Groundwater Salinity Drivers in Arid Endorheic Basins:

Insights from Hydrogeochemical and Isotopic Analyses in Bahira, Morocco

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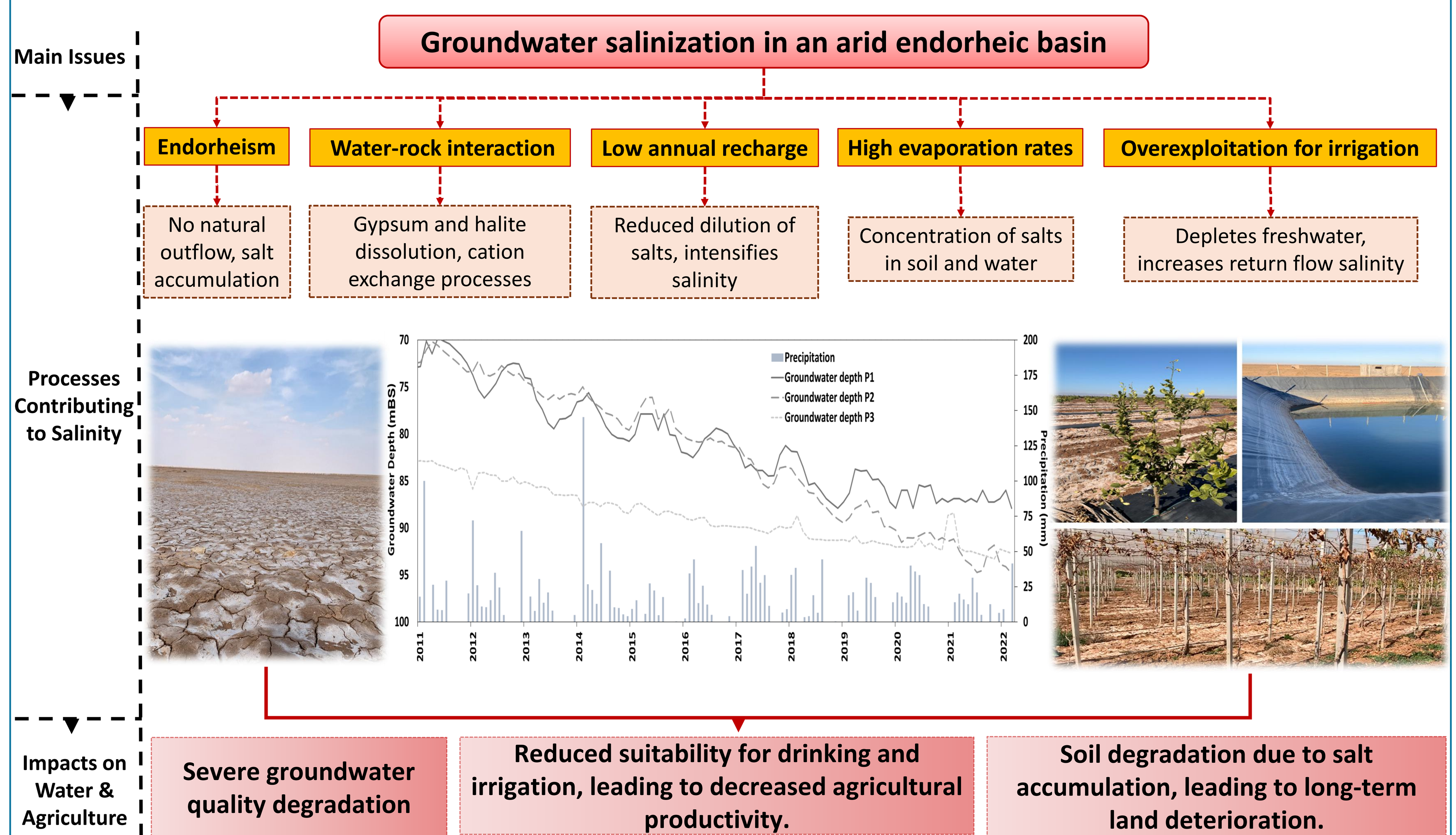
1- Introduction

- **Groundwater salinity** is a critical challenge in **arid** regions, impacting **water quality** and **agricultural sustainability** and **long-term resource** management.
- **Endorheic basins** are vulnerable due to limited **recharge**, leading to **salt accumulation** driven by **evaporation, water-rock interactions,** and **human activities.**
- Understanding **salinity mechanisms** is essential for sustainable groundwater management, focusing on key **geochemical** and **isotopic processes** controlling its spatial distribution.



