Numerical Modeling of the Future Climate Change Impacts on the Ghis-Nekkor Aquifer under RCP4.5 and RCP8.5 (Al Hoceima, North of Morocco)

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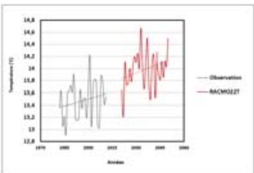
1 Introduction

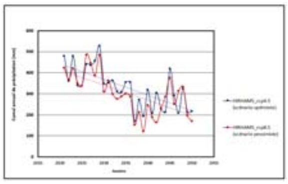
Semi-arid regions, such as the Mediterranean basin, are experiencing a growing water deficit due to:

- a combination of **increasing demands** (resulting from rapid population growth and agriculture),
- **excessive resources exploitation**, and
- the **reduction of groundwater resources** caused by **climate change**.

- The Mediterranean region is particularly vulnerable to climate change.
- Temperature increases could potentially reach 3.8°C by 2100 under the RCP 8.5 scenario, exceeding the global average temperature predictions.
- Reduction in precipitation by 10 to 30%, varying by region.
- These developments will further strain already heavily demanded water resources.



Future evolution of minimum temperature using the RACMO22T model.



Future evolution of annual cumulative precipitation

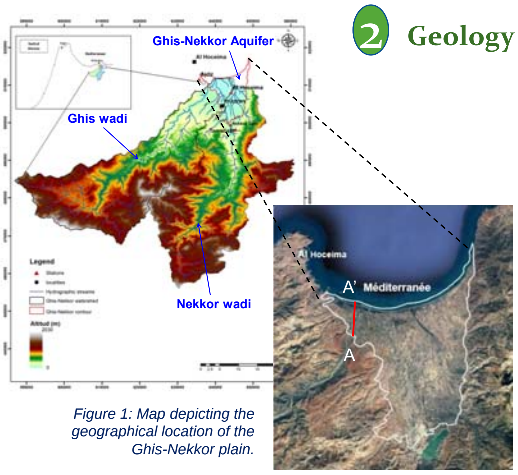


Figure 1: Map depicting the geographical location of the Ghis-Nekkor plain.

2 Geology and extension of the aquifer

The Ghis-Nekkor plain is situated in the northern region of Morocco (see Fig. 1), and it is entirely bordered by impermeable schistose formations, except for the northern part, which is open to the Mediterranean Sea.

From a climatic perspective, the Ghis-Nekkor plain falls within a semi-arid zone characterized by:

- High average temperatures, typically around 18°C, and
- Low annual rainfall, which does not exceed 300mm.

The aquifer primarily consists of **Plio-Quaternary alluvium age** with a varying thickness reaching approximately **240m**.

Its schistose bottom gradually slopes from South to North beneath the Plio-Quaternary covering.

The aquifer receives its **main recharge** from:

- Lateral boundaries (about 34%)
- Precipitation (around 38%) and
- Subflow from the wadis as they enter the plain (approximately 22%).

The Mediterranean Sea serves as the **primary outlet** for the aquifer, with losses to the sea accounting for approximately 67% of the total groundwater output.

3 Conceptual model

The process of building the **FEFLOW model** begins with the generation of a super mesh encompassing the domain.

This generation of the super mesh takes into account the:

- **Geometric characteristics of the modeled area,**
- **Locations of pumping wells and control piezometers.**

- The next step involves **mesh discretization** in two dimensions, with a focus on optimizing the sizes of the triangular elements in the horizontal plane.
- The resulting two-dimensional mesh is subsequently projected in three dimensions, following the various depth-defined layers, as illustrated in Figure 2.
- These defined sublayers enable vertical discretization of the elements, resulting in a mesh consisting of **4 general layers**.
- In total, the study area contains 8625 triangular elements (2D) leading in total to 6696 nodes.

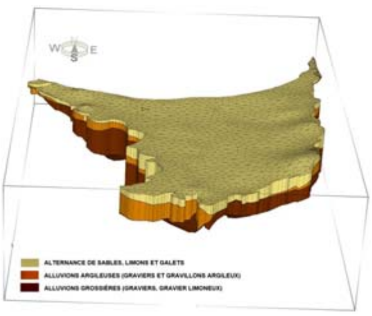


Figure 2: 3D representation of the Ghis-Nekkor aquifer reservoir under FEFLOW

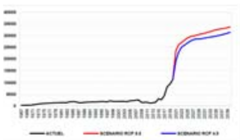


Figure 6: Future evolution of salinity in the third layer of the model at observation well 1684/5 under the two projected scenarios (scenarios 3 and 4).

4 Numerical Modeling on the Ghis-Nekkor Aquifer

In general, seawater intrusion was analyzed and studied in the Ghis-Nekkor aquifer for four future scenarios.

