



Nuclear Techniques Application for WR in Tunisia



Nuclear techniques used for water resources management and future challenges

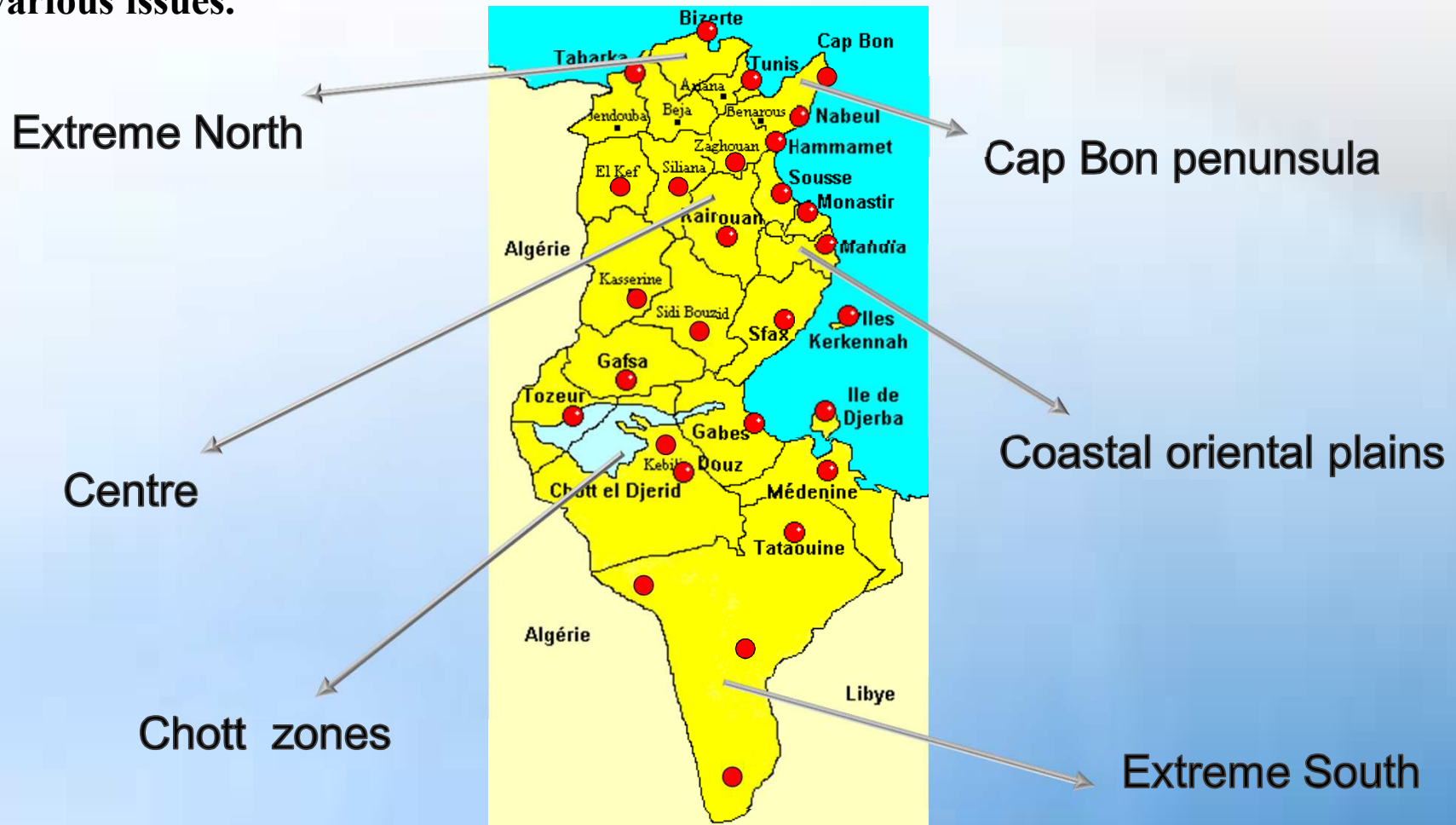


- Identification and delimitation of aquifer recharge zones and rates,
- Estimation of residence time and identification of fossil groundwater,
- Update of water budget
- Groundwater/surface water interaction in arid and semi-arid areas
- Impact of exploitation/overexploitation on regulated aquifers
- Impact of artificial recharge
- Aquifer disturbance (water availability and quality)
- Salinization processes
- Impact of non conventional water resources on aquifers
- Impact of highly anthropogenic pressures on catchment and related water systems (urbanisation, intensive agriculture,...)
- Climate change and its impact on water resources
-



Selected Outcomes of Nuclear Techniques Applications on WR in Tunisia

➔ Nuclear techniques have been applied on several basins all over the country and for various issues.





