Application of Isotope Hydrology in Groundwater Resources Management in Tunisia

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Situation
Most experts consider a 1000 m³ per capita per year is water shortage warning line.

Tunisia is 393 cubic meters in 2011 !!!

Tunisia is considered as a freshwater scarcity country
Tunisia is a country of physical water scarcity, which means water resources development is approaching sustainable limits.
The water basins in Tunisia are considered **Over Exploited**

<table>
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Sources:
a. Policies and Institutions for coping with environmental aspects of water scarcity in western Asia, by Hosni Khordagui Ph.D., Lebanon
# General Informations

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit</th>
<th>Value</th>
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<tr>
<td>Total area</td>
<td>Km²</td>
<td>164420</td>
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<tr>
<td>Population</td>
<td>Hab</td>
<td>10,7 $10^6$</td>
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<tr>
<td>Average density</td>
<td>Hab/km²</td>
<td>65</td>
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<td>Maximum altitude</td>
<td>M</td>
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<tr>
<td>Average Altitude</td>
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<tr>
<td>Principal lake area (Ichkeul)</td>
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<td>Average Rainfall</td>
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<td>Temperature of December</td>
<td>Celsius</td>
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<td>Temperature of July</td>
<td>Celsius</td>
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Pluvial water resources 36 Billions $^3$m 225 mm/y
Topography
Water resources $4850$ Mm$^3$

Surface water: $2700$ Mm$^3$ which $2170$ Mm$^3$ can be mobilized

Groundwater resources $2125$ Mm$^3$

$745$ Mm$^3$ shallow aquifers
$1380$ Mm$^3$ confined aquifers
$650$ Mm$^3$ are non renewable
Water resources mobilization and transfer
COMBINED USE OF ISOTOPES AND CHEMISTRY

**Piezometric Salinity**
- Ratios
- Nitrates maps

**Na/Cl**
- Br/Cl Ratios

**Isotopes**
- $^{18}$O, $^2$H

**Radioactive Isotopes**
- $^3$H, $^{14}$C

**Time series PL +TDS**

**$^{18}$O/Cl Ratio**

**Groundwater recharge and origin**
- Interconnexion between Aquifers

**Localisation of vulnerable zones to the**
- overexploitation, to salinisation and pollution

**Seawater fresh water mixing**
- Origin and mechanism of salinisation

**Localisation vulnerable zones to SW intrusion**

**Preferential zones of recharge and SW intrusion**

**Groundwater Age**
- Dating, Infiltration velocity

**Estimation of seawater fraction**

**Estimation of renewal and recharge rate**
Stable Isotopes In Hydrology

take advantage of natural variations of isotopes in water to study hydrological systems

- Isotope fractionation

Natural Water Cycle

13
IAEA-WMO Global Network for Isotopes in Precipitation (GNIP)
Stables isotopes ($^{18}$O, $^2$H)

Plot of $^{18}$O-$^2$H in the Eastern Coast aquifer

- **P.Q Shallow aquifer:**
  - 1st group: Contribution of rain recent recharge
  - 2nd group: influence of SW intrusion and evaporation

- **M & O deep aquifers:**
  - Isotopic fingerprint Caracteristic of old water

Mixing line with sea water
Evaporation line
Recent water
Old water
Tritium $^3$H indicator of recent recharge

Undergo a Radioactive decay

1 TU = 0.118 Bq/l
Tritium distribution map

PQ (CO), Q (H):
High $^3$H content
recent water + Post nuclear water

Low content:
Up flow

High content $^3$H near the rivers

Recharge from rain water

Low content in $^3$H
Deep aquifer

Fingerprint of Old water
$^{14}\text{C}$ Groundwater Dating
Flow velocity = 2.2 m/a

unconfined (phreatic) conditions
confined (artesian) conditions

After Vogel et al. (1982)
Distribution map of $^{14}$C in the Eastern cost aquifer

- $^{14}$C dating ages confirm hydrogeologic information
- High activities in $^{14}$C PQ aquifer
  - Near the rivers
  - confirmation stable isotopes results
  - High recent recharge
- Low activities Miocene et Oligocene:
  - Old water fingerprint
- Flow velocity: 0.3 to 2 m/year
Distribution map of $^{14}$C in El Haouaria aquifer

Shallow aquifer:
- recent water (High $^{14}$C activities)

Pliocene confined aquifer:
- Corrected Ages from 100 to 16000 years according to the depth and underground route

Low water velocity 0.2 to 2.5 m/year
Pizometric data with \((^{18}\text{O} + ^{2}\text{H})\), \(^{3}\text{H}\), \(^{14}\text{C}\)

**R : Recharge**

- \(\text{PL} > 0\); rise in PL (time series)
- \((^{18}\text{O} + ^{2}\text{H})\) close to WA isotope composition TC
- \(^{3}\text{H}\):
- \(^{14}\text{C}\):

**E : Overexploitation :**

- \(\text{PL} < 0\); Continuous decrease (time series)

**CO:** The inertia zone is located in the south of O. Boulidine (interconnexion between aquifers).

Map of localisation de recharge and overexploitation zones
H: the inertia zone is very limited due to the small surface and the thickness of the aquifer.