1. Scenario 1: Constant pumping + natural recharge (RCP4.5)

- A slight increase in the extent of seawater intrusion (0.64km) compared to the year 2020 (refer to Fig. 3).
- The volumes of incoming seawater intrusion would remain relatively close to those recorded in 2020, approximately around 0.35 Mm^3/year by 2040.

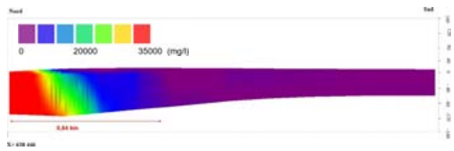


Figure 3: Salinity and extent of seawater intrusion along cross section AA' for Scenario 1 by 2040.

2. Scenario 2: Excessive pumping + natural recharge (RCP4.5)

- Intensive pumping could lead to an expansion of the area affected by seawater intrusion, especially in the 3rd layer of the aquifer model (refer to Fig. 4).
- This expansion is estimated to be approximately 0.81km along section AA', situated to the north-west of the aquifer and intercepting the ONEE well field (Fig. 1).
- By 2040, the volume of seawater intrusion is projected to be around 0.85 Mm^3/year.
- Consequently, salinity levels would exceed 25g/l in the northwestern part of the Ghis-Nekkor aquifer.

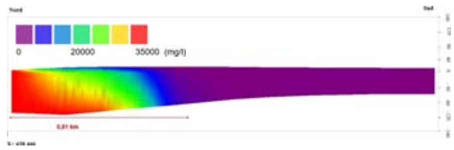


Figure 4: Salinity and extent of seawater intrusion along cross section AA' for Scenario 2 by 2040.

3. Scenario 3: Excessive pumping + recharge (RCP4.5) + Sea Level Rise (SLR) RCP4.5

- The northwestern part of the aquifer (refer to Fig. 5) would be particularly affected, with a substantial advancement in the extent of seawater intrusion observed across all three layers of the model.
- Salinity levels would exceed 30g/l (Fig. 6), and the expansion of seawater intrusion would reach approximately 1 kilometer at the third layer of the model (see Fig. 7), representing a 23% increase compared to the results of scenario 2.
- Intensive pumping, in conjunction with a potential SLR, would result in a significant decline in hydraulic head levels, especially in the northwestern section of the aquifer, where drawdowns are projected to reach negative values of around -10 meters by 2040.
- The volume of seawater intrusion would increase and it is estimated to be around 1.2 Mm^3/year.

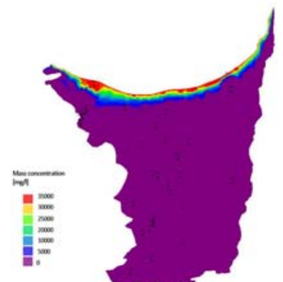


Figure 5: Map depicting the spatial distribution of simulated salinity for 2040 under scenario 3 in the 2nd and 3rd layers.

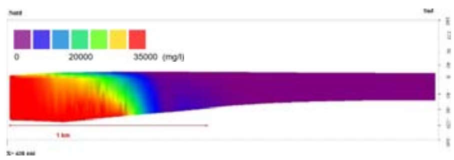


Figure 7: Salinity and extent of seawater intrusion along cross section AA' for scenario 3 by 2040 (SLR +0.18m projected for RCP4.5 scenario).

4. Scenario 4: Excessive pumping + recharge (RCP8.5) + SLR (RCP8.5)

- An expansion in the extent of seawater intrusion, which could reach 1.23 kilometers along section AA' (see Fig. 8).
- The results indicate a substantial increase in the volumes of seawater invading the aquifer, projected to reach 1.78 Mm^3/year, representing a 48% increase compared to the results of the RCP 4.5 scenario, with salinity levels trending towards 34,000 mg/L (Fig. 6).
- Drawdowns are expected to reach more negative values of approximately -20 meters by 2040.

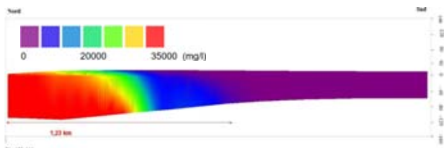


Figure 8: Salinity and extent of seawater intrusion along cross section AA' for scenario 4 by 2040.

5 Conclusion

It is evident that intensive pumping is the primary driver of seawater intrusion advancement in the Ghis-Nekkor aquifer. The northwestern part, due to its proximity to the Ghis-Nekkor ONEE well field, is particularly vulnerable to seawater intrusion. The SLR, in line with the two IPCC assessment scenarios (RCP4.5 and RCP8.5), when combined with increased pumping, could further intensify the already concerning situation in the era of climate change.

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