South Western Sahara Aquifer Systems



Use of isotopic methods in the assessment of non renewable transboundary groundwater resources.

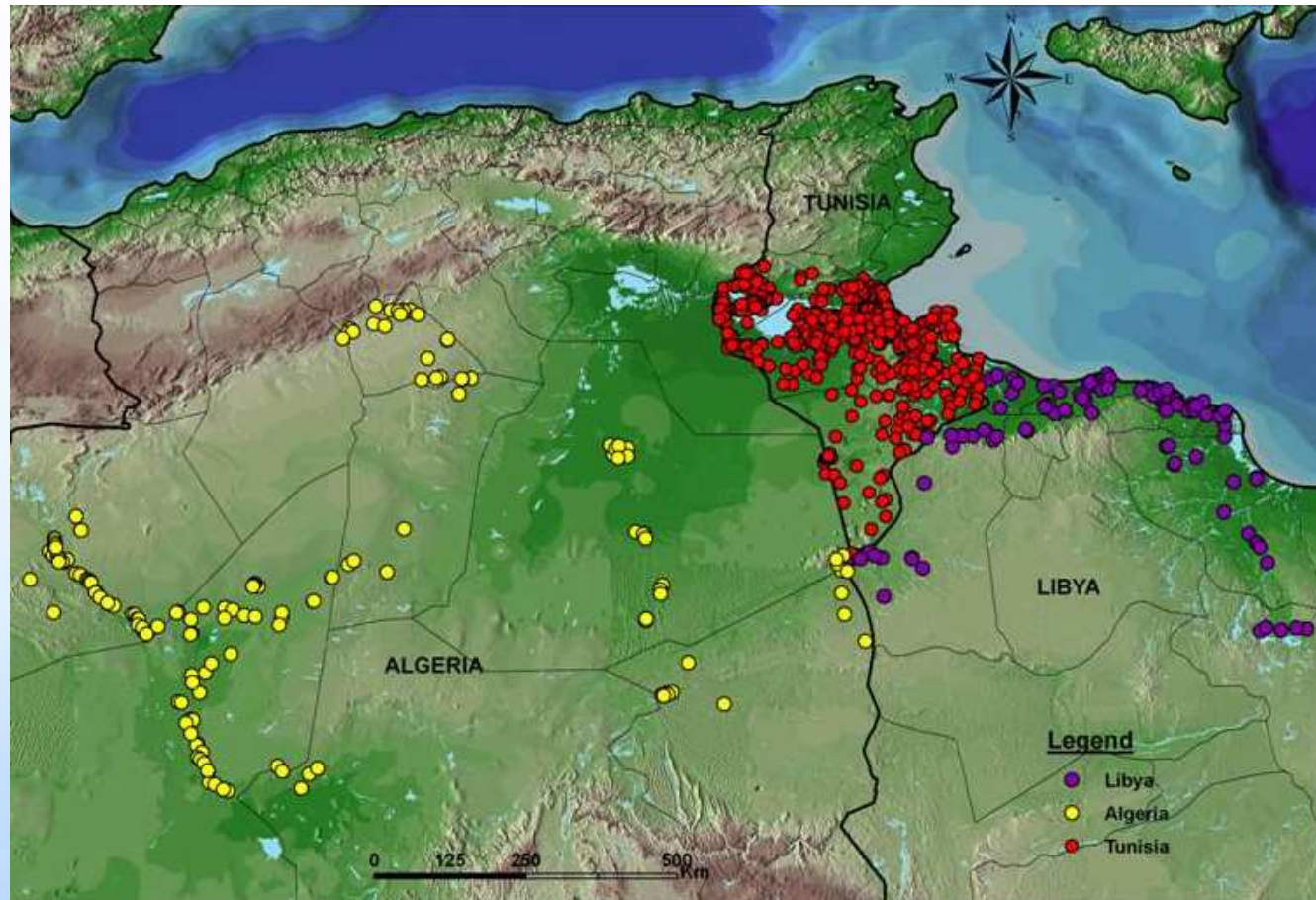


The NWSAS extends over much of Algeria (700.000 km²), Libya (250.000 km²) and Tunisia (80.000 km²) in an arid region with rainfall ranging from 20 to 150 mm/yr.

