NUMERICAL GROUNDWATER FLOW MODELING. A CASE STUDY OF GHRISS PLAIN CATCHMENT, NORTH-WESTERN OF ALGERIA.

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ABSTRACT

The Ghriss Plain is the most productive agricultural area in the west-northern part of Algeria. Although the aquifer system of the Plain contains an important water resource, excessive pumping in the last three decades, mainly for irrigation, has resulted in a significant depletion of the reservoir. The water table of the Ghriss Plio-Quaternary aquifer decreased drastically in some sectors, by more than 60 meters from 1970 to 2001. The restrictions of groundwater pumping imposed by the authorities since the beginning of 1990 have contributed to a decrease the total withdrawal. The paper reports a groundwater flow model developed to allow the sustainability of the groundwater resource to be estimated such that appropriate environmental policy can be initiated.

Keywords: Groundwater modeling, Ghriss plain, Anthropogenic factor, Climatic factor.

1 INTRODUCTION

The drought which has been affecting the north western Algeria for the three last decades had important effects on all the water resources and more particularly on groundwater resource. The overexploitation of this resource, in order to supply the various water uses of the local populations and especially the agricultural uses, imperils his perenniality. The water-level drawdown of the Ghriss Plio-Quaternary aquifer towards alarming levels causes major apprehension for the population of the area and also for the local and national authorities.

In this article, groundwater flow in the Ghriss plain Plio-Quaternary aquifer was simulated using steady-state numerical model. This unconfined aquifer is located in an agricultural plain in northwest Algeria (Fig. 1). The groundwater is the most used resource for the agricultural activities and for the supply water in the study area.

2 STUDY AREA

The Ghriss plain has a semi-arid climate with hot and dry summers, and mild and wet winters. Rainfall measurements are available from 13 pluviometers, taken between 1976 and 2001. The average annual rainfall for this period is about 313 mm. Rainfall mainly occurs in the wet season (October-March) and is generally correlated with altitude. The analysis of the rainfall recharge evolution in the study area showed a clear reduction since 1973 which is estimated to 25% (Bekkoussa et al., 2008). The pluviometric deficit was recurrent during several years, which results in the reduction of the flow of the principal river of the Ghriss plain, the Fekan Wadi, before it totally dried this last years. The water table of the Ghriss Plio-Quaternary aquifer decreases drastically up to more than 60 meters between 1970 and 2001 in some sectors. The restrictions of groundwater pumping imposed by the authorities since the beginning of the 1990 have contributed to decrease the withdrawal. The estimated recharge of the Ghriss plain aquifer system is 65.3 million m^3 per year and the total withdrawn volume is 64.7 million m^3 per year (Bekkoussa et al., 2008). A fragile equilibrium is noted since the year 2000, between recharge and withdrawal in the Ghriss plain aquifer system which results in a stabilization of the piezometric heads of the Plio-Quaternary aquifer.

3 HYDROGEOLOGICAL CONTEXT

The Ghriss plain is composed of three superposed aquifers (Fig. 2):

- Plio-Quaternary aquifer,
- The Pliocene limestone and sandstone aquifer,
- The Jurassic calcareous dolomitic aquifer.

Plio-Quaternary aquifer is an unconfined reservoir which extends across the plain with an area of 605 km^2. It consists of Quaternary alluvium, porous white limestone, sand, sandstone and lacustrine limestone. Natural recharge occurs directly as infiltration from precipitation. A significant lateral flow comes from the Jurassic aquifer in the east southern and from the Pliocene aquifer in the north. Other forms of recharge are excess irrigation, which is not evapotranspired. The water table depth ranges from -6 to -80 m. This aquifer is bounded by Miocene marls.The direction of groundwater flows is from north-east and south to south-west towards a common outlet called Ain Fekan, which is a spring dried in the beginning of 80's. The rainfall infiltration rate is estimated at about 20%. Transmissivity values ranges from5.10^{-5} to 10^{-2} m^2/s (Assens et al., 1977).

