Climate Change Impact in a Shallow Coastal Mediterranean Aquifer, at Saïdia, Morocco

Júlio F. Carneiro[1], *M. Boughriba*[2], *A. Correia*[1], *Y. Zarhloule*[2], *A. Rimi*[3] and *B. EL Houadi*[4]
[1]Geophysical Centre of Évora, Department of Geosciences, University of Évora, Évora, Portugal
[2]Laboratory of Hydrogeology-Environment, Faculty of Sciences, Oujda, Morocco
[3]Scientific Institute, Department of Physics of the Globe, Rabat, Morocco
[4]Hydraulic Basin Agency of Moulouya, Oujda, Morocco

ABSTRACT
A density dependent numerical flow model was applied to study the climate change impact in an unconfined shallow aquifer in the Mediterranean coast of Morocco. The stresses imposed to the model were derived from the IPCC emission scenarios and included recharge variations, rising sea level and advancing seashore. The simulations show that there will be a significant decline in the renewable freshwater resources and that salinity increases can be quite large but are limited to a restricted area.

INTRODUCTION
The IPCC fourth assessment report (IPCC 2007) reinforces that consistent climate changes are underway. Changes in the temperature, precipitation and sea level may deeply impact the groundwater quality and quantity of coastal aquifers, notably due to changes in the recharge patterns and to encroachment due to the rising seawater level. Therefore, it is of relevance to study the climate change impacts on the groundwater quality and quantity in coastal aquifers.

This paper presents one such study, focusing in a shallow unconfined aquifer, the Saïdia coastal aquifer, located in the Mediterranean coast of Morocco. The climate change impacts were addressed using a numerical groundwater flow and transport model for several of the IPCC climate change scenarios.

STUDY AREA
The coastal aquifer of Saïdia (figure 1), located in northeast Morocco, occupies an area of around 30 km^2. It is limited to the west by the river Kiss and to the east by the river Moulouya. In the south, the Ouled Mansour hills bound the coastal plain, while the northern boundary is the Mediterranean Sea. The aquifer is made up of a sequence of alluvial and beach deposits, composed of fine to medium sands with remains of shells. Its thickness varies from 10 m to 25 m, with maximums at the two sand dunes that align parallel to the seashore. Between those dunes, the sand layers are covered by a clay layer up to 4 m thick (figure 1). The alluvial and beach deposits overlay marls from the Miocene outcropping at the Ouled Mansour hills.

The aquifer is of local relevance, its waters being used mainly for irrigation, since its high salinity does not allow for other uses. The main pumping zones are located in the fertile areas close to the Kiss and Moulouya rivers. Several sources of salinity contribute to the low quality of the groundwater, apart from the influence of the sea. At the SW edge of aquifer (figure 1), two springs (Ain Zebda and Ain Chebbak) of high salinity groundwater from the adjacent Triffa aquifer discharge into the Saïdia aquifer. Additionally, agriculture relies abundantly on pesticides and resulting in irrigation returns enriched in dissolved substances (Melloul et al. 2006).

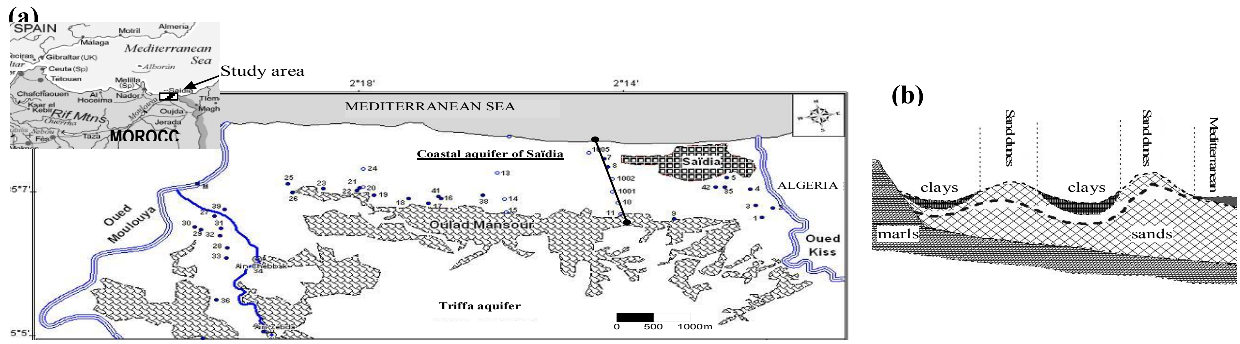

Figure 1. a) map of the study area; b) schematic N-S cross section

The large Mouluoya river is an influent source, but the role of the seasonal Kiss river is less clear, varying along the year. Recharge to the aquifer occurs mainly in the dunes strips and is about 23% of precipitation (Melloul et al. 2006). Recharge from runoff coming from the Ouled Mansour hills also plays a significant role.