2- Study Area

The **Bahira** in central Morocco is a complex **endorheic** system with interconnected aquifers, in an arid region with **limited recharge, intense evaporation** and **extreme groundwater salinity (66,000 µS.cm⁻¹).**

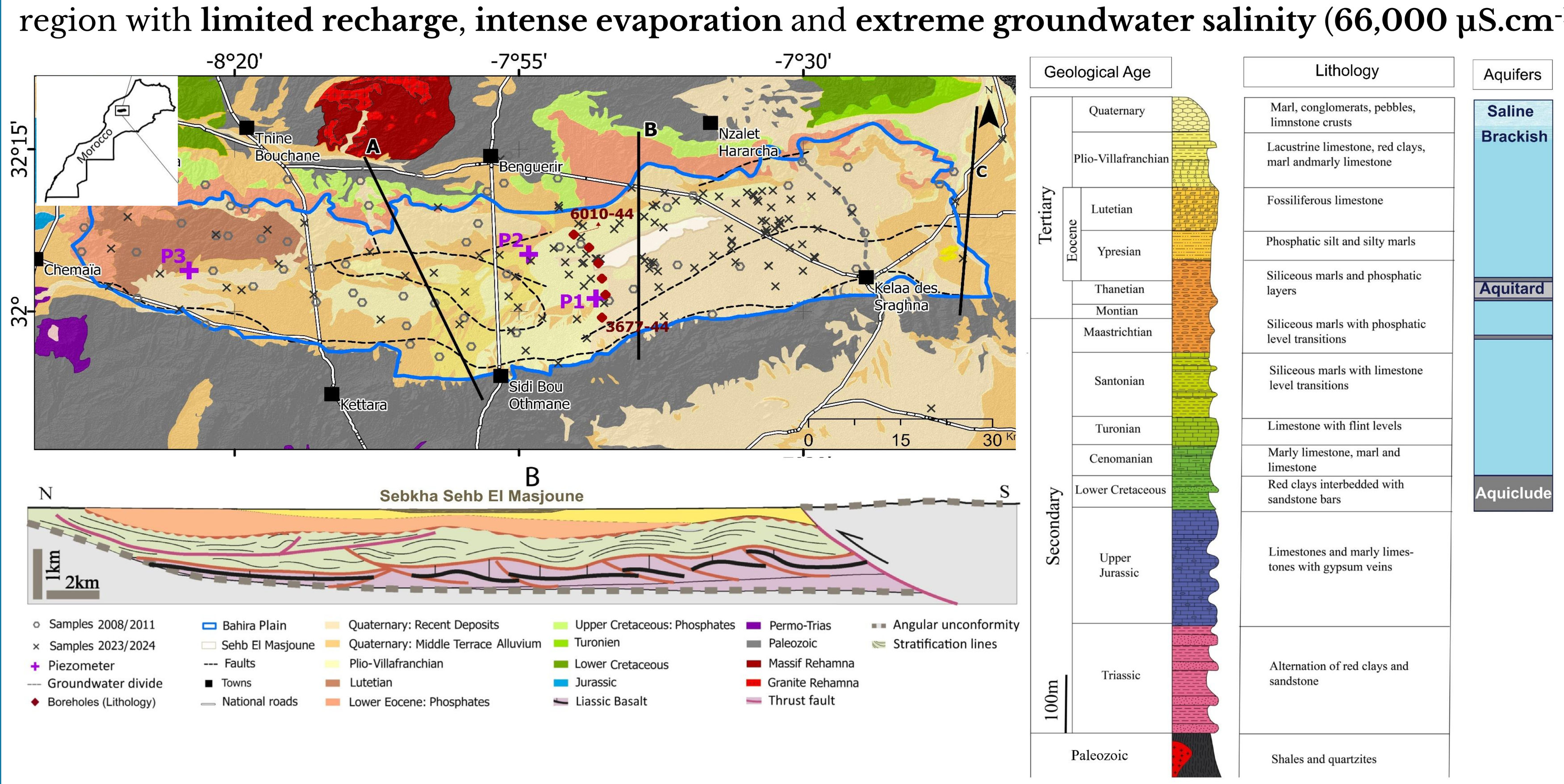
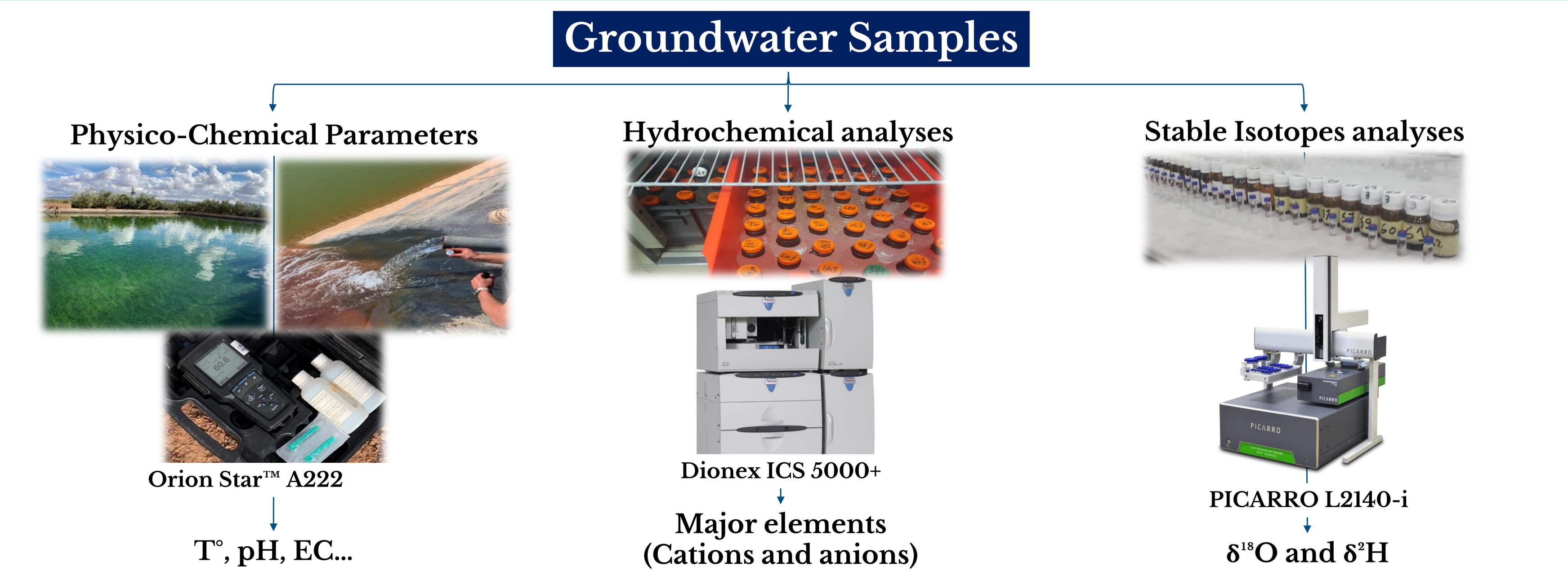


Fig.1: a) Geological map, cross sections and synthetic lithostratigraphic column of the study areas and sampled wells (1).