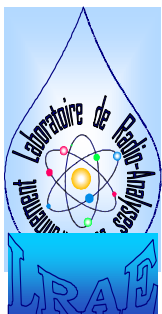
The CT and CI, as well as the Djeffara aquifer, represent the most important aquifers in Southern Tunisia. The increasing demand for domestic, touristic and agricultural led to the overexploitation of these aquifers.



Several national and international projects have been carried out to assess the NWSAS potential groundwater resources (UNESCO, 1972; PALYDHAF, 1990; CE Avicenne, 1996; RAF/ 8/035; OSS, 2003 & SASS, 2005; BESASS, 2011; TUN7001, 2011).



More than 1200 samples have been collected and analyzed for various isotopes.



Complexe Terminal Aquifer

Nuclear tools $^{18}\text{O}/^2\text{H}$; $^{14}\text{C}/^{13}\text{C}$; ^{36}Cl ,
 $^{234}\text{U}/^{238}\text{U}$

$^{18}\text{O}/^2\text{H}$

$^{14}\text{C}/^{13}\text{C}$

Dating
limit $\approx 50\text{ka}$

$^{36}\text{Cl}/\text{Cl}$

Dating limit $\approx 301\text{ka}$

$^{234}\text{U}/^{238}\text{U}$ Disequilibrium

Recharge processes

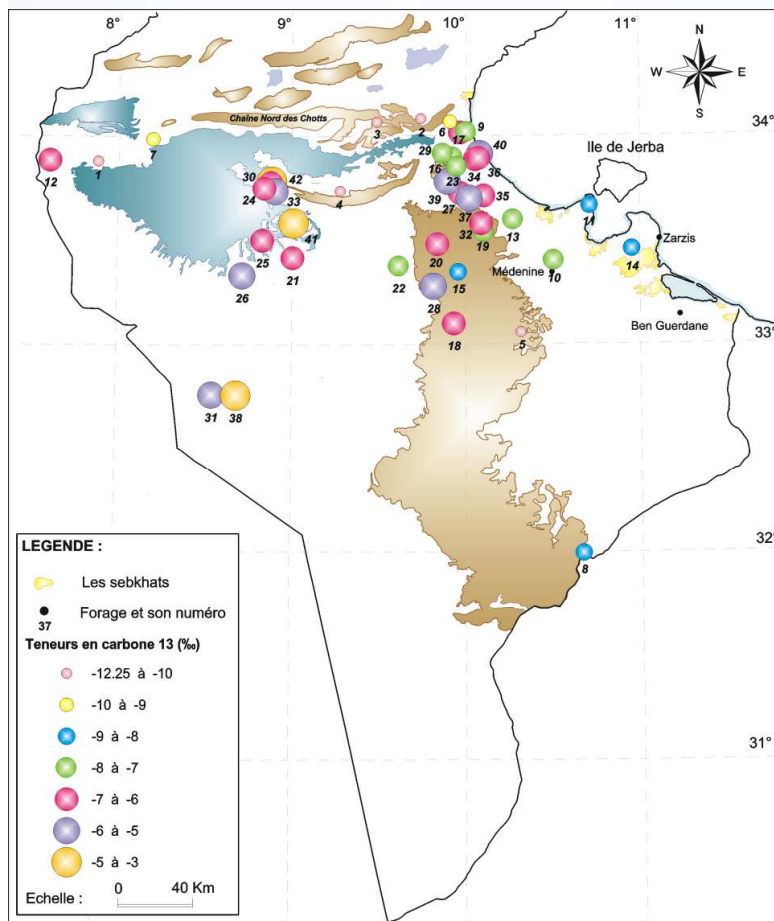
- ◆ Paleorecharge of the CT occurred during the Early to mid Holocene
- ◆ Evaporation effect and decline of water quality
- ◆ Recent Recharge at Dahar outcrops

Renewable processes

- ◆ Highest $^{36}\text{Cl}/\text{Cl}$ ratios ($\sim 100 \cdot 10^{-15}$) and ^{14}C confirm the recharge occurring through the Dahar mountains.
- ◆ Evaporation rate more than 50%
- ◆ Mixing between water masses

