Assessment of Climate Change Impacts on Groundwater Resources
- The Bahira Aquifer-

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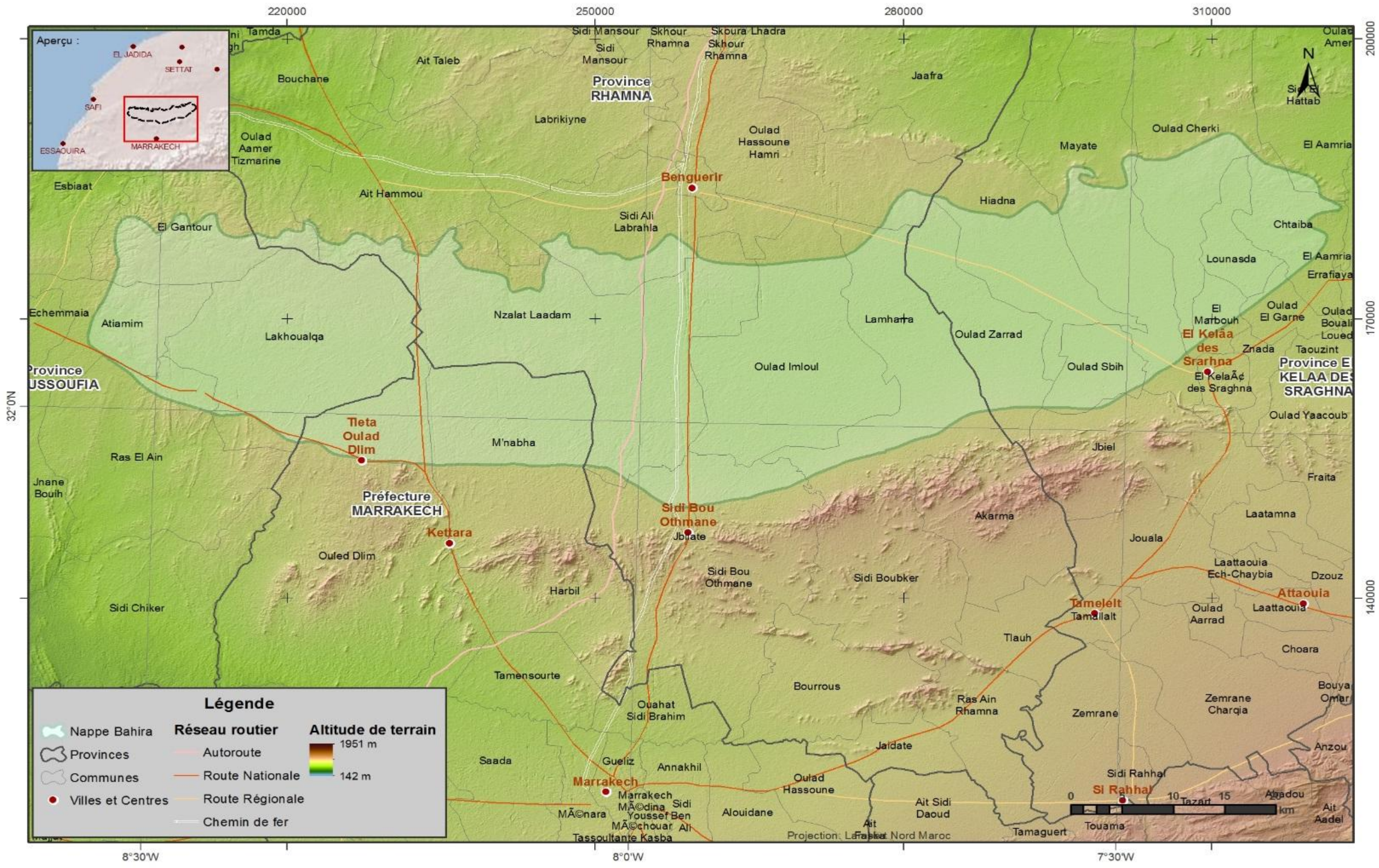
Morocco, December 1st, 2025

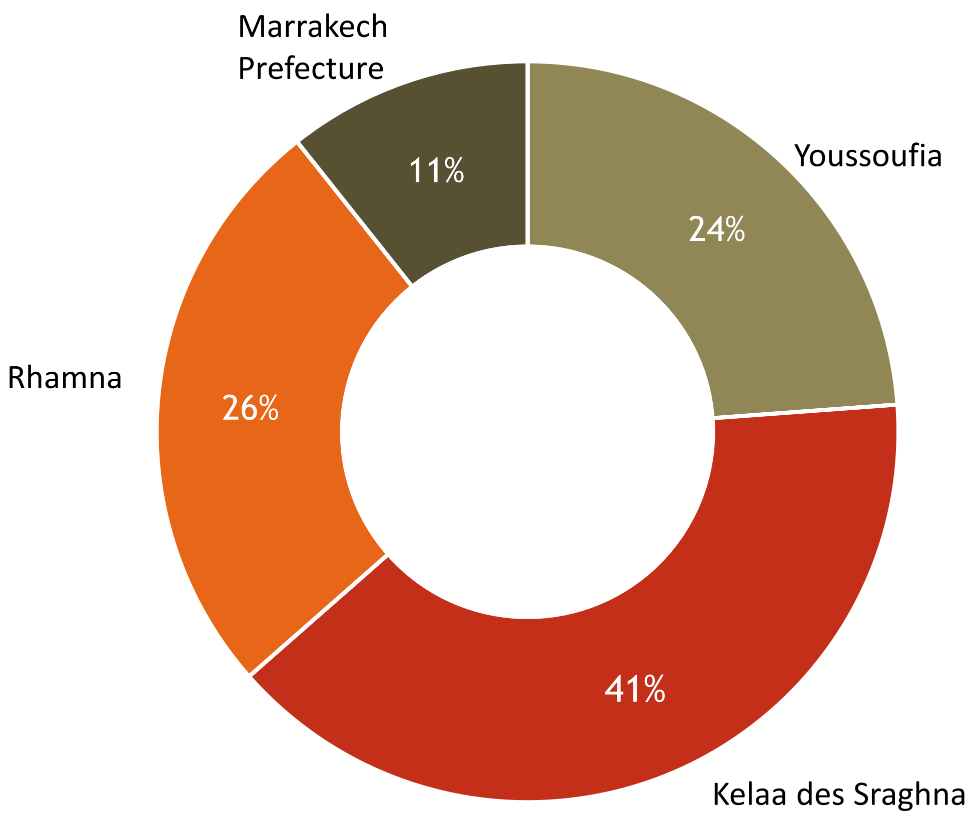
Study Area



The Bahira Aquifer :

- ✓ The Bahira groundwater aquifer is located in the central region of Morocco ;
- ✓ It extends over an area of 3600km², between the Jbilet and Rhamna zones ;
- ✓ It partially covers four provinces: Youssoufia, El Kelaa des Sraghna, and Rhamna, in addition to the Marrakech region ;
- ✓ It includes 24 rural communes ;
- ✓ It constitutes a strategic water resource in an arid region with limited water availability.

Population



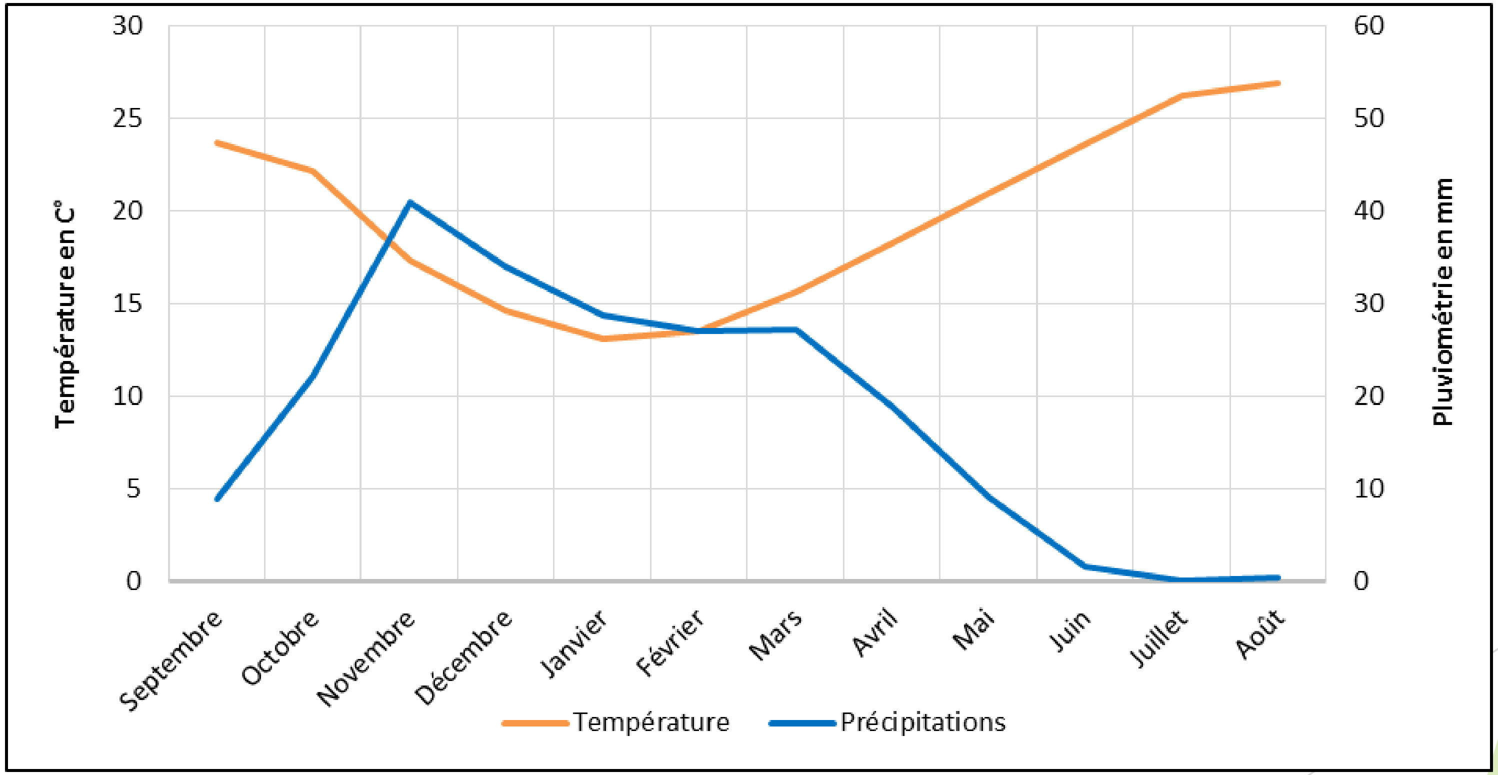
Weight of the Population of the Provinces within the Bahira Aquifer