3- Methods



4- Results & Discussion

- Groundwater salinity is primarily driven by elevated Cl^-, Na^+, and SO_4^{2-}, indicating **mineral dissolution,** further intensified by **evaporation**

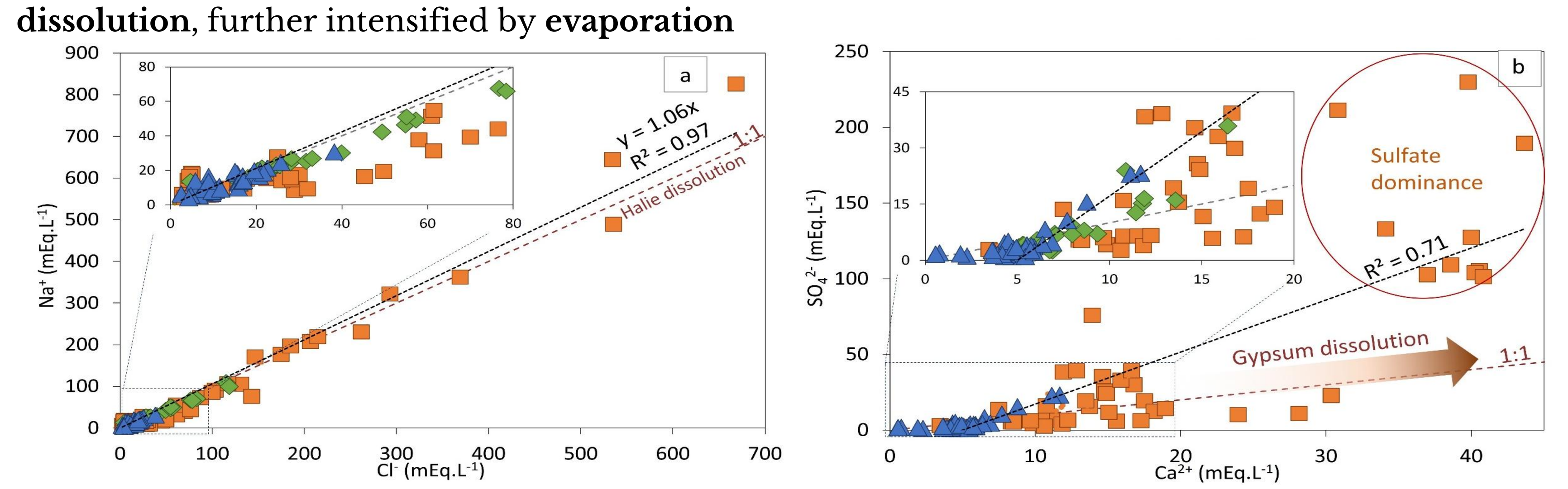
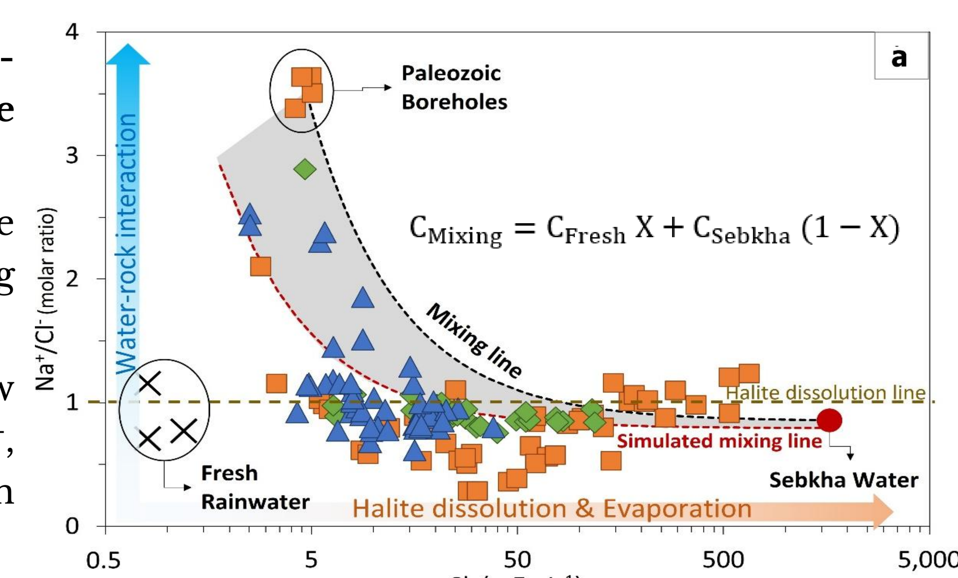