Mixing processes

- ◆ Water rock interaction process
- ◆ Mixing between aquifers



Carbon 13 over the CT



Continental Intercalaire Aquifer

Nuclear tools $^{18}\text{O}/^2\text{H}$; $^{14}\text{C}/^{13}\text{C}$; ^{36}Cl , ^{81}Kr ,
 $^{234}\text{U}/^{238}\text{U}$

$^{18}\text{O}/^2\text{H}$

$^{14}\text{C}/^{13}\text{C}$

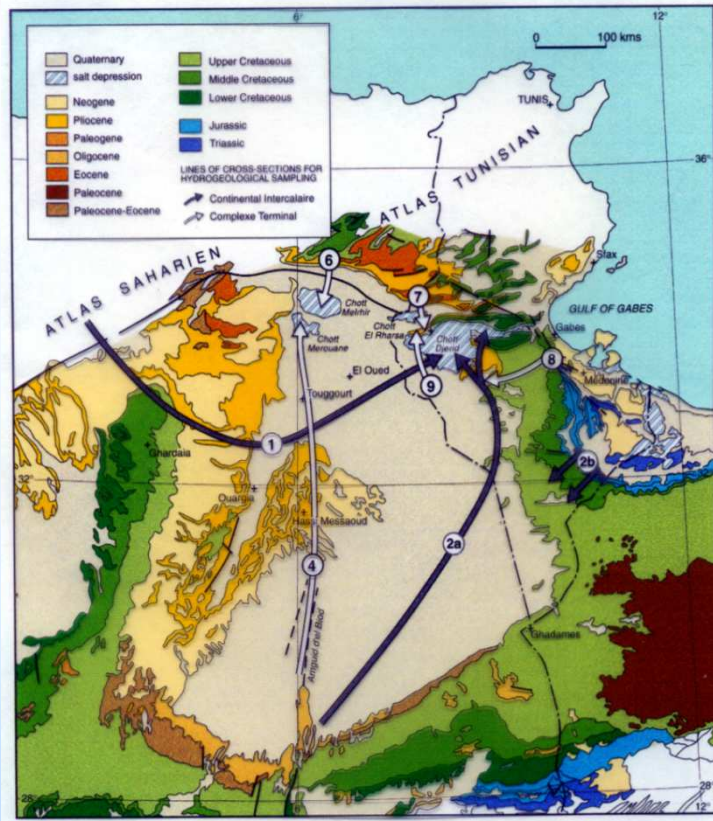
Dating
limit $\approx 50\text{ka}$

$^{36}\text{Cl}/\text{Cl}$

Modeling using ^{36}Cl isotope: Dating limit $\approx 301\text{ka}$

^{81}Kr isotope

$^{234}\text{U}/^{238}\text{U}$ Disequilibrium



Recharge processes

- ◆ **Fossil groundwater**
- ◆ Recharge periods: Holocene/ late Pleistocene.
- ◆ Recent Recharge at Dahar outcrops.

Renewable processes

- ◆ ^{14}C ages are $> 20\text{ky}$.
- ◆ Recharge rate $0,03 \text{ m}^3/\text{s}$.
- ◆ Highest $^{36}\text{Cl}/\text{Cl}$ ratios ($\sim 100 \cdot 10^{-15}$) confirm the recharge occurring through the Dahar mountains.

Dating groundwater

- ◆ $100\text{ky} < \text{MODFLOW age} < 300 \text{ ky}$
- ◆ $200\text{ky} < ^{36}\text{Cl} \text{ age} < 600 \text{ ky}$
- ◆ $150\text{ky} < ^{81}\text{Kr} \text{ age} < 630 \text{ ky}$



Djeffara Aquifer

- **Marine intrusion** in coastal aquifer due to intensive agriculture exploitation in southeastern Tunisia.