The population of the Bahira plain is 251,537 inhabitants, distributed across 42,698 households (2014 General Population and Housing Census)

Climate

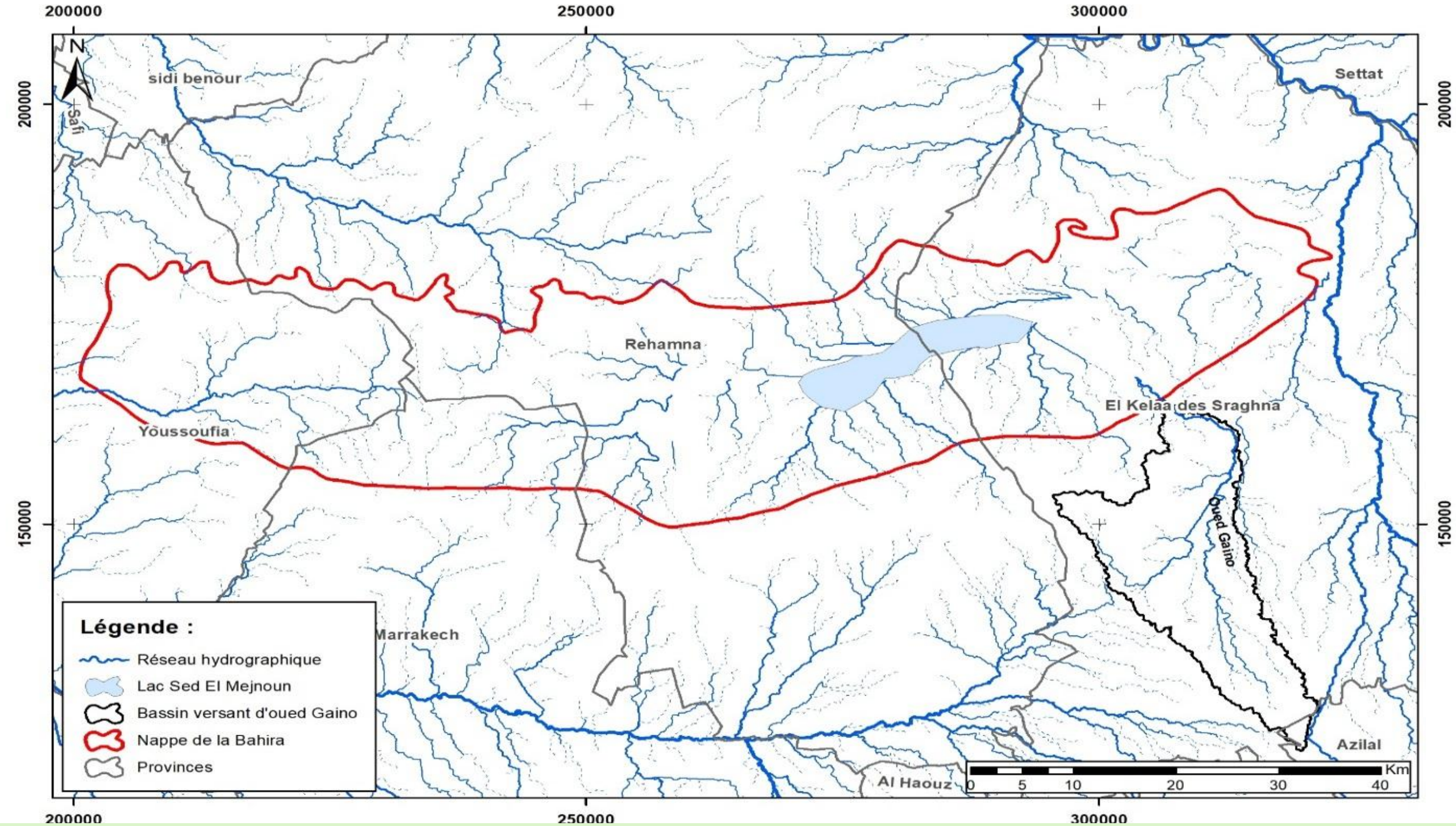
The study area is characterized by:

- ✓ Irregular and low rainfall throughout the year
- ✓ A dry climate with a long dry season extending up to 6 months.



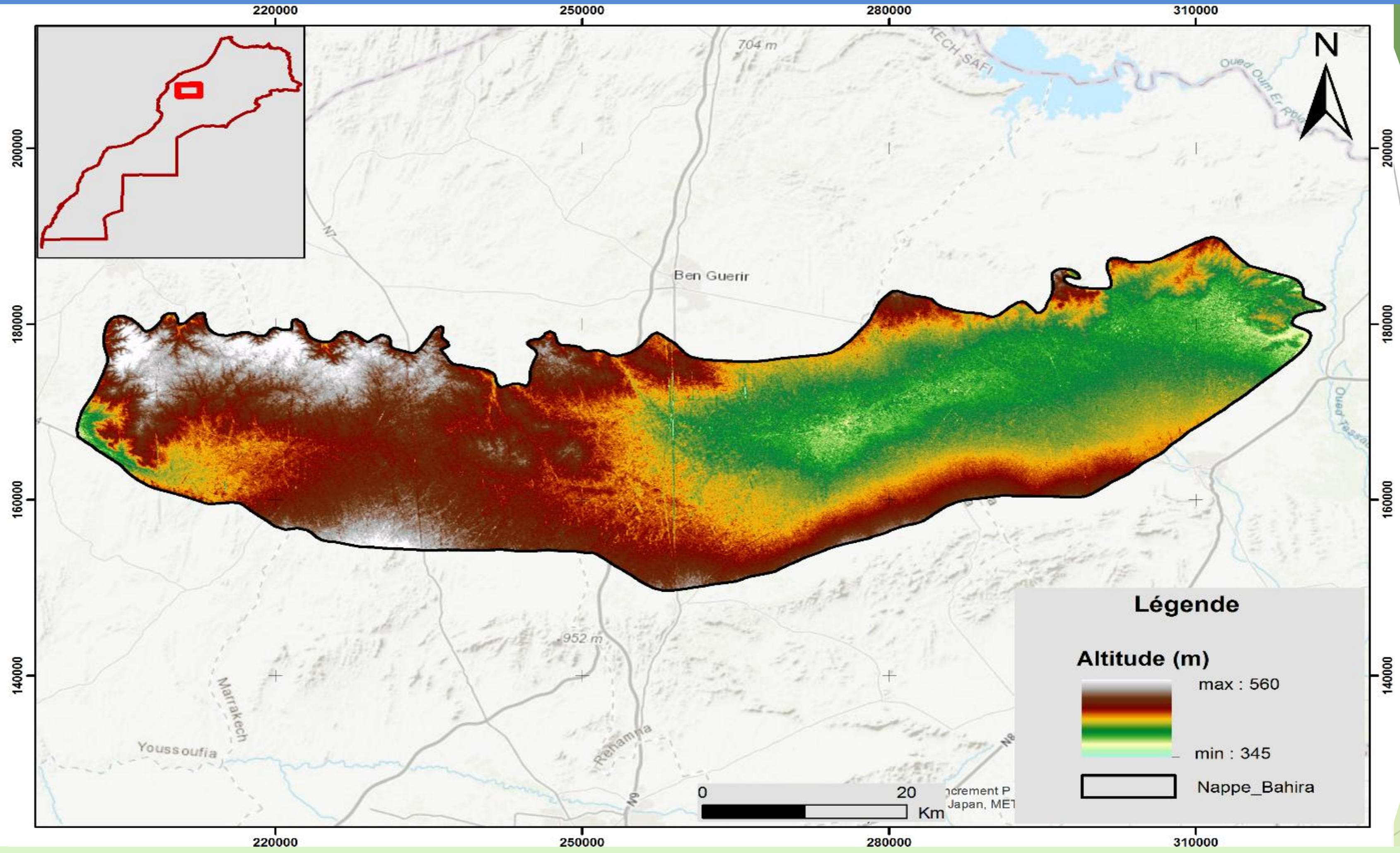
Ombrothermic Diagram of the Bouchane Station