Fig.2: a) Correlation between Cl⁻ and Na+, b) Correlation between SO_4^{2-} and Ca^{2+}

- Na^+/Cl^- trends show recharge from **silicate-rich** mountains at **low salinities** and **halite dissolution** at **high salinities.**
- Groundwater compositions deviate from the **theoretical mixing line** (Fig. 2b), indicating **additional geochemical processes.**
- **Cation exchange** is evident in the shallow aquifer with **higher variability** in Na^+, Ca^{2+}, and Mg^{2+}. Deep aquifer shows less variation due to **prolonged water-rock interactions.**



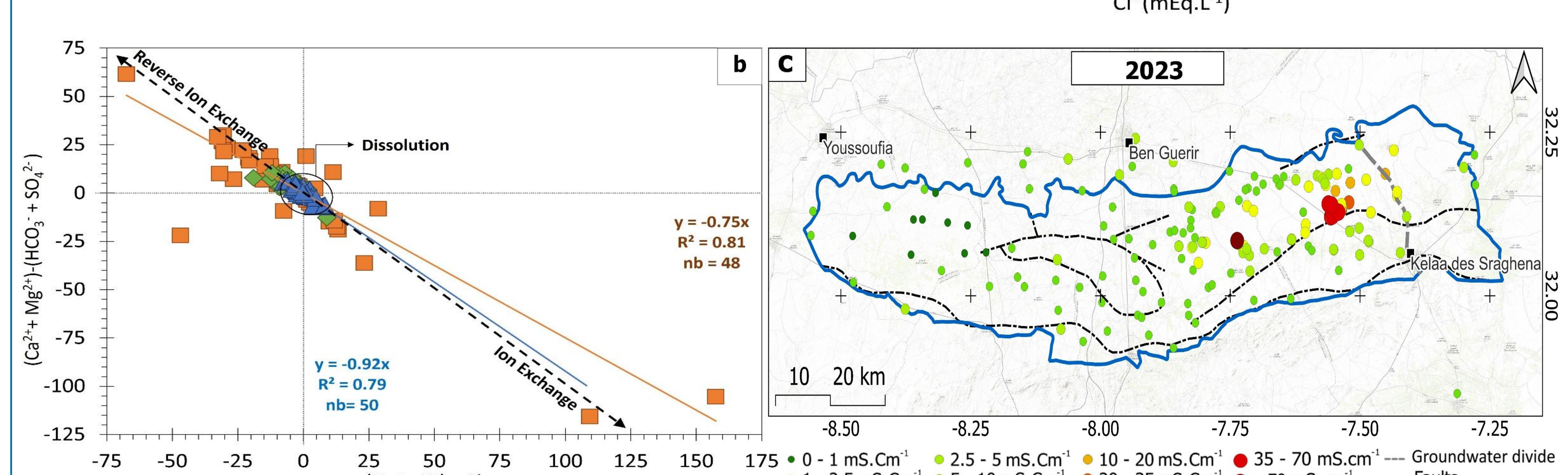
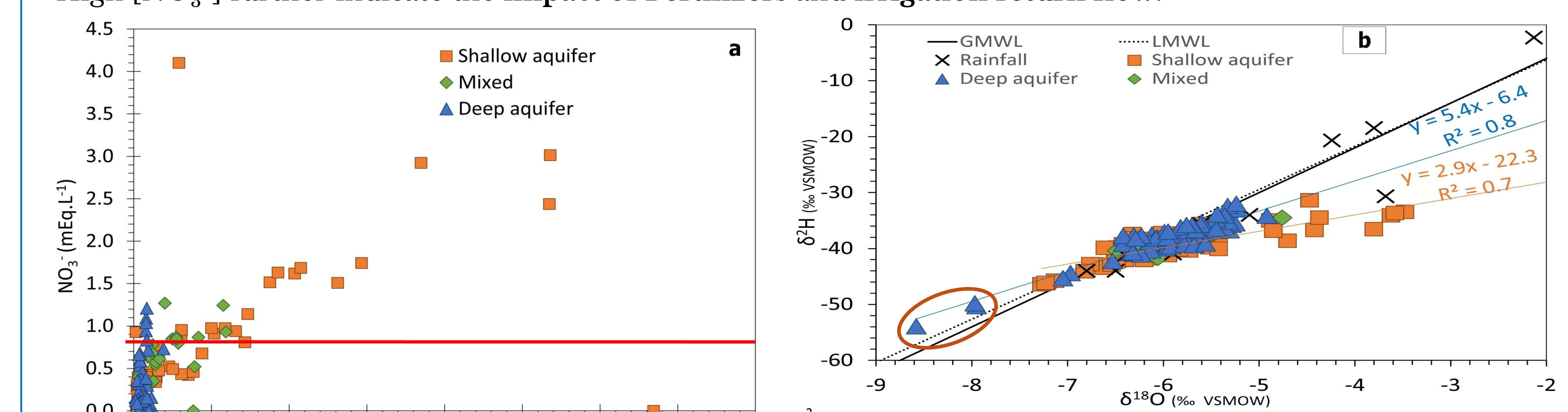