Nuclear Tools ^{18}O & ^2H ; ^3H ; ^{14}C & ^{13}C

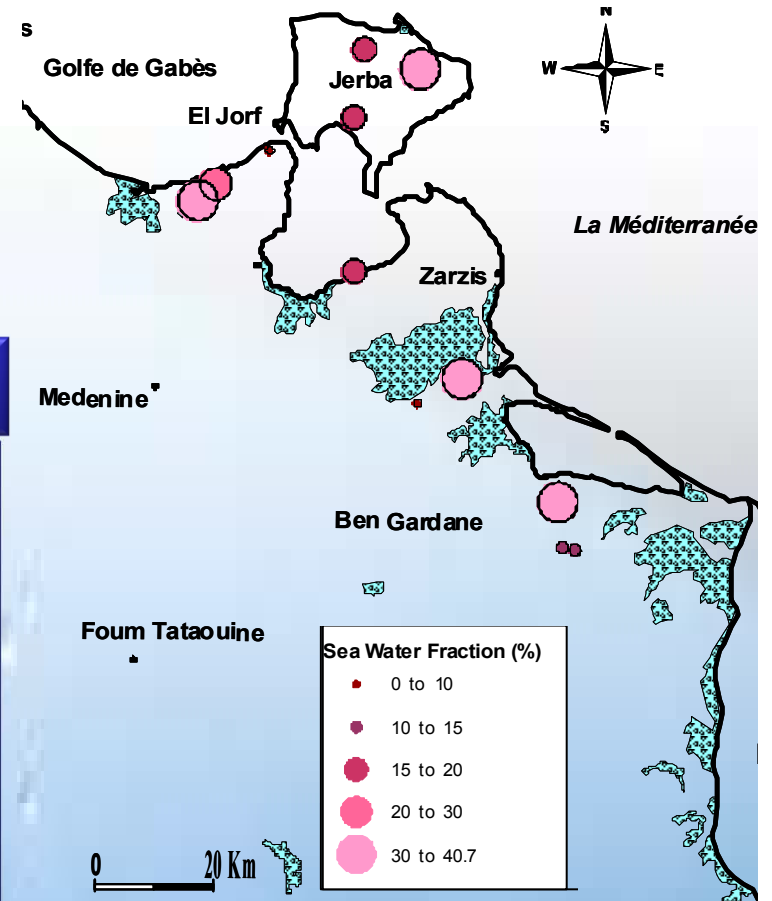
Quantification of seawater intrusion

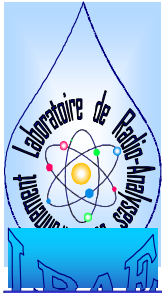
- ◆ Seawater intrusion rate vary from **0 to 41%**.
- ◆ The region of El Jorf is the mostly affected by seawater intrusion.

Assessment of recharge/Renewable rate

- ◆ $2 < ^{14}\text{C}$ activities < 40 pmc
- ◆ Recharge periods: Holocene/Late Pleistocene.