Surface Water and the Hydrographic Network



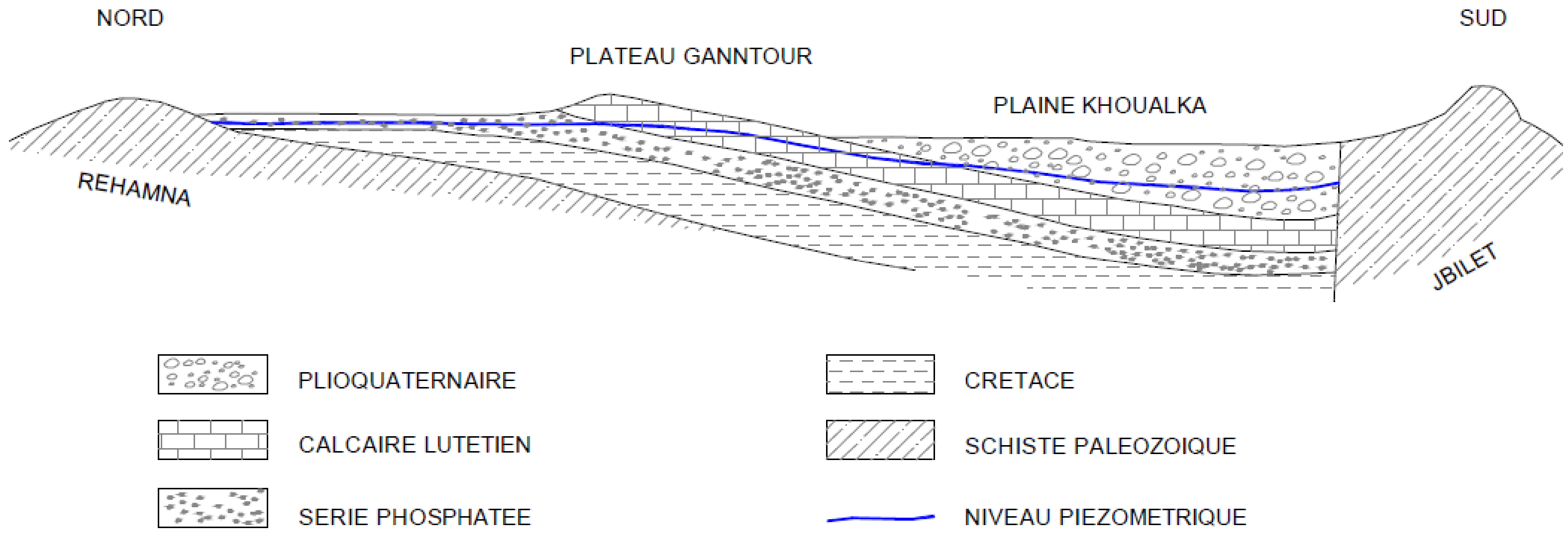
- ✓ Surface water resources are very limited; except for Oued Ghiyou, no permanent watercourses cross the Bahira plain.
- ✓ Oued Tassaout (one of the main tributaries of Oued El Abid) forms the eastern boundary of the aquifer.
- ✓ Runoff water infiltrates into the soil or accumulates in closed depressions (lacustrine areas of Sed El Mâajoun and Zrima).

Geomorphology



- ✓ The Bahira plain is considered a closed depression (an internal basin).
- ✓ The highest elevations are located in the Ghentour Plateau, reaching up to 560 m.
- ✓ The lowest elevations are found in the eastern and central parts of the plain (down to 345 m).

Hydrogeology

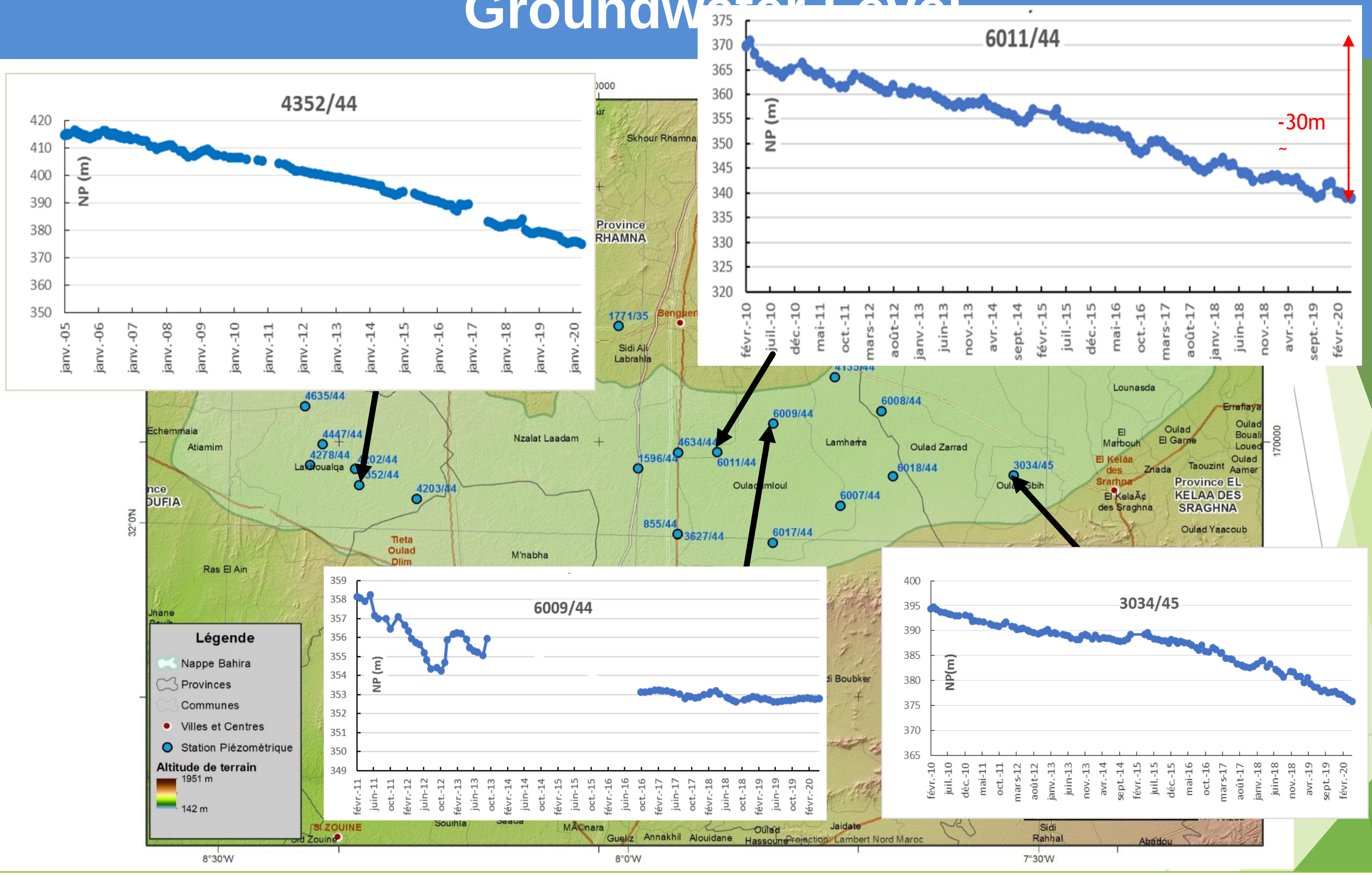


The Bahira groundwater flows within a multilayer hydrogeological system, comprising:

- ✓ The Plio-Quaternary aquifer (Plio-Quaternary reservoir);
- ✓ The Lutetian limestone and Upper Phosphates reservoir (Lutetian limestone reservoir);
- ✓ The Lower Phosphates reservoir (Cretaceous reservoir);
- ✓ The Paleozoic reservoir (fractured schist reservoir).

The aquifers of the Bahira system are significantly interconnected both horizontally and vertically, **therefore**, for modelling purposes, ►the system must be considered as a single-layer aquifer.

Groundwater Level



- ✓ The groundwater level monitoring network consists of **23 observation wells**.
- ✓ Monitoring these wells shows **significant declines**, reaching **up to 30 meters** in some areas ► due to intensive agricultural abstraction and the reduction of natural recharge caused by decreasing rainfall.

