likewise, we need the annual evaporation rate as a spatial output for the study area, which is estimated at $6.65 \cdot 10^{-8}$ $m \cdot s^{-1}$.

For geological data, we need to know the geological characteristics of the layers in study area. Nevertheless, we relied our study on previous studies, where the three layers mentioned in Table 1 were identified with their characteristics.

After completing the collection of morphological and geological data, we imported them into the Modflow 6 program; the results are demonstrated in Figure 9.

Afterwards, the initial conditions and hydrological data are introduced for the determination purpose of the hydrogeological model of the Mougheul aquifer.

Subsequently, the initial conditions and hydrological data are introduced so as to determine the hydrogeological model of the Mougheul aquifer; the results thereof are demonstrated in Figure 10.

For a better representation of the hydrological modelling results, we exported the results from Modflow 6 in shapefile format and imported the same into the ArcGIS program; the results of heads of Mougheul groundwater appear in Figure 11, whilst the results of the water table of Mougheul groundwater appear in Figure 12.

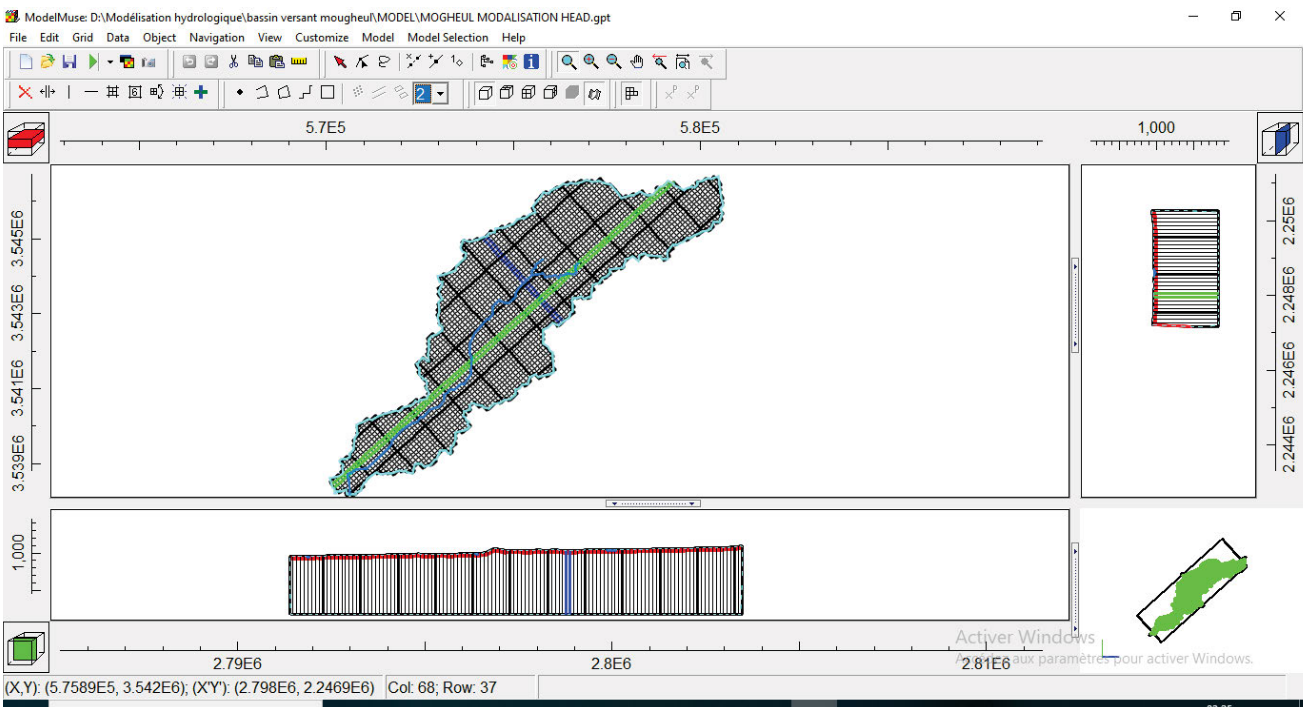

Fig. 9. Modflow representation of Mougheul aquifer; source: own elaboration

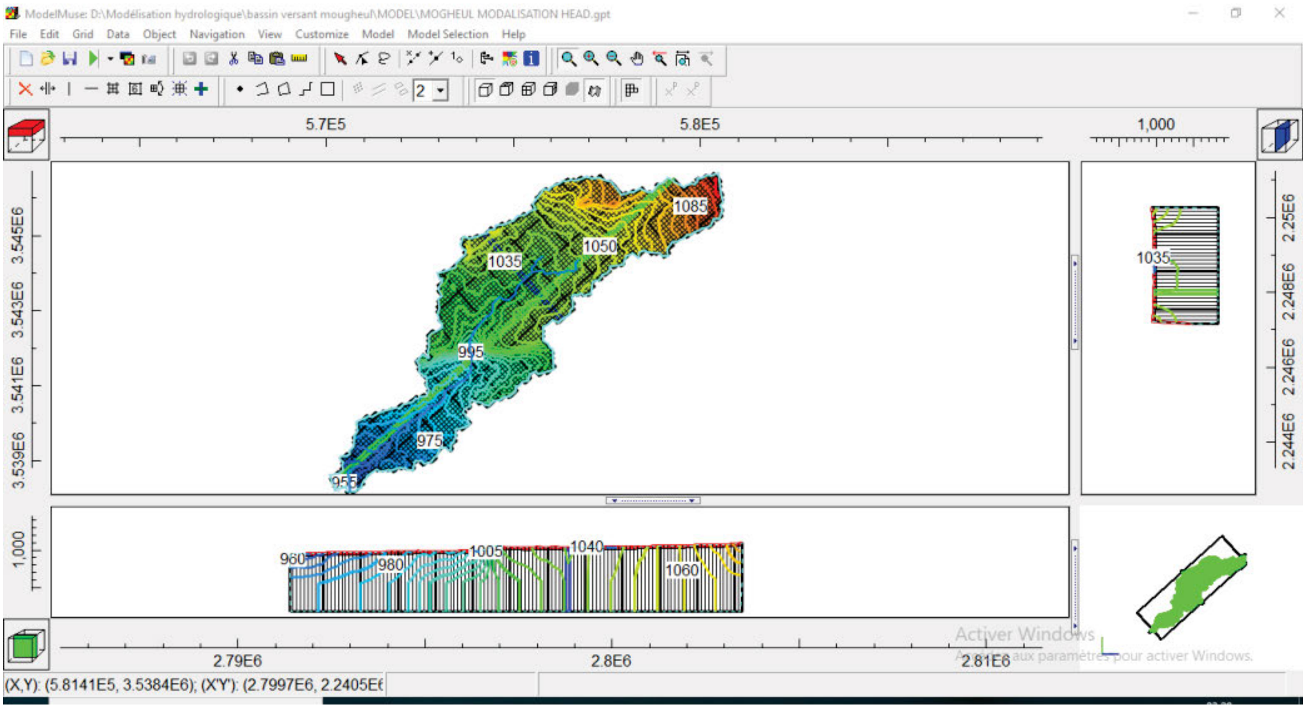

Fig. 10. Simulation Modflow modelling; source: own elaboration

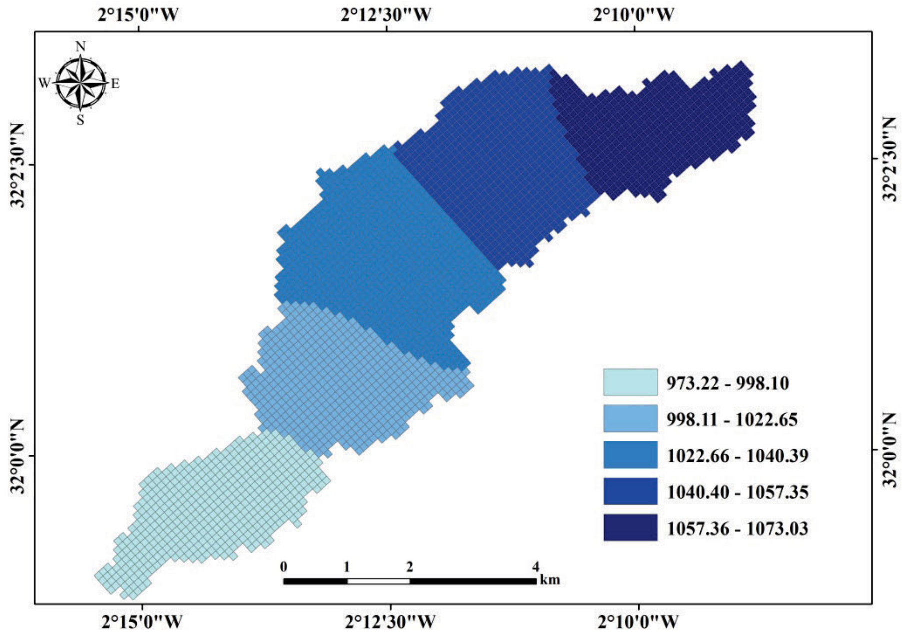

Fig. 11. Heads map of Mougheul groundwater from ArcGIS; source: own elaboration

Upon comparing the result obtained for the piezometric map (Fig. 7), together with those obtained for water table map (Fig. 12) it was observed that the water table values of the validated model were matching with the calculated values.

RESULTS AND DISCUSSION

Our study integrates multiple data sources, including remote sensing (RS), geographic information systems (GIS) and an aquifer modelling system (Modflow) for strategic