Seawater intrusion over the Djeffara





Djeffara Aquifer

Nuclear Tools ^{18}O & ^2H ; ^3H ; ^{14}C & ^{13}C

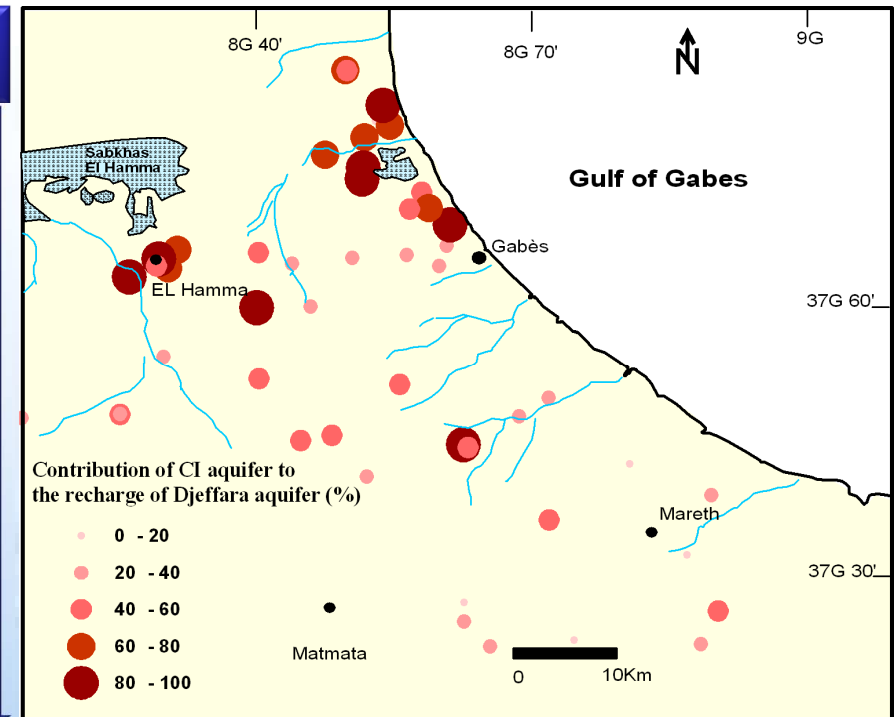
Quantification of flow exchange

- Computed values of the mixing proportion indicate that the vertical leakage of the CI aquifer is significant in **El Hamma region** and northern part of the basin where the contribution can reach 100%.

Assessment of recharge/Renewable rate

- ◆ Carbon 14 activities of the Djeffara of Gabes groundwaters are relatively low with an average about 12.6%.
- ◆ Lowest carbon 14 activities are observed near the El Hamma-Chenchou region and support the existence of a leakage from the CI through El Hamma faults.

Groundwater flow exchange between Continental Intercalaire and Djeffara Aquifer System





Main outcomes/Results



**Paleowater : Early to mid Holocene for CT and Holocene/
late Pleistocene for the CI**

Recent Recharge at Dahar outcrops for the CT and the CI

**Salinization due to overexploitation: Salt intrusion from
drainage water, from sebkha hypersaline water,
up leakage from underlying levels**

**Water/rock interaction processes enhance
mineralization/salinisation**

Decreasing water availability : spring disappearance,

Mixing between water masses



Central Tunisia Basins



- Convergence of three important wadis (Zeroud, Merguellil and Nebhana) and their affluent;
- Dense network of hydraulic devices ;
- Most of water systems are regulated;
- Most of groundwater systems are overexploited.





Main problems that WR are facing in Central Tunisia

- ➡ **Disturbance of natural water system processes**
- ➡ **Drastic decrease of water levels in aquifer system**
- ➡ **Salinization of aquifer systems disconnected from fresh surface water**
- ➡ **Artificial recharge planning and regulation**
- ➡ **Overexploitation for agriculture purposes**
- ➡ **Large evaporation losses and loss of storage by siltation**



Nuclear Tools ($\delta^{18}\text{O}$, $\delta^2\text{H}$, ^3H , ^{14}C) applications



- The occurrence of modern recharge is modest in shallow aquifers, but it is very limited in deep aquifers (paleoclimatic effect).



- The open surface water of most reservoirs has been reduced, heavily impacting the basin's economic activities.



- Disturbance in aquifers processes after the building of surface reservoirs and dams.



- Deterioration of groundwater quality due to the mixing with sabkhas salt water, return flow irrigation....



- The actual isotopic signature show that the effect of artificial recharge from the large dams and WSCS is very limited.