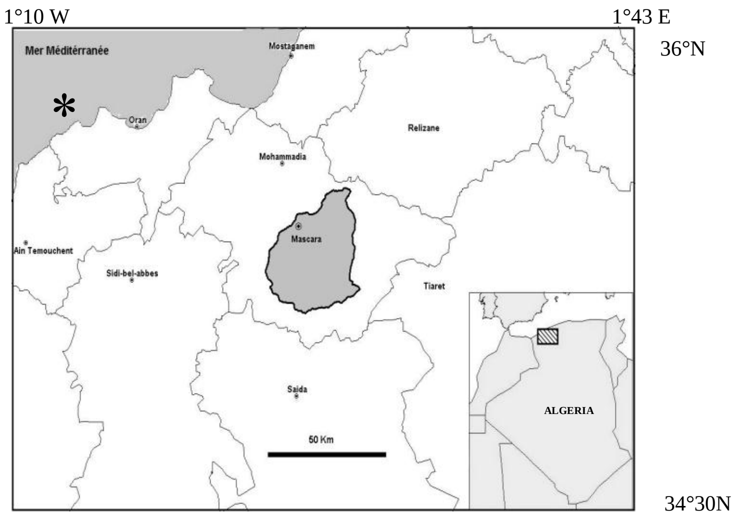

Figure 1. Location of the study area

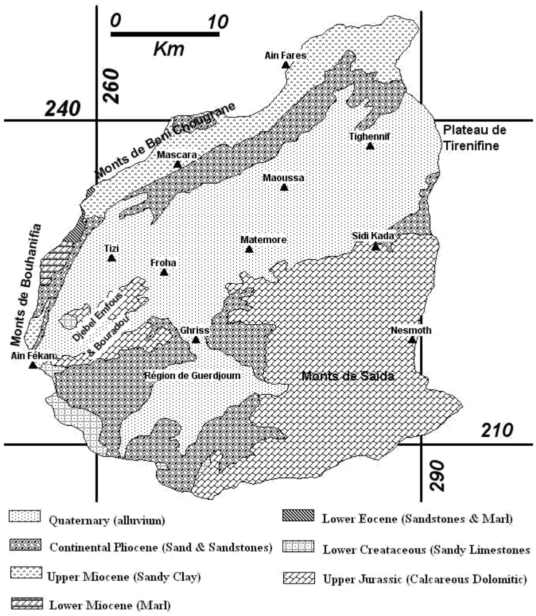

Figure 2. Hydrogeological map

4 NUMERICAL MODEL

The code selected to develop the numerical model was MODFLOW; a modular, three-dimensional finite difference groundwater flow model developed by the US Geological Survey (McDonald & Harbaugh, 1988).The governing partial differential equation for an unconfined aquifer used in MODFLOW is:

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]-W=S_s\frac{\partial h}{\partial t} \quad (1)$$

Where:

K_{xx}, K_{yy} and K_{zz} : the values of hydraulic conductivity along the x, y, and z coordinate axes (L/T) h is the potentiometric head (L);

W : volumetric flux per unit volume representing sources and/or sinks of water, (T^{-1});

S_s : the specific storage of the porous material (L^{-1}); and

t : time (T).

The model grid describes a square mesh of 45 km x 45 km bordering the limits of the Plio-Quaternary aquifer. The grid is formed by 7832 cells. Two types of meshes are used in the model: small mesh (0.202 km^2) and large mesh (0.81 km^2).The distribution of these cells depends on the density of information available and the desired accuracy. The model was run in steady-state conditions to simulate initial conditions. The boundary of the Ghriss plain was determined by the natural and hydrogeological features (Fig. 3).

In the extreme south, the line of contact between the Plio-Quaternary aquifer and the Jurassic aquifer is a specified head boundary determined from the piezometric map. To the east and west of the Ghriss plain the watershed divide correspond to no-flow boundaries. Recharge by the Pliocene aquifer, infiltration of effective rainfall and volume of water extracted from sampling wells are specified flow boundaries.

Hydrogeological and hydrodynamic data used in this work are taken from reports, maps and geological sections. The topography of the studied area was taken from the digital elevation model using a GIS. Average rainfall applied to the model is calculated for the period 1976-2001, namely 313 mm / year.

5 MODEL CALIBRATION

The purpose of calibrating the groundwater flow model of the Ghriss Plio-Quaternary aquifer was to update the critical input parameters such that the simulated hydraulic head values are in close agreement with the observed values.

The reference state for the calibration of the model should reflect a quasi permanent system. Stabilization of groundwater levels since 2000 can represent a steady state. Therefore, the steady-state calibration was performed by the restitution of the piezometric heads of January 2000.

