Assessing the Future Climate Change Impacts on the Foum El Oued Groundwater Aquifer in Laâyoune, Morocco: A Numerical Modeling Approach

Abdelkader Larabi, Mohamed Jalal El Hamidi, Mohamed Faouzi

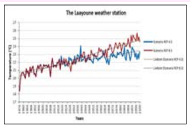
Regional Water Center of Maghreb, LAMERN, Mohammadia School of Engineers, UM5R, Rabat-Morocco

Published in Book series: Lecture Notes in Geoinformation and Cartography
(eISSN 1863-2351) Indexing: Scopus

Introduction:

- This aquifer is located between the city of Laayoune to the east and the coastal area of the ocean to the west, covering a width of approximately 17 km and an area of around 350 km² (refer to Fig. 1).
- The Foum El Oued aquifer basin is extended along the ocean coast of the sedimentary basin encompassing Laayoune, Boujdour, and Dakhla.
- The significant decline observed in the Foum El Oued aquifer underscores the necessity for a numerical tool capable of accurately simulating the hydrodynamic behavior and seawater intrusion in this aquifer system.
- The aim is to understand the hydrogeological characteristics and to formulate a comprehensive conceptual model and subsequently a hydrodynamic/transport model under both steady and transient conditions.

Climate change projections 2020-2100



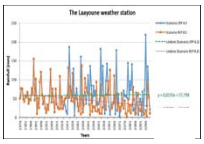


Figure 1: Aquifer location in proximity to the city of Laâyoune

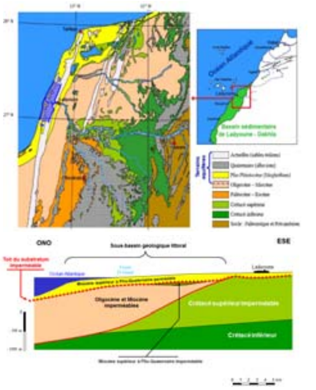


Figure 2: (a) Geological map of the Basin, (b) Schematic cross-section of the Foum El Oued geological sub-basin.

Geology:

This basin consists of various geological layers ranging in age from the Triassic to the recent Quaternary (Fig. 2). Within the geological sub-basin of Foum El Oued, the aquifers mainly comprises post-Upper Miocene formations characterized by complex combinations of detrital, biochemical, and chemical sediments, including sands, conglomerates, clays, marls, limestones, chalks, evaporites, and more.

Simulation in transient state:

The assigned data are outlined as follows:

- **Recharge**:
  - This involves the aquifer's replenishment through the inflow of floodwaters from Saguia El Hamra Wadi during specific years (1987, 1991, 2016).
  - Recharge rates were determined annually based on measured data and specific parameters to the model.
- **Pumping Rates for Drinking and Industrial Water Supply:** Pumping rates allocated to pumping points have been assigned to corresponding grid cells.
- **Storage Coefficient**: Given the predominantly sandy sandstone or mildly fractured limestone composition of the aquifer formations, the storage coefficient values are based on few measurements ranging between 10 and 15%.
- **Periods and Calculation Steps**: The calibration process for the transient model of the Foum El Oued aquifer is over a period of 44 years, from 1976 to 2019, with an annual time step (model constraint period = 1 year).

The results demonstrate that the correlation coefficient in four piezometers, is notably high, indicating a strong agreement (see Fig. 5).

Figure 6 illustrates the various components contributing to the calculated balance.

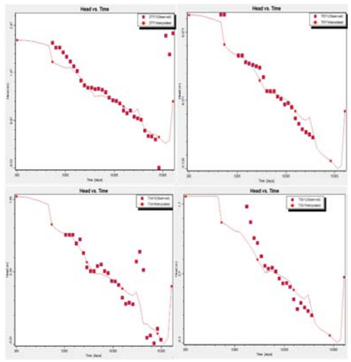


Figure 5: Water Balance showing the Main Components (1976-2019)

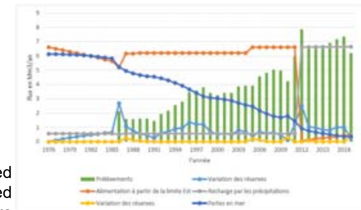


Figure 6: Water Balance showing the Main Components (1976-2019)

Discretization of the study area:

- The study area was subdivided into a grid composed of squares/rectangles, each designed to accurately represent the aquifer system's geometry and structure.
- A finer grid translates to enhanced accuracy in representing borehole locations and aquifer contours, consequently yielding highly dependable outcomes.
- For our specific numerical model, we opted for a **spatial discretization** interval of **250 meters**, resulting in a grid layout of **101 columns** and **81 rows**.
- Based on the available hydrogeological conditions, boundary conditions are set up as described in Fig. 3a.
- The hydrodynamic parameters used, such as transmissivity values have been determined from pumping tests at the ONEE well field.
- The recharge resulting from floods in Saguia El Hamra Wadi is illustrated in Figure 3b.