North Eastern Tunisia basins





Intensive land use + Demography + Tourism



Overexploitation and quality deterioration for most aquifer systems

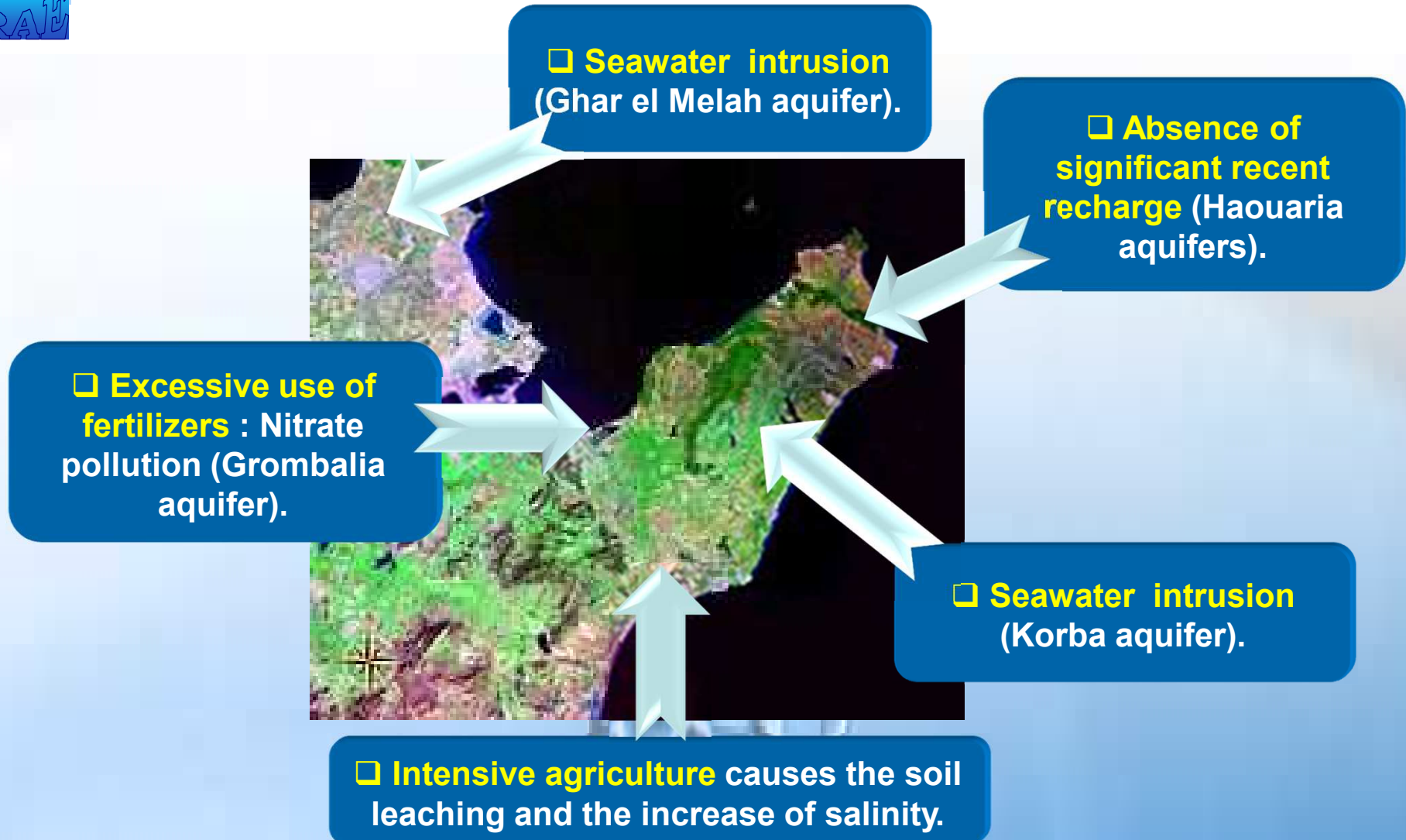
- **Generalized declines in water levels;**
- **Degradation of groundwater quality and soil properties;**
- **Excessive use of nitrogen fertilizers (nitrate pollution);**
- **Seawater intrusion.**



Refine knowledge of natural and anthropogenic processes that control groundwater quality using hydrogeological, geochemical and isotopic investigations



Nuclear tools ($\delta^{18}\text{O}$, $\delta^2\text{H}$, ^3H , ^{14}C , ^{15}N) applications





Nuclear tools: Nitrate isotopes



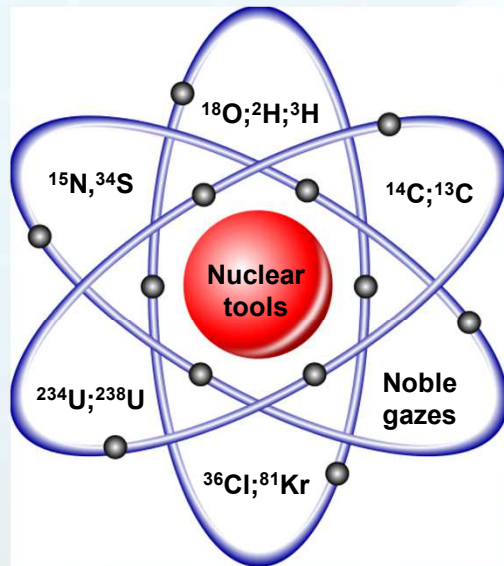
- **Nitrate** concentrations are **relatively high** in the Cap-Bon groundwater.
- $\delta^{15}\text{N}$ is a useful tool to identify the main **sources** and **processes** that control nitrate transport in groundwater, and to assess the impact of long-term irrigation practices on groundwater quality.
- High nitrate concentrations appear to be mainly related to **agricultural land-use** patterns, and suggests that the application of **nitrogen fertilisers** leads to increased nitrate leaching, in addition to **manure** and **organic matter** sources. The decline in N-NO_3 concentrations in some boreholes is related to the **denitrification** process.