Inputs of the Simulation Model

Rainfall Data

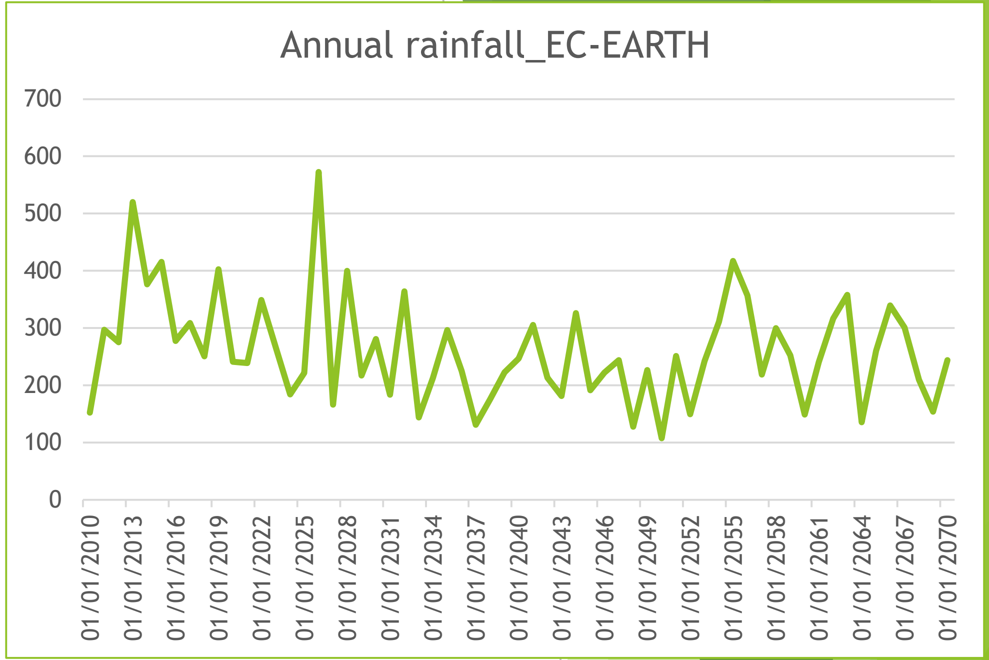
For this study, rainfall data were extracted from the **EC-EARTH 8.5** and **CNRM-CM5** climate models, covering the period from **2010 to 2070**.

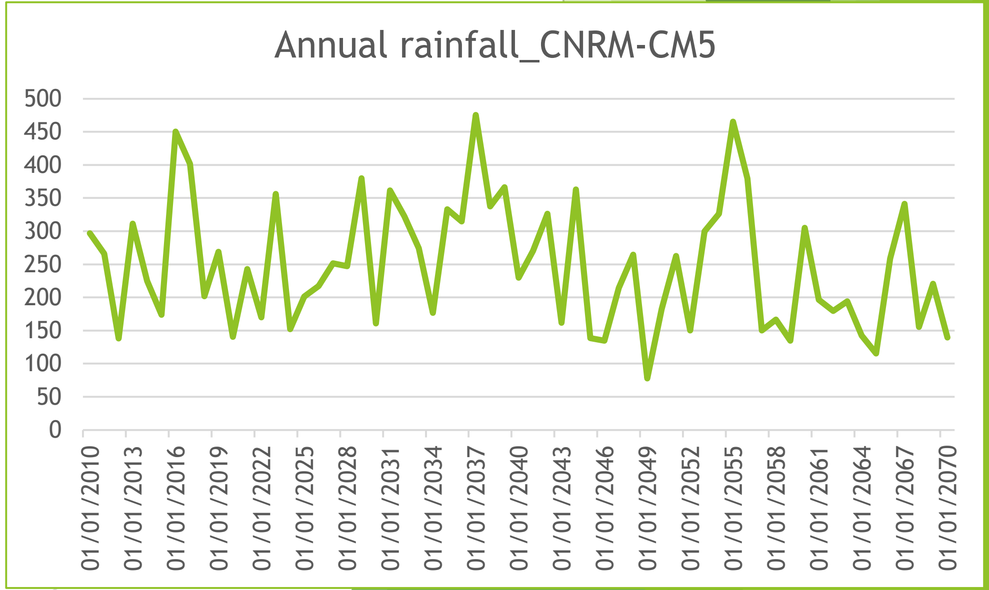
Change (%)							
	2010-2022	2023-2030	2031-2040	2041-2050	2051-2060	2061-2070	**Average**
EC-EARTH 8.5	0%	-8.54%	-30.38%	-32.28%	-16.14%	-18.99%	**-21.27%**
CNRM-CM5	0%	-2.77%	26.09%	-15.81%	4.35%	-23.32%	**-2.29%**

Table: Percentage Variation of Precipitation

These data indicate a noticeable change in rainfall patterns over the study period, highlighting the following :

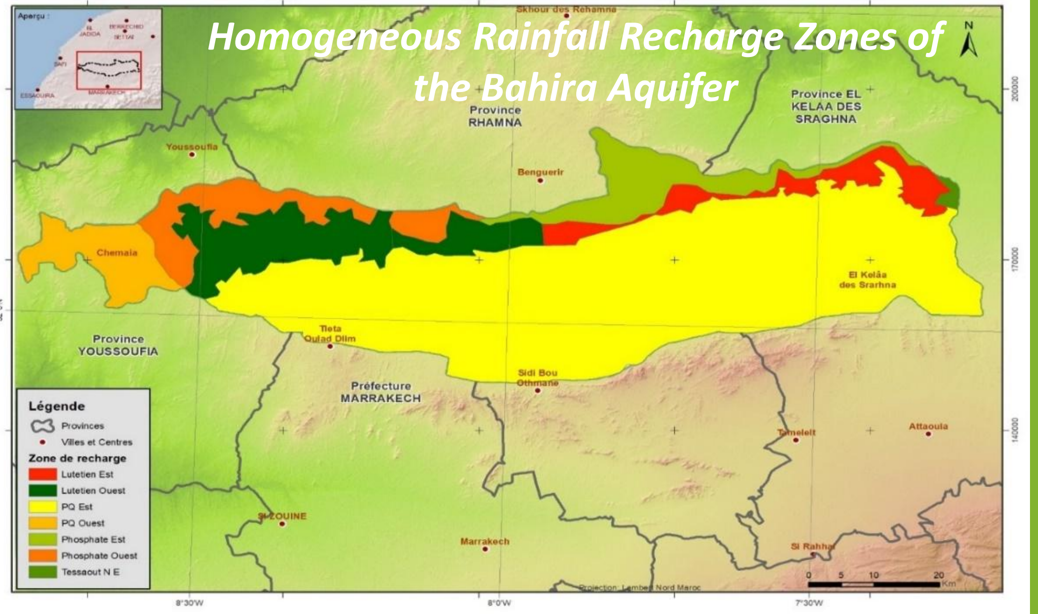
- ✓ A general downward trend in rainfall in the EC-EARTH 8.5 model.
- ✓ A significant variability in rainfall in the CNRM-CM5 model.CNRM-CM5





Rainfall Recharge of the Groundwater Reservoir

- The rainfall infiltration rate is applied to the area based on the classification of the exposed geological formations.
- The following table shows, for each recharge zone, the rainfall infiltration rates used in the models.



			Recharge (m/day)						
Zone de recharge pluviale	Infiltration Coefficient	Model	2010-2022	2023-2030	2031-2040	2041-2050	2051-2060	2061-2070	Average
PQ_West	0.0025	EC-EARTH 8.5	2.16438E-06	1.9795E-06	1.5068E-06	1.4658E-06	1.8151E-06	1.75342E-06	1.78082E-06
		CNRM-CM5	1.73288E-06	1.6849E-06	2.1849E-06	1.4589E-06	1.8082E-06	1.32877E-06	1.69977E-06
Phosphate West	0.005	EC-EARTH 8.5	4.32877E-06	3.9589E-06	3.0137E-06	2.9315E-06	3.6301E-06	3.50685E-06	3.56164E-06
		CNRM-CM5	3.46575E-06	3.3699E-06	4.3699E-06	2.9178E-06	3.6164E-06	2.65753E-06	3.39954E-06
Lutetien West	0.1	EC-EARTH 8.5	8.65753E-05	7.9178E-05	6.0274E-05	5.863E-05	7.2603E-05	7.0137E-05	7.12329E-05
		CNRM-CM5	6.93151E-05	6.7397E-05	8.7397E-05	5.8356E-05	7.2329E-05	5.31507E-05	6.79909E-05
PQ_East	0.025	EC-EARTH 8.5	2.16438E-05	1.9795E-05	1.5068E-05	1.4658E-05	1.8151E-05	1.75342E-05	1.78082E-05
		CNRM-CM5	1.73288E-05	1.6849E-05	2.1849E-05	1.4589E-05	1.8082E-05	1.32877E-05	1.69977E-05
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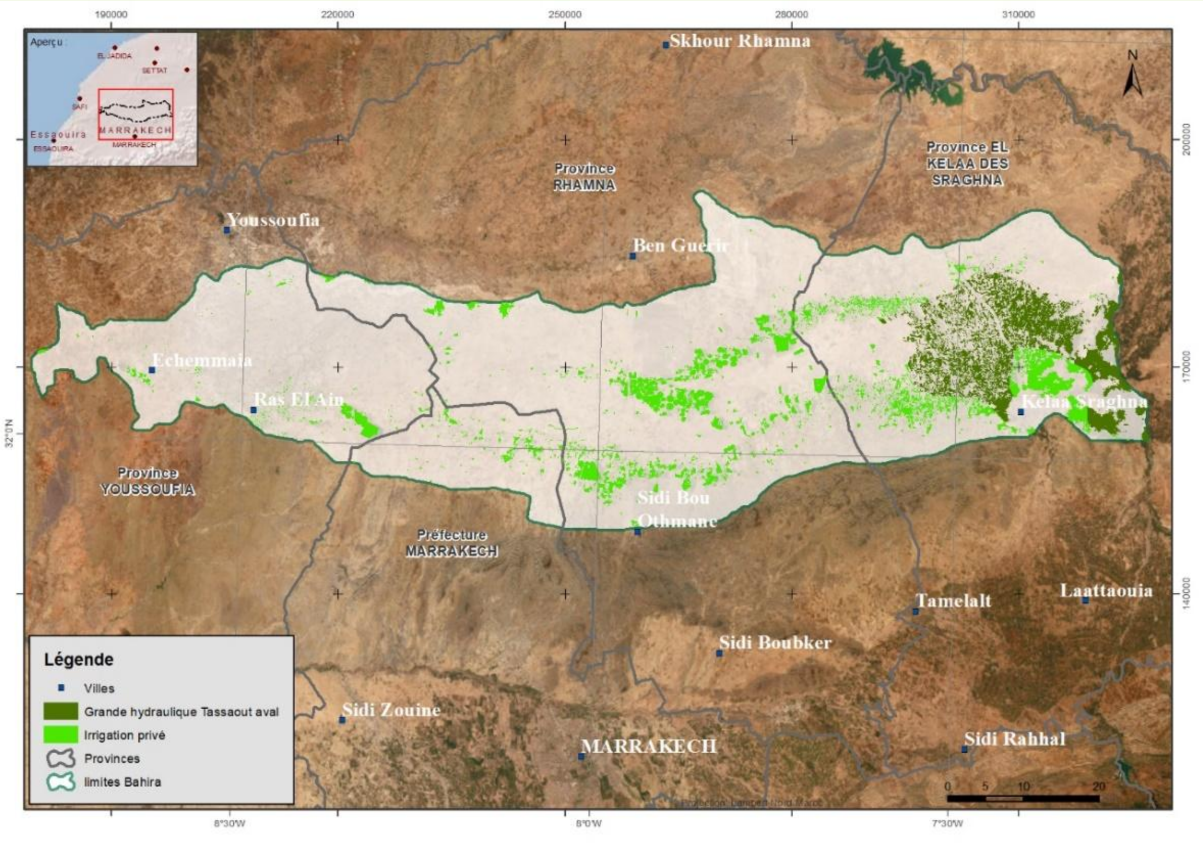
Tessaout_N E	0.025	EC-EARTH 8.5	2.16438E-05	1.9795E-05	1.5068E-05	1.4658E-05	1.8151E-05	1.75342E-05	1.78082E-05
		CNRM-CM5	1.73288E-05	1.6849E-05	2.1849E-05	1.4589E-05	1.8082E-05	1.32877E-05	1.69977E-05