NUMERICAL MODEL AND SIMULATED CLIMATE CHANGE SCENARIOS

A density dependent numerical model was built to simulate the flow and transport behavior of the aquifer. A finite element model was built using the code FEMWATER (Liu et al 2001) where flow and transport are coupled though the dependence of the density and dynamic viscosity on the salinity of the groundwater. The finite element mesh was refined along the seashore (figure 2) and although the geologic complexity is small, the numerical model considers five vertical layers to represent accurately the density variation with depth. The model was extended three to four kilometers into the Mediterranean, where a constant head-constant salinity boundary was imposed. Along the top layer, within the Mediterranean, a constant head boundary was considered. Calibration of the model was done against measurements collected in 45 piezometers and wells scattered around the modeled area.

It was decided to study the climate change impact in the Saïdia aquifer for three IPCC (IPCC 2007) emission scenarios: a) **A1B scenario** (the IPCC reference one); b) **B1 scenario**, which shows the smallest variations in temperature and sea level rise; and c) **A1FI** scenario, which is the worst case scenario. The stresses considered were (table 1): a) **sea level rise** – the effect of which is incorporated by changing the constant head value in the Mediterranean boundary; b) **advance of the seashore line** – the new location of which is found from a digital terrain model; c) **variation of recharge** – since runoff in the plain is negligible, recharge variation was computed considering the changes in precipitation (P) and real evapotranspiration (ETR), where the ETR is computed resorting to Turc's equation, as a function of precipitation (P) and temperature (T):

$$ETR = -P\left[0.9 + P^2\left(300 + 25T + 0.05T^3\right)^{-2}\right]^{-1/2} \quad (1)$$

Table 1. Stresses imposed by climate change

IPPC scenario	*Temperature change (ºC)*	*Sea level rise (m)*	*Precipitation decrease*	*Recharge decrease*	Observations
B1	1.1	0.18	6%	9%	*B1 lower values*
A1B	2.8	0.35	12%	19%	*A1B mean values*
A1FI	6.4	0.59	38%	47%	*A1FI higher values*

RESULTS

Scenario A1FI, the worst case scenario, shows that by 2099 decrease in hydraulic heads due to reduced recharge will not be substantial, reaching maximum values around 0.9 m at the southern limit of the aquifer (figure 2). Particularly at the main pumping area close to the Moulouya river, drawdown will increase by 0.7 m, which is not significant. However, there is a considerable decline in the hydraulic gradient and in the freshwater flowing volume, that decrease on certain areas up to 50% to 60% of the present day values. That is, the renewable freshwater resources decrease considerably. Even in the zones near the Moulouya, and despite the stabilizing influence of the river, flow volumes decrease by as much as 20% to 30%.

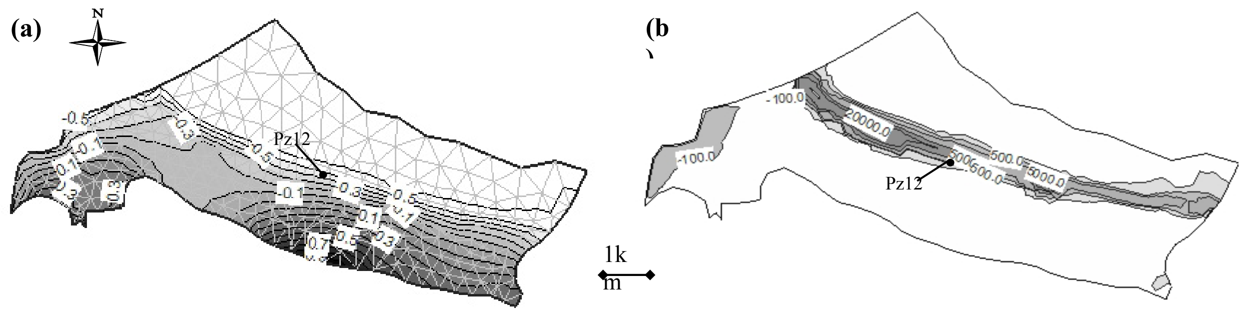

Figure 2. A1FI simulations at 35000 days: a) Decrease in hydraulic head (m). Also shown the finite element mesh; b) Variation of salinity (mg/l)