planning and resource allocation to efficiently map and monitor groundwater resources over large, hard-to-reach areas. Similar GIS-based methods have proven valuable in mapping groundwater potential zones (Elewa *et al.*, 2024).

A groundwater model stands for a simplified representation of a more complex reality (Fig. 10). In this work, using established boundary conditions and field data, a Modflow model is created to estimate the water balance of a portion of the Mougheul aquifer. Incorporating field monitoring allows you to validate model predictions.

Using sound hydrogeological judgment is the most effective way to lower modelling errors. Based on the information at hand, the model was calibrated.

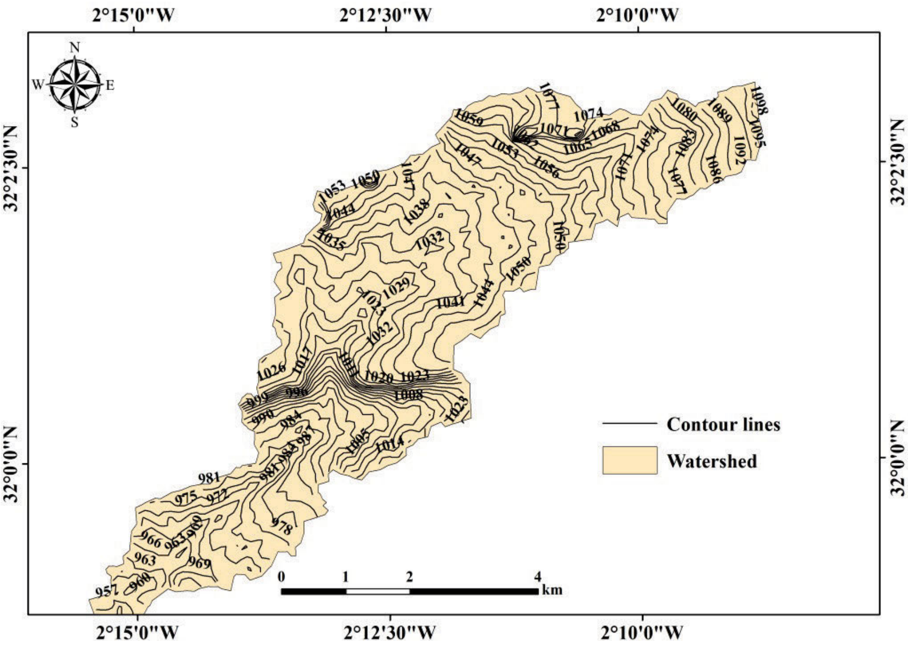

Fig. 12. Water table map of Mougheul groundwater from ArcGIS; source: own elaboration

Besides, the model's results demonstrate that the computed values and the measurement data agree well, demonstrating the model's dependability (Fig. 10).