Aquifer Recharge from Irrigation Return Flow

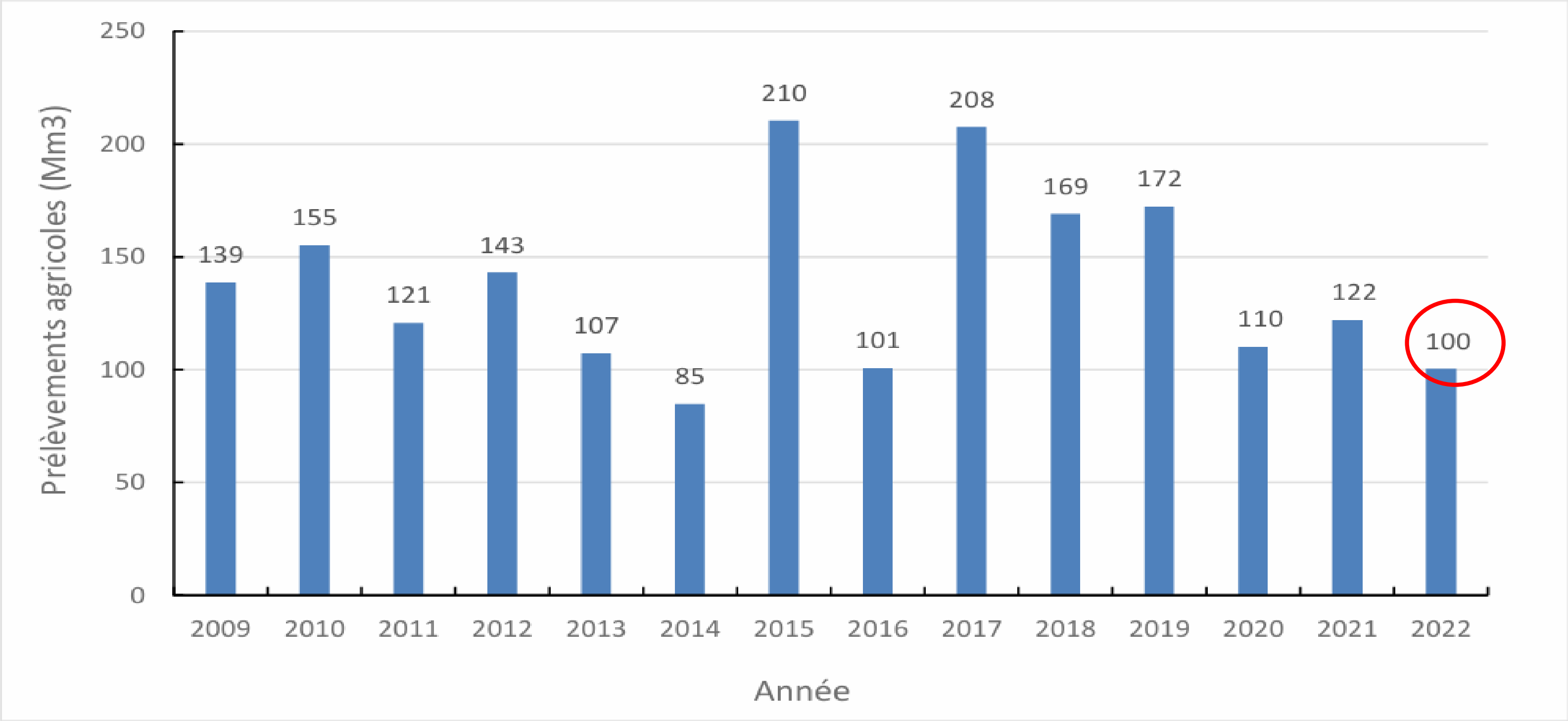
Irrigation return water: Irrigation return flow uses excess irrigation water originating from surface water and groundwater. The applied coefficients are :

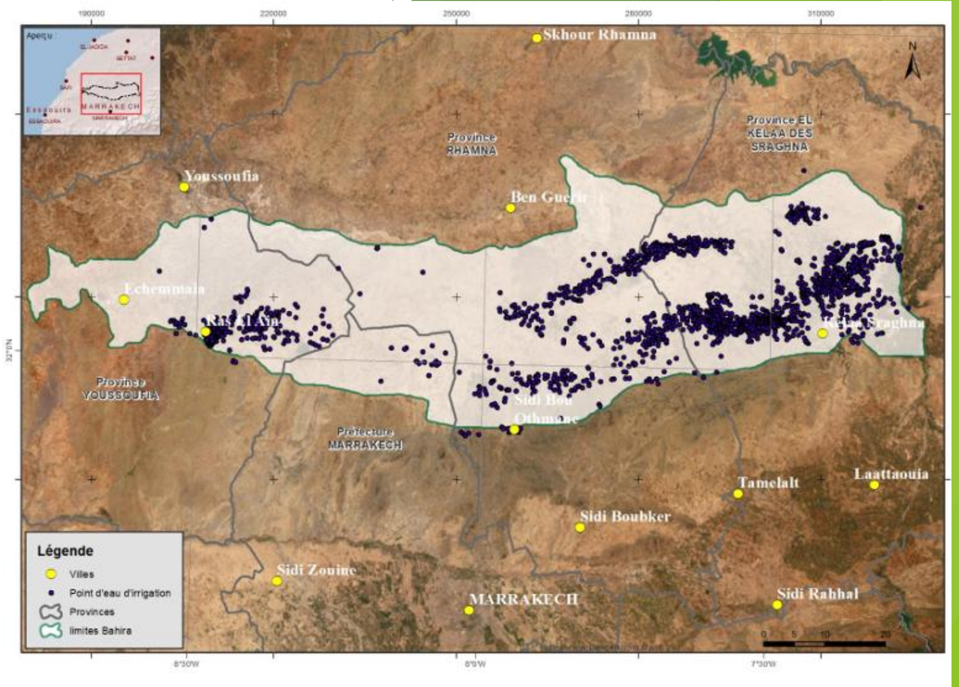
- **2.5%** in areas with **private (small-scale) irrigation**.
- **15%** in areas with **large-scale irrigation** in Tassaout.