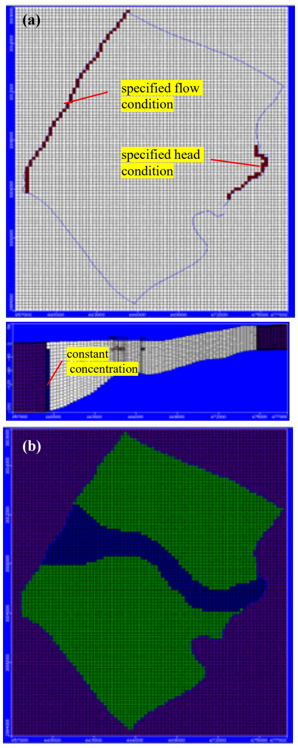


Figure 3: (a) Mesh configuration and boundary conditions, (b) GW recharge map.

Seawater intrusion modeling:

- SEAWAT code intrusion was selected to deal with seawater, it is developed based on the hydro-dispersive transition zone approach.
- The developed model can serve as a tool for predicting the aquifer's response to scenarios proposed by decision-makers to aid in the planning process and facilitate informed decisions regarding aquifer management.
- Two projected climate scenarios (RCP4.5 and RCP8.5) coupled to the GW exploitation were assessed to gauge their potential quantitative and qualitative impacts on the aquifer.

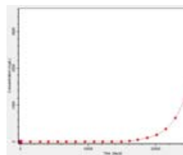


Figure 8: Evolution of calculated salinity under the RCP8.5 scenario at ONEP well fields

By 2050, the projections indicate that the salt front will have moved forward by roughly 6.5 km, as depicted in Figure 7. The iso-concentration line of 10 g/l is predicted to extend to 6.2 km, while the highest concentration line (35g/l) is anticipated to reach a distance of around 5.8 km. Figure 8 illustrates the concentration evolution at ONEP well fields.

Groundwater flow model:

- A steady-state flow model is accurately designed to produce the approximate magnitudes of the hydrodynamic parameters and flow directions (Fig. 4b).
- Models are developed for this aquifer system using the MODFLOW code, which is integrated into the Visual MODFLOW 2015 software.

Steady-state Calibration and Sensitivity Analysis:

- The initial K-values were introduced in the model based on pumping tests, and modified during the calibration process in steady state regime.
- The map (Fig. 4a) illustrates the result of the model calibration for the distribution of K-values.
- Sensitivity tests were conducted to apprehend how the model responds to altered conditions such as multiplying calibrated K-values with corrective factors of 0.5 and 1.5.

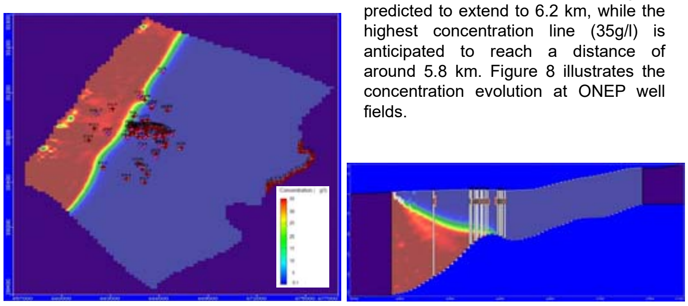


Figure 7. Calculated salinity in 2050 (RCP8.5 scenario) (a) Salinity Distribution in Layer 13 (b) Cross-Sectional Salinity Profile (Selected along Line 42 of the Model)

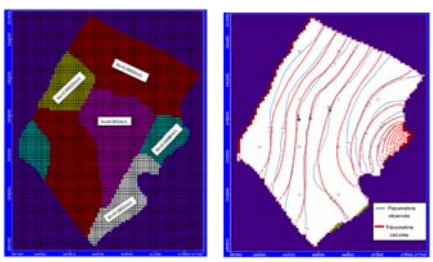


Figure 4: (a) Calibrated K-values map, (b) Comparison between measured and calculated piezometric data (1976 state).

Conclusions:

This GW model serves as a crucial decision support system for water resource management, particularly for the population of Laâyoune and the irrigation of the Foum El Oued agriculture area. By implementing effective management strategies, the coastal area can be protected from contamination, ensuring its sustainable use and preventing abandonment due to increasing salinity levels in irrigation and pumping wells.

Acknowledgements: The authors express their gratitude to the Moroccan Ministry of Water for providing data to conduct this research. This study is a part of the OCP research project "GEO-LAR-01/2017" funded by the OCP Foundation.