Fig.3: a) Na^+/Cl^- ratio vs. Cl^- concentration illustrating the identified end-members and salinization processes in the Sebkha system, b) relationship between $(Na^+ + K^+) - Cl^-$ and $(Ca^{2+} + Mg^{2+}) - (HCO_3^- + SO_4^{2-})$, c) Spatial distribution of the groundwater salinity in the study area.

- **Declining precipitation** and **groundwater** levels, **increased agricultural activity** and **over-exploitation,** contribute to **rising salinity** in the Bahira aquifer.
- High $[NO_3^-]$ further indicate the **impact of Fertilizers** and **irrigation return flow.**



- Most samples fall below the Global (2) & Local (3) Meteoric Water Lines, indicating **evaporative enrichment.**
- Groundwater of Bahira recharged from **Jebilet & Gantour,** with deeper Tassaoute aquifers possibly linked to **High Atlas recharge.**

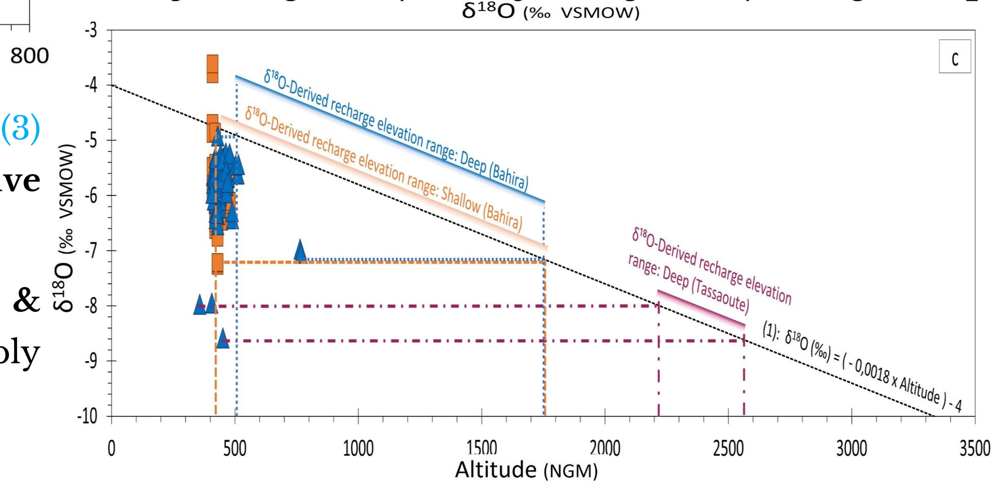
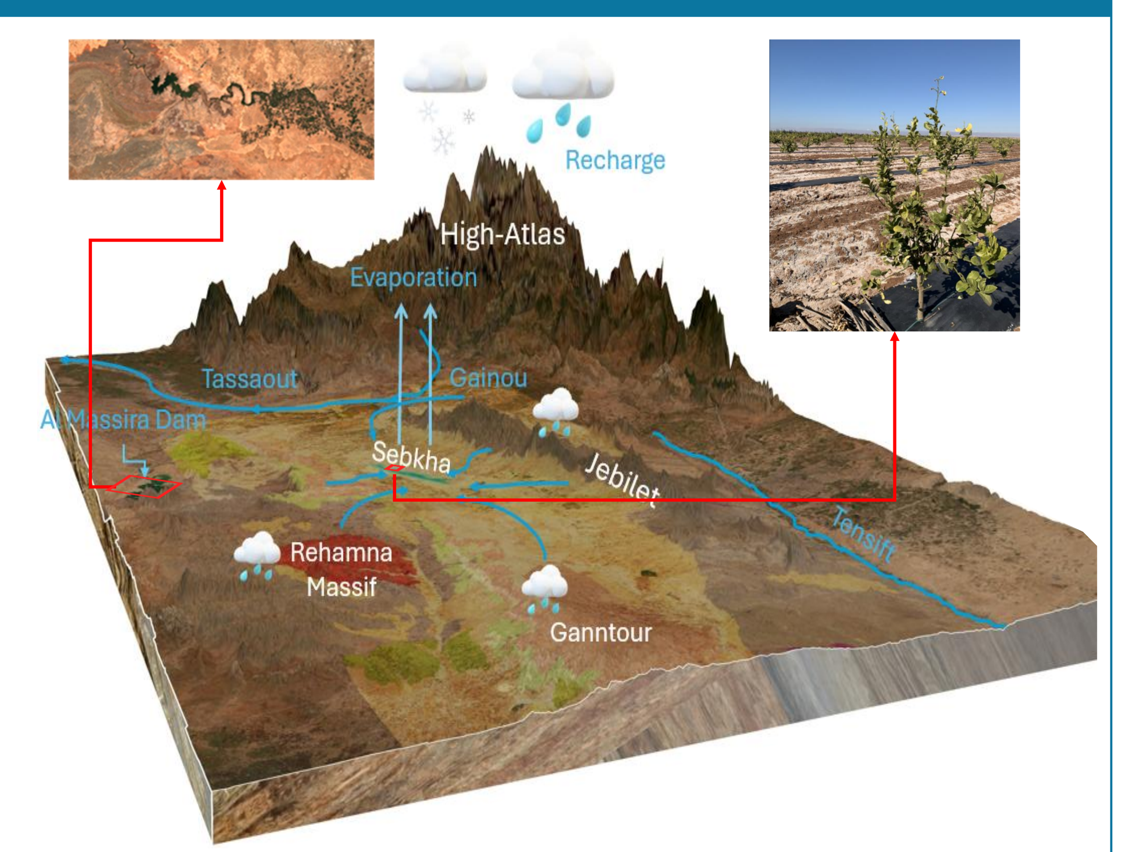


Fig.4: a) Nitrate concentrations vs. Cl⁻ concentration, b) δ²H vs. δ¹⁸O in groundwater samples from different aquifers, and rainfall samples, c) δ¹⁸O vs recharge elevation, based on the altitude gradient (4).

5- Conclusion

- ❑ **Groundwater salinity** in the Bahira basin is mainly driven by **halite** and **gypsum dissolution,** intensified by **high evaporation** and **low recharge,** especially in the shallow aquifer.
- ❑ The **shallow aquifer** is **highly saline** and unsuitable for use, while the **deep aquifer remains fresh** but is increasingly **over-exploited** for **agricultural needs.**
- ❑ The **sustainability** of the **deep aquifer** under low recharge conditions is now the **primary concern** for **long-term water resource management.**



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7- References

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