Recharge zone from irrigation return flow

Agricultural Uses





Répartition des points d'eau d'irrigation (Inventaire 2005 ABHOER)

The data used in the simulation are distributed over three time steps:

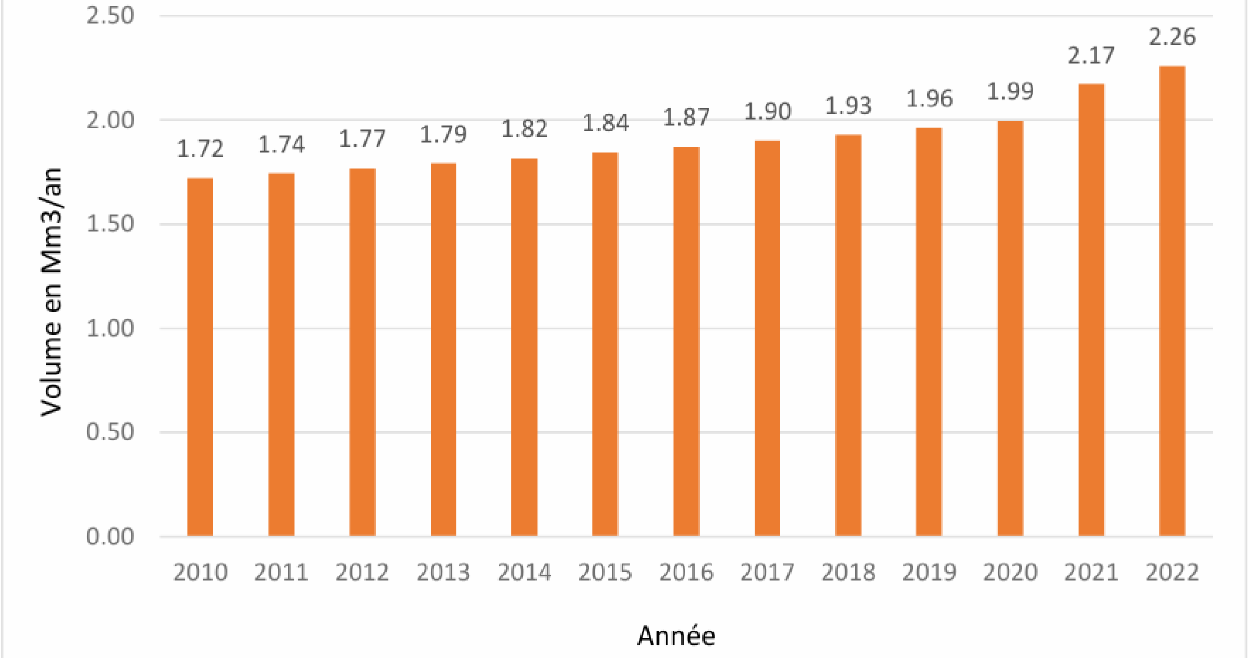
- **2009–2024**: This period represents the historical time series of groundwater abstraction rates.
- **2025–2030**: A gradual increase in pumping is projected, at a rate of 2% per year until 2030.
- **2031–2070**: Pumping rates are assumed to stabilize at the levels recorded in 2030.

Drinking Water Supply

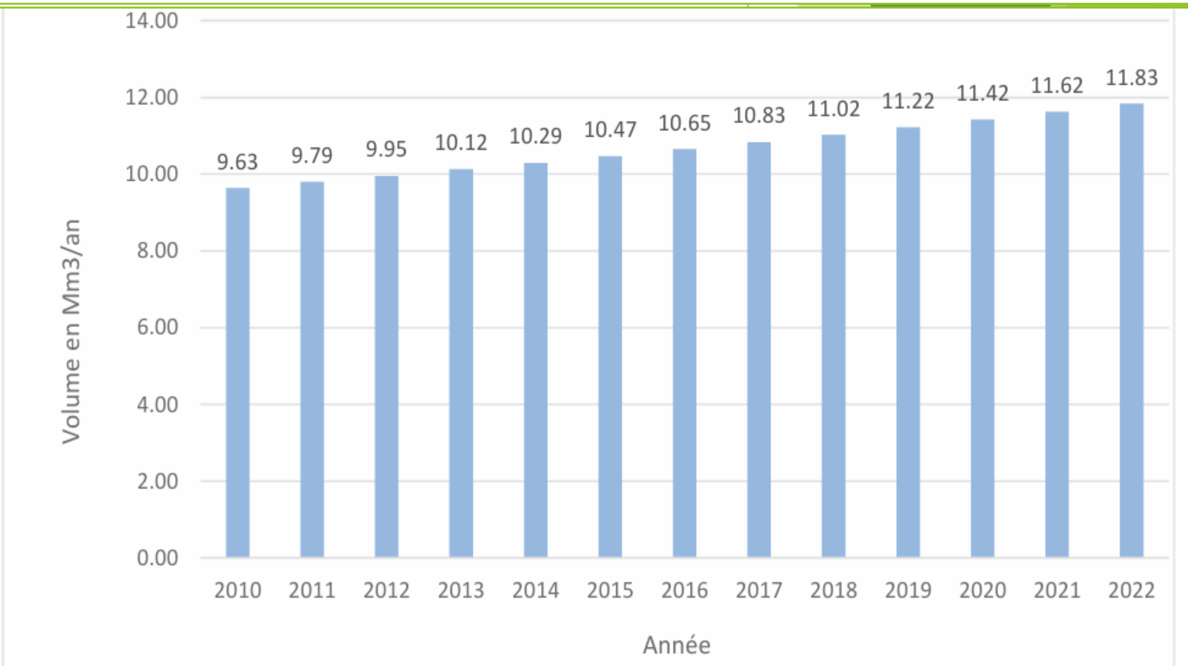
Groundwater abstraction for drinking water will follow demographic developments, while taking into account regional policies and adopted strategies, through:

- A gradual shift toward the use of surface water by the National Office for Drinking Water (ONEE).
- The use of non-conventional water resources by the OCP Group (Office Chérifien des Phosphates).

For the areas not yet connected to the ONEE drinking water network and currently supplied by groundwater, reliance on groundwater will continue until 2030.
From 2031 to 2040, these areas will progressively shift toward surface water supply, once connected to the ONEE network.



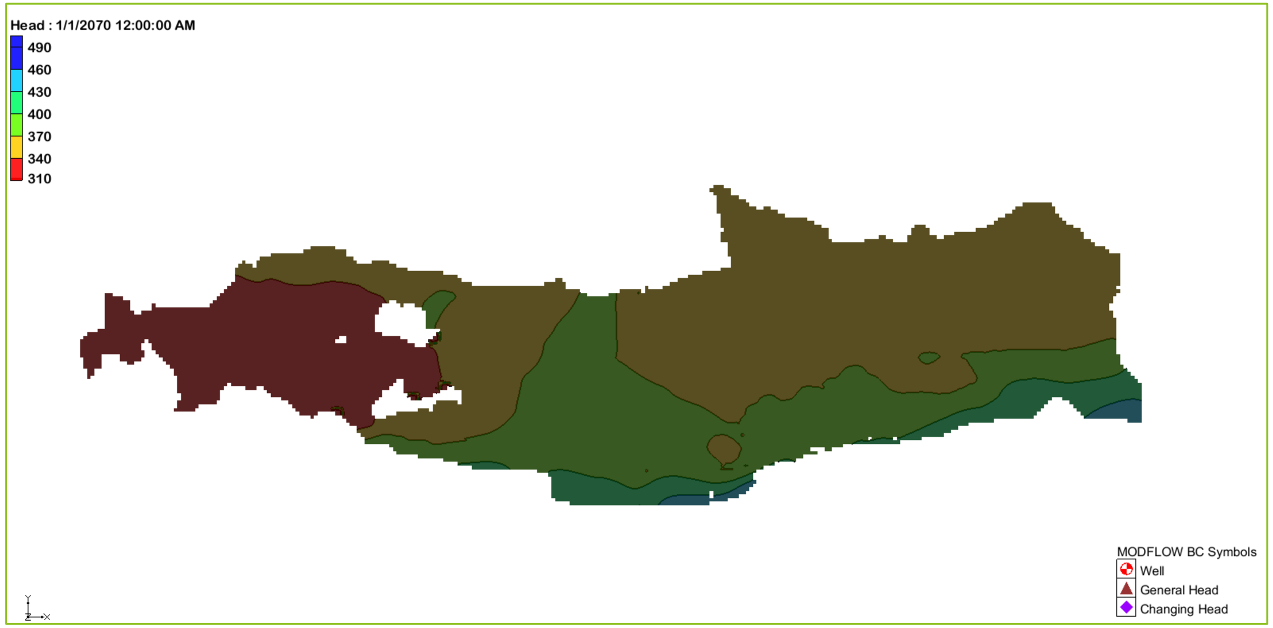
Evolution of Drinking Water Demand in Villages Not Connected to the ONEE-Water Network



Evolution of Groundwater Abstractions by ONEE-Water in the Bahira Area

Presentation of the Simulation Model Results

Presentation of Simulation Results: ***Groundwater Levels in 2070***



Map: Simulated Piezometry in 2070

- CNRM-CM5 -

Map: Simulated Piezometry in 2070

- EC-EARTH 8.5 -

- The two maps show a decline in groundwater (piezometric) levels across several areas by the year 2070, confirming the negative impact of climate change on groundwater resources.
- The simulations reveal larger and more severe drawdown zones, particularly in the western and southwestern parts of the aquifer.
- Fully dried-out areas appear in the western part of the groundwater reservoir.
- Although the declines are evident in the EC-EARTH 8.5 scenario, the extent of the affected areas appears smaller when compared to the CNRM-CM5 scenario.