The large scale use of N-fertilizers ($\text{Ca}(\text{NO}_3)_2$; $(\text{NH}_4)_2\text{SO}_4$; MgSO_4 -fertilizers) where flood irrigation is applied, is responsible of the high nitrate concentrations. This confirms the return flow process of irrigation water.

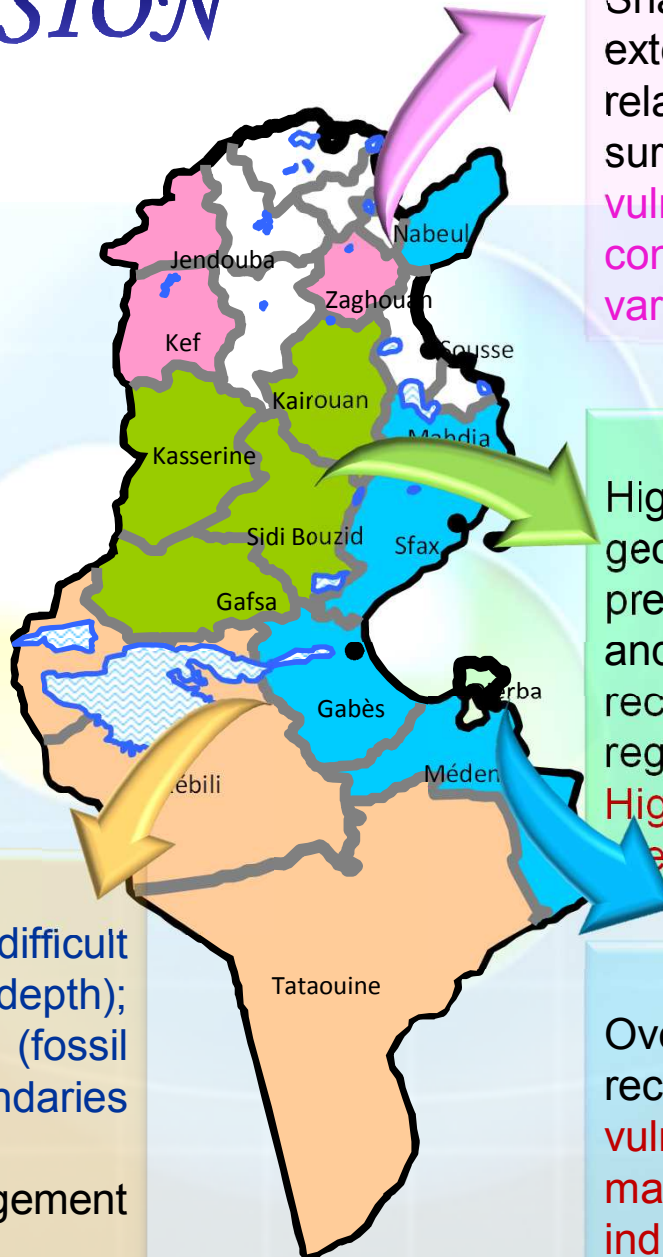


CONCLUSION



Southern Basins

Important reservoirs with difficult access (more than 1000 m depth); Very low renewal rates (fossil groundwater); Transboundaries resources
High vulnerability to management strategies.



Northern Basins

Shallow aquifers of limited extension with recent recharge related to precipitation and surface water network, **High vulnerability to human induced contamination and climate variability**.

Central Basins

High resources in complexe geological formation, high human pressure enhanced by drought and desertification, Limited recharge related to surface water regulation
High vulnerability to human pressure and climate change.

Coastal basins

Overexploited systems with recent recharge: **High vulnerability to over exploitation, marine intrusion and human induced contamination.**



Recommendations



The scientific outcomes of studies carried out on several basins all over Tunisia have highlighted important implications for groundwater management:

- ➡ **to enhance water and soil harvesting in order to increase artificial recharge efficiency (adequate location);**
- ➡ **to develop sustainable practices in agriculture sector (adequate crops, water saving techniques, limited fertilizers,);**
- ➡ **to reduce the risk of salt water intrusion by the regulation/interdiction of the pumping;**
- ➡ **to develop intergovernmental authority concertations/collaborations.**