Map of localisation de recharge and overexploitation zones
Conclusion for these 2 aquifers in term of Groundwater recharge Management

Monitoring Pizometry Hydrogeologic informations

stable Isotopes \(^{18}\text{O} , ^2\text{H}\)

Tritium \(^{3}\text{H}\)

\(^{14}\text{C}\) GW Dating

PQ, Q: High Act.

O, M, P: Low Act

PQ, Q: Aquifers recharged
Rain water

\cdot Post Nuclear
\cdot Last decades
\cdot Up flow

\begin{itemize}
  \item Ages 0 to 16000 years
  \item \(Tr = 0.3\%\)
  \item Recharge 12 mm/an
\end{itemize}

Fast Infiltration
Seawater Intrusion

\begin{itemize}
  \item in the preferential zones of recharge authorize exploitation
  \item Zones of overexploitation Establish a save and forbidden areas
\end{itemize}
In Tunisia we have
Forbidden & Save areas: 32
Save : 23 (green)
Forbidden: 9 (red)
Use of geochemical and isotope tracers for the characterization of water leakage at the Joumine dam, Tunisia

Upstream watershed: 418 km²
Capacity: 130.10⁶ m³

After its construction
Leakage of 500 l/s
observed: D1 and D2

2000 tons of mining residues in the sinkhole

Leak: 500 l/s to 120 l/s
reduction of 75% of leakage
Evolution of salinity and water level in reservoir from 1985 to 2011

Decrease of the flow rate was accompanied by an increase of the Salinity in D2

Which was interpreted as a risk of stability of the dam
The two pillars integrated Cretaceous limestone, based on Triassic formations.
Determination of origin and paths of leaks
Quantify leakage
Corrective action to minimize losses
Reduce the risk of security and stability of dam

Water level, Temperature and EC at boreholes
Water samples geochemical and isotopes

Determination of origin and paths of leaks
Quantify leakage
Corrective action to minimize losses
Reduce the risk of security and stability of dam
Upstream

downstream
Valuable information on the local groundwater flow and hydraulic connections in the dam and in the surrounding areas.

The leakage emerging in D1 and D2 is related to infiltration occurring near the uptake tower where the sinkhole was found.

The arrows show the preferential pathway of water escaping from Reservoir 31.
Similar EC in R & D1

D2: EC 2.34 mS/cm

It was not clear high salinity

Dissolution of material used for the dam construction

Consequence of GW discharging from the underling Triassic formations

The 2\textsuperscript{nd} hypothesis was the valid one

Distribution of EC values at the Joumine dam expressed in mS/cm at 25 °C
The samples which are located on the paths of leaks have a temperature close to the Temp °C best traceur for leaks.

Temp R = 14.5 °C

Distribution of temperature in °C values at the Joumine dam.
Breakthrough curves obtained in drain D1 and D2

\[ A = \int C(t) \cdot dt \]

\[ Q = \frac{V}{\int C(t) \cdot dt} \quad \text{were} \quad Q = \frac{A}{\int C(t) \cdot dt} \]

Where \( A \) indicate the surface of the curve,
\( Q \) represent the flow rate
\( C \): concentration
\( T \): time

\[ Q_{D1} = 57.88 \, l/s \quad \text{et} \quad Q_{D2} = 44.28 \, l/s \]
Various chemical water types

The reservoir & D1 same facies

Water is unsaturated Vs. gypsum and anydrite

Progressive Saturation Vs increase in $SO_4$
Correlation ($^2$H, $^{18}$O) in Joumine dam

1st group:
-4,4 < $^{18}$O < -3,7

Proximity to the reservoir: same origin: water leakage

2nd group:
-5,6 < $^{18}$O < -4,9

Water depleted: Local groundwater

confirming the above fact that the reservoir water is the main source of water leakage
Map of distribution of Tritium in Joumine dam (2013)

Determine the pathways of water leaks and estimate any recent recharge to the aquifer from the reservoir.

1st group
1,2 UT < Tritium < 5UT
Recent water coming from reservoir.

2nd group:
1,2 UT < Tritium
Old water mixing with water coming deep aquifer.
Determination of suspended elements in Medjerda river by using nuclear probe

Watershed of Medjerda river, NW Tunisia

- 20 to