Presentation of Simulation Results :*Groundwater Level Time Series (EC-EARTH 8.5)*

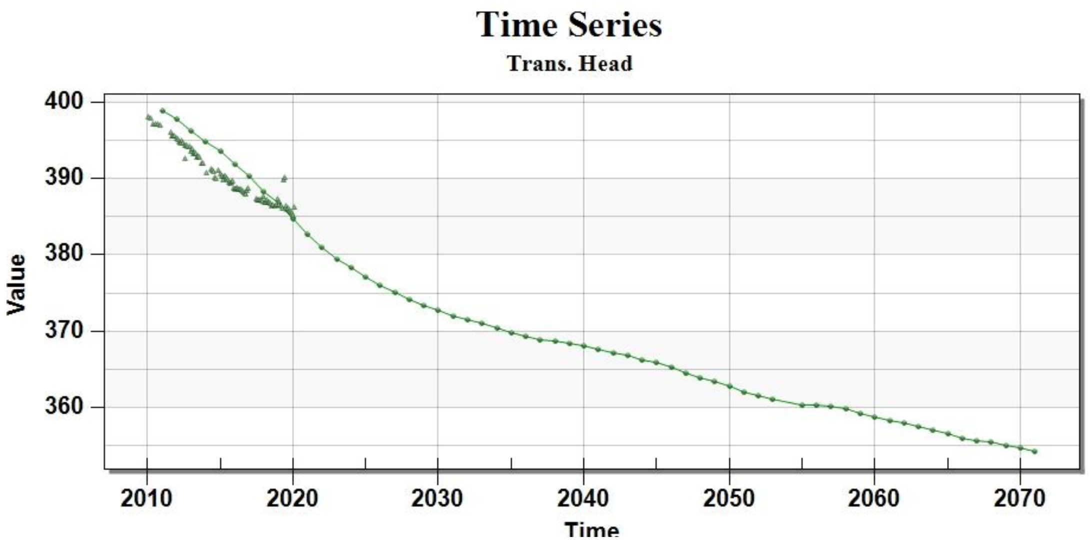
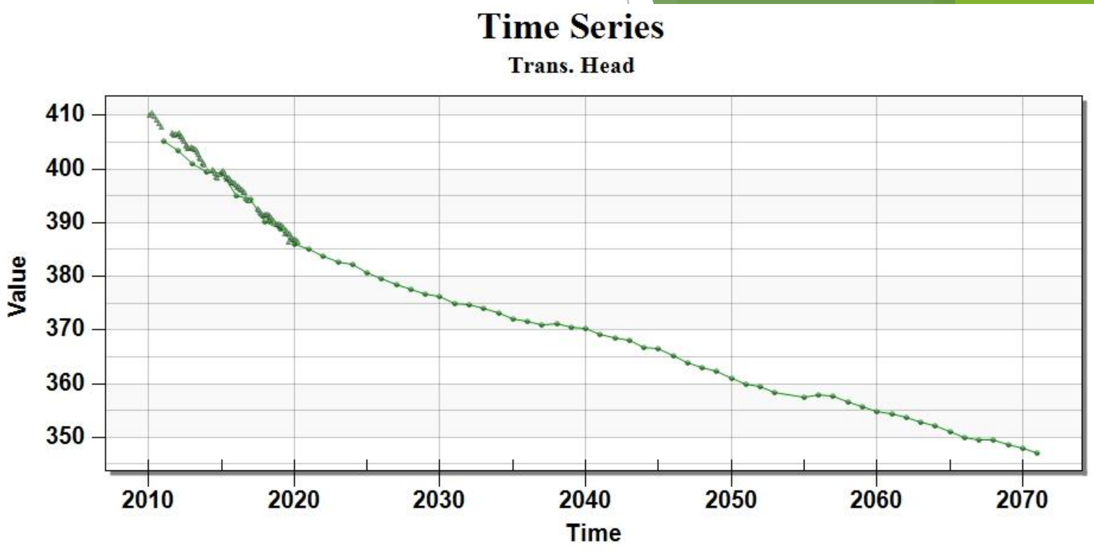
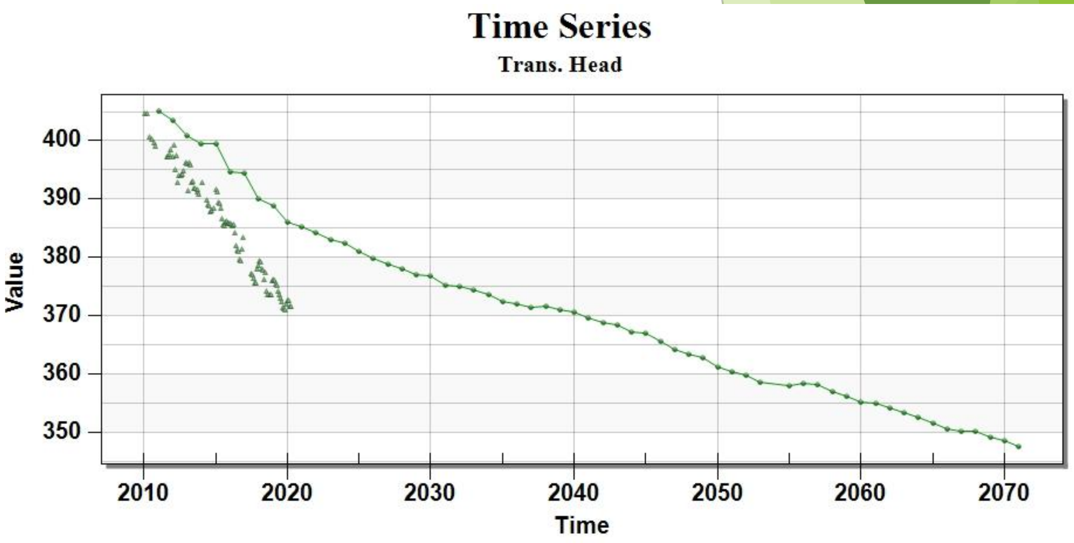


Figure : Simulated and observed piezometric time series – Piezometer 4279/44



Simulated and observed piezometric time series – Piezometer 4278/44



Simulated and observed piezometric time series – Piezometer 4202/44

The three time series indicate a continuous decline in groundwater levels between 2010 and 2070.

An annual decrease of about 1 meter per year is recorded,

► indicating a progressive degradation of groundwater resources within the study area.

Presentation of the Simulation Results: *Groundwater Level Time Series (CNRM 8.5)*

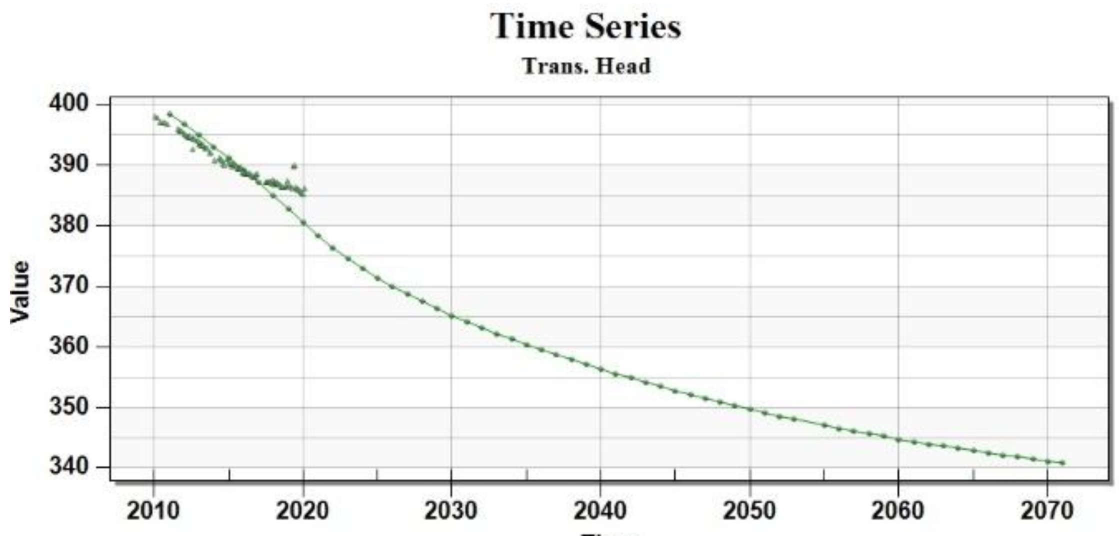


Figure : Simulated and observed piezometric time series – Piezometer 4279/44

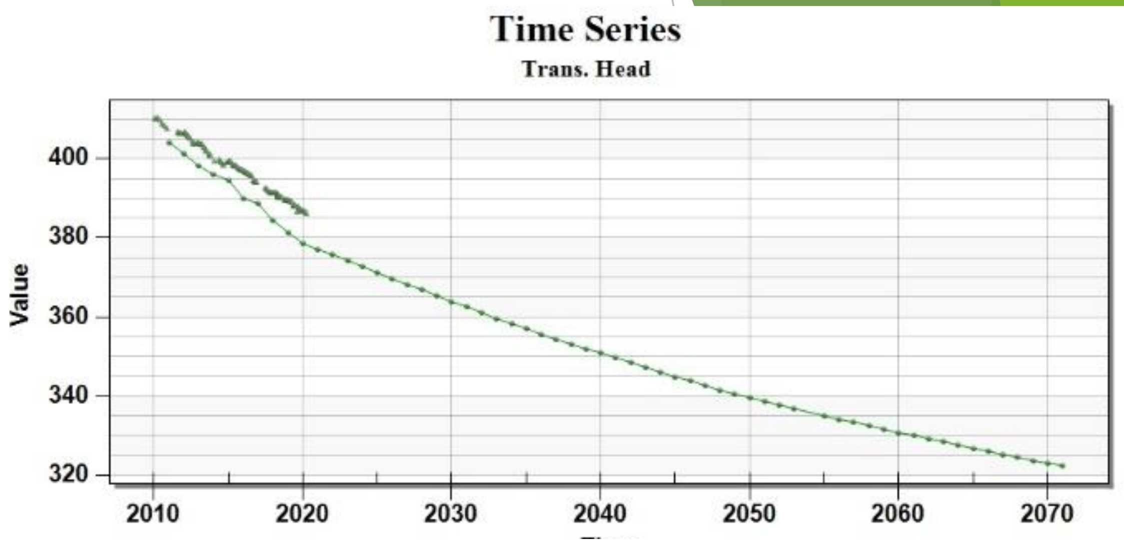


Figure : Simulated and observed piezometric time series – Piezometer 4278/44

A **noticeable and continuous decline** in groundwater levels is observed, with average annual decreases ranging between 0.67 m/year and 1.17 m/year.