Scenario A1FI also shows that the salinity will increase sharply in the area closer to the advancing shoreline. For instance, the salinity at piezometer Pz12 is expected to rise as much as 3000 mg/l. Such an increase is restricted to a very narrow area near the freshwater/saltwater interface, with the remainder of the aquifer maintaining its mean salinity (figure 2). At the upstream Moulouya river it is expected that salinity will decrease, due to added contribution of leakage from the river of the aquifer and diminished discharge from the Triffa aquifer. Scenarios A1B and B1, which consider smaller climate change variations, show smaller impacts in the renewable resources and in the water quality of the Saïdia aquifer. This can be envisaged by the behavior of hydraulic heads in the area closer to the Moulouya and in the evolution of salinity in piezometer Pz12 (figure 3).

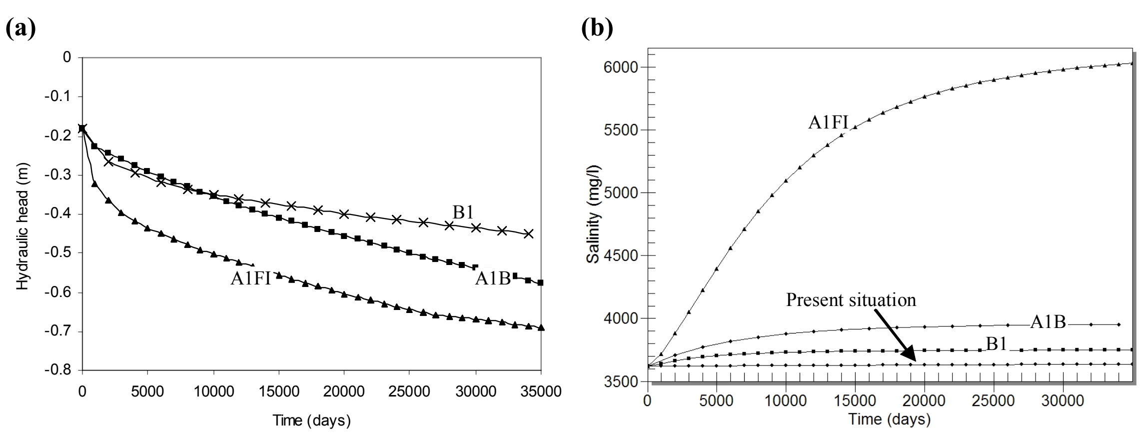

Figure 3. a) Decrease in hydraulic head near the Moulouya (m); b) Increase in salinity expected at piezometer Pz12.

CONCLUSIONS

A numerical model of the shallow unconfined Saïdia aquifer in the Mediterranean coast of Morocco was implemented with the aim of studying the impacts due to rising temperatures and sea level during the 21st century. Regional predictions of the IPCC scenarios B1, A1B and A1FI were used. The variation in recharge was determined by taking into account the anticipated variations in precipitation and in temperature.

The simulations were conducted for a period of approximately 100 years. The main effect of the climate change in the Saïdia aquifer will be the decrease in renewable resources, which in the worst case scenario may be reduced by to 50% to 60% of present day values, due to the decline in recharge and the diminished contributions from the adjacent Triffa aquifer. The water quality will be affected mostly in the area immediately adjacent to the advancing seashore. Localised areas may see a small decrease in salinity due to the added inflow freshwater from the Moulouya and diminished inflow from high salinity springs.

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Contact Information: Júlio F. Carneiro, Geosciences Department, Rua Romão Ramalho 59, 7000 Évora, Portugal, Phone: +351 266745301, Email: jcarneiro@uevora.pt