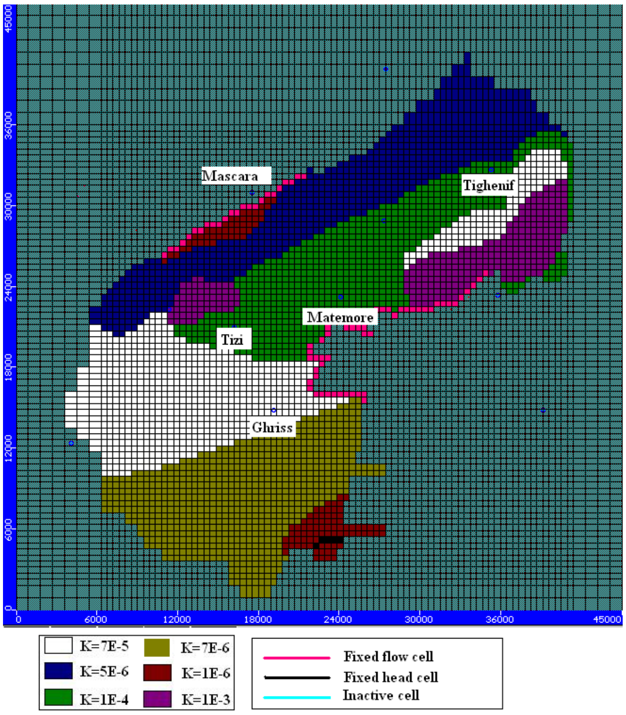

Figure 3. Model grid and boundaries.

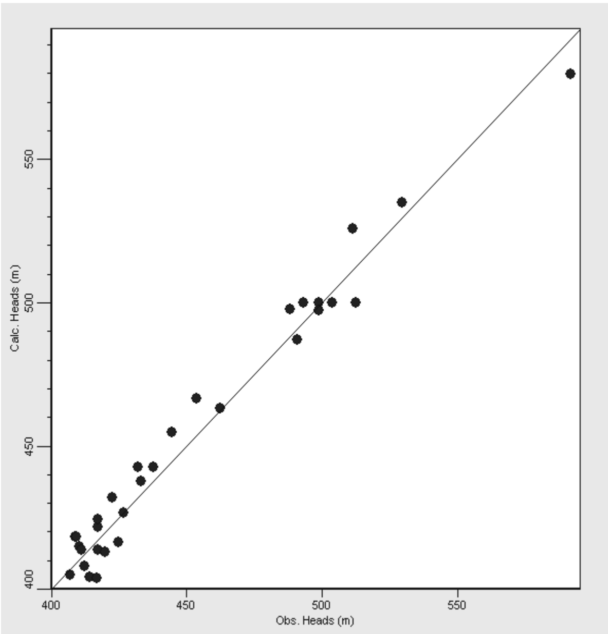

Figure 4. Calculated vs. Observed hydraulic heads for January 2000 (steady state).

Calculated vs. observed hydraulic head cross-plots (Fig. 4) shows a good correlation between observed and simulated heads. The correlation coefficient is 0.98 and the normalized RMS (*Root Mean Squared error given in eq. 2*) average is 4.2 %.

$$RMS = \frac{\sqrt{\sum (H_{cal} - H_{obs})^2}}{N} \text{.........(2)}$$

Where:

H_{cal} : hydraulic head calculated by the model;

H_{obs} : observed hydraulic head;

N : number of wells used in the model.

A normalized RMS of 10% is considered acceptable in groundwater flow applications (Anderson & Woessner, 1992; Hill & Tiedeman, 2007; Kahn et al., 2008), suggesting that the model adequately replicates groundwater conditions observed in the watershed.

6 SIMULATION RESULTS

Two simulations of the Plio-Quaternary aquifer in steady state were carried out to estimate firstly, the effects of future increase in groundwater extractions and secondly, the effects of decrease of precipitation recharge.

6.1 Simulation N°1

Agriculture is the largest consumer of water in the region with a volume of more than 52 million m^3 per year (DPAT, 2005). In this simulation, we considered an increasing in the agricultural areas with 2000 ha. This will result in over-consumption of water estimated at 38350 m^3 per day. Additional groundwater extractions will be located in the central and northern plains, where are fertile agricultural lands. This simulation indicates a drawdown in Plio-Quaternary aquifer of over 44 meters located in southwest of Mascara city (Fig. 5).