Through the results obtained and represented in Figure 11, after hydrological modelling of groundwater, the head of the water changes from north to south, as in the north the head has shown to be more important (1,073 m) than in the south (973 m). Nonetheless, this is primarily due to the great slope of the watershed and to the geological layer of the earth in the area study, which is affected by the change in soil permeability.

Through the results obtained and represented in Figure 12, after hydrological modelling of groundwater, we note that the water top changes as well from north to south, as in the north the water table is farther from the model top (1,098 m) than in the south (956 m). Nevertheless, this is due to the thickness of the geological layer of the earth in the area study and to the steep slope of the watershed of Wadi Mougheul.

Finally what can be said from the results obtained is that determining the locations of groundwater can be confined to the southern region of the Wadi Mougheul watershed, moreover determining the locations for drilling wells depends primarily on the location of groundwater confinement, so the choice of locations for drilling wells was successful and appears clearly in Figure 8.

CONCLUSIONS

The manuscript presents a comprehensive study on the assessment of groundwater potential in arid areas, using geographic information systems (GIS) and hydrological modelling (Modflow) of the Mougheul aquifer, in similar studies a multi-source non-spatial and spatial dataset of several variables was used to define watersheds.

The Mougheul region is located in the east of the city of Bechar, which is considered one of the northern palaces of the Sura region. Further, it is characterised by a hot and dry climate with a precipitation rate equal to 240 mm annually, together with an evaporation rate equal to 2,100 mm annually.

Moreover, the Mougheul region is considered one of the regions that contains a large amount of groundwater in the southwest for Algeria and of good quality according to several previous studies of the region, which must be studied and highlighted to know its size and statistical level in the groundwater aquifer, as well as the direction of its movement so as to monitor and capture the same for the purpose of evaluation and preservation of the same from waste and pollution through good management.

In this study, firstly we delimitated the watershed of Wadi Mougheul as a study area, as the water network is considered one of the feeding factors for the aquifer and stands for one of the data required for hydrogeological modelling.

Similarly, we estimated the amount of precipitation in the study area, which is considered an important factor for recharging the aquifer, as it is an input for modelling, accordingly. In addition, we made a geological study of the study area to determine the quality of the geological layers by determining the permeability to be used as data for modelling.

Secondly, we made a piezometric map of the study area using the ArcGIS program in order to calibrate and validate the model based on the available data for the water table in the wells and springs distributed in the study area, estimated at 14 points.

Moreover, the Modflow 6 and model Muse programs were considered programs for the hydrogeological modelling of our study area. Likewise, we collected all the necessary data that were previously mentioned and entered the same into the Modflow 6 program.

As a consequence, the results of hydrological modelling illustrated great agreement between the results calculated and extracted from the model as a means of calibration, together with verification of the validity of the model.

More to the point, we can say from the above that the Mougheul region contains a significant amount of groundwater that heads from north to south in relation to the watershed, and this is due to the great slope of the watershed. Also, we can say that the recharge of the aquifer comes from precipitation or through watershed adjacent to the study area.

Importantly, this hydrological model of the aquifer in the Mougheul region is considered the first of its kind and has not been addressed in previous studies. As a consequence, it is considered a database for future studies, in respect such as studying the possibility of groundwater contamination or studying the effects of well pumping on neighbouring wells and groundwater. More and more, we can use it for simulating possible scenarios for the region according to any data that may occur and use it to determine a map of the areas at risk.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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