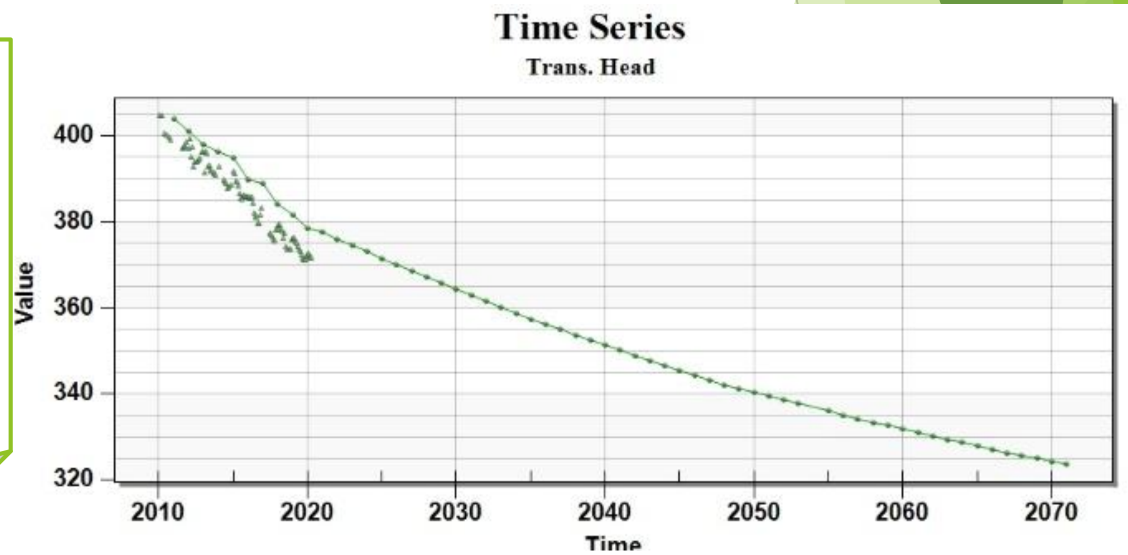


Figure : Simulated and observed piezometric time series – Piezometer 4202/44

Water Balance of the Bahira Aquifer (2070)

Inputs (Mm³)	**Specified-Flux Boundary (Jbilet)**	**2.8**
	Rainfall recharge and irrigation return flow	5.9
Outputs (Mm³)	Imposed-Potential Boundary (Youssoufia – Bouchane)	0.13
	Agricultural and drinking water pumping	104
	General Potential Boundary (Oued Tassaout)	3.13
	Evapotranspiration	0
Storage Change (Mm³)		**-98.5**

Inputs (Mm³)	**Specified-Flux Boundary (Jbilet)**	**2.2**
	Rainfall recharge and irrigation return flow	14.6
Outputs (Mm³)	Imposed-Potential Boundary (Youssoufia – Bouchane)	1.2
	Agricultural and drinking water pumping	107
	General Potential Boundary (Oued Tassaout)	3.7
	Evapotranspiration	0
Storage Change (Mm³)		**-95**

The water balance of the Bahira aquifer by the horizon year 2070 shows a clear deficit estimated at approximately :

- **–98.5 million m³ under the CNRM 8.5 climate model.**
- **–95 million m³ under the EC-EARTH 8.5 climate model.**

Annual Depletion of the Groundwater Storage

It is observed that the aquifer storage undergoes annual depletion during the simulation period at a rate of::

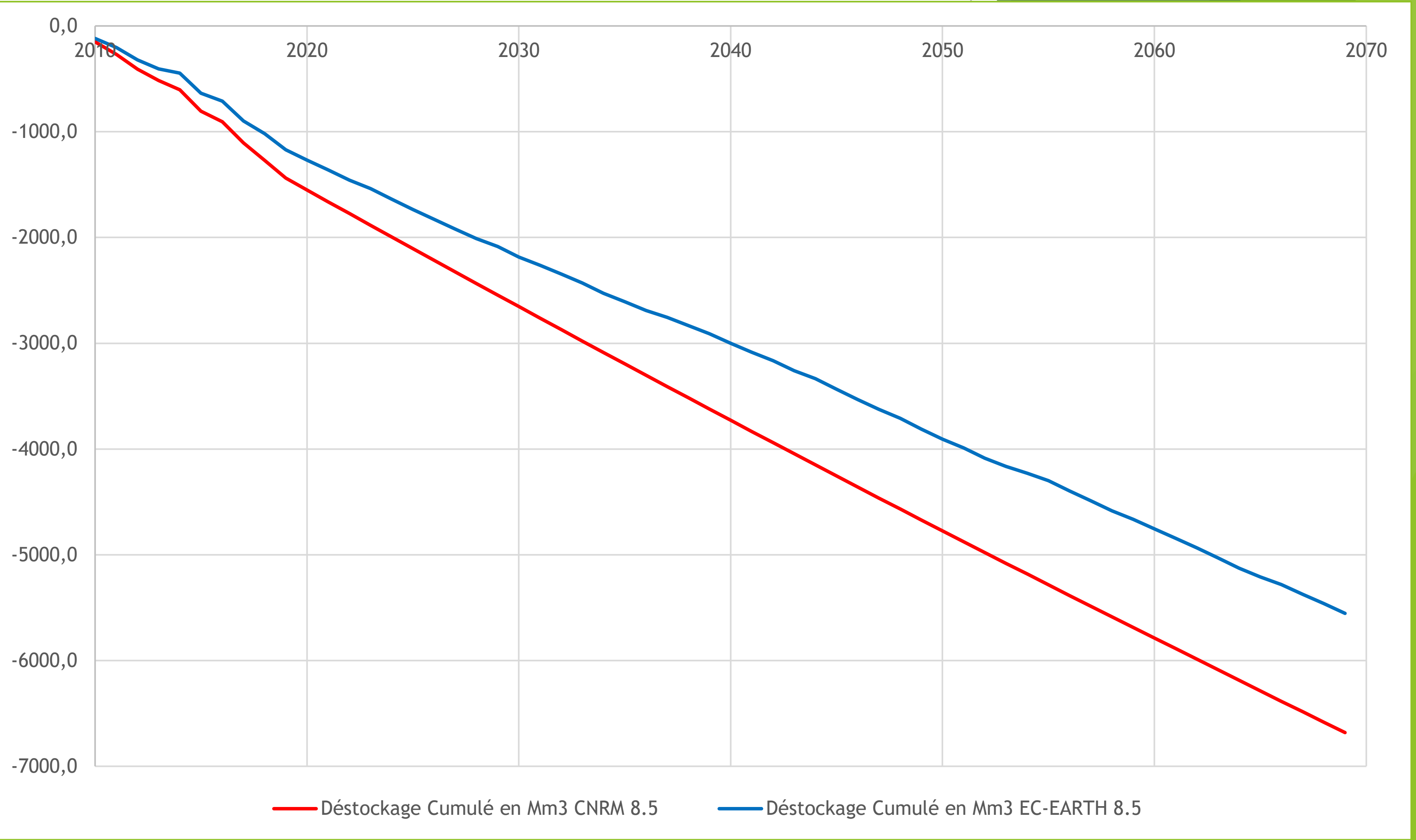
•**–111 million m³/year** under the **CNRM 8.5** climate model

•**– 93 million m³/year** under the **EC-EARTH 8.5 c**limate model

The **cumulative groundwater storage depletion** by the horizon year **2070** is estimated as follows:

•**–6681 million m³** for the **CNRM 8.5** model

•**–5554 million m³** for the **EC-EARTH 8.5** mode



Cumulative Aquifer Depletion over the Period 2010–2070

Conclusion and Recommendations

The study highlights significant pressure on the Bahira aquifer, which is increasingly affected by climate change and unsustainable exploitation practices.

► Transitioning toward sustainable water management practices, supported by effective adaptation policies, has become essential to preserve this strategic resource..

Given these alarming results, it is necessary to adopt tangible and sustainable strategies to mitigate these pressures and ensure the long-term viability of the aquifer for future generations.

Based on the above, we propose the following recommendations:

- **Integrated Water Resources Management**
  - Increasing reliance on surface water to meet drinking water needs.
  - Reducing dependence on non-conventional water resources.
- **Improving Agricultural Practices**
  - Expanding irrigated areas equipped with localized irrigation systems (drip irrigation).
  - Promoting the development of less water-consuming crops.
- **Artificial Recharge**
  - Implementing artificial recharge projects for the Bahira aquifer.
- **Strengthening Monitoring**
  - Installing new monitoring wells to better track groundwater levels.
  - Enhancing compliance with legal and regulatory extraction limits.
- **Awareness and Cooperation**
  - Raising awareness among farmers and stakeholders to foster participatory management of the water resource.

Thank you for your attention