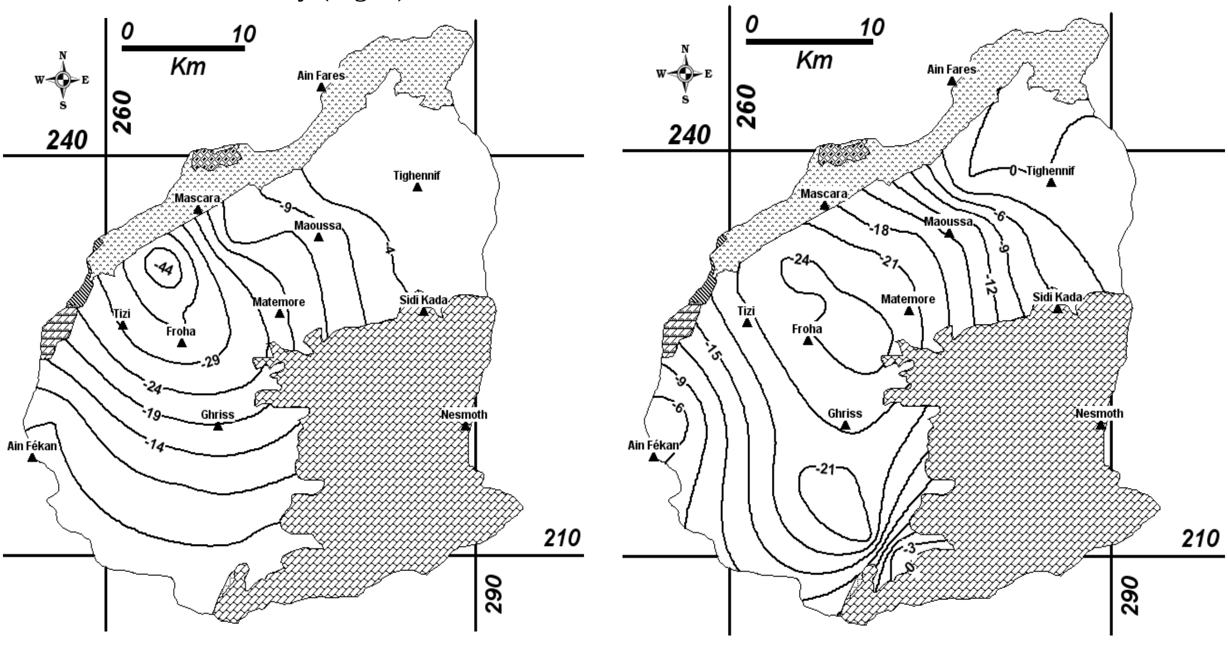

Figure 5. Drawdown in meters of the Plio-Quaternary water table for the simulation N°1 (left) and N°2 (right).

6.2 Simulation N°2

This scenario prefigures a climate forcing affecting the region. Recharge applied to the model is reduced by 32%, equivalent to a decrease of 100 mm in the average annual precipitation. This pessimistic scenario is not completely imaginary. Indeed, a difference of more than 100 mm was recorded for several pluviometric stations, particularly in the early 80's and 90’s (Meddi & Meddi, 2009; Meddi & Hubert, 2003). The drawdowns vary between 0 and 24 m. This decrease in the groundwater resource was predictable. Indeed, 75% of the Plio-quaterrnary aquifer recharge comes from the infiltration of the precipitations. Maximum drawdown is recorded in the region between Matemore and Froha (Fig. 5).

7 CONCLUSION

The Ghriss plain is one of the most productive agricultural areas in northwestern Algeria. Modeling anthropogenic and climatic forcing on groundwater resource in the Ghriss plain indicates that:

- The most drawdown (44 m) will be caused by the increase of agricultural areas (2000 Ha).
- The Froha region is the most sensitive to increased exploitation of the Plio-Quaternary groundwater resource.
- The north-east and far south of the plain are almost insensitive to the increase in groundwater pumping. This is mainly due to the inflow coming from the Jurassic aquifer.

The model and the obtained results can be an important tool for prediction and risk assessment. Future agricultural practice and subsurface water management can be forecasted and appropriate measures may be foreseen. Mitigating measure, such as artificial groundwater recharge in wet seasons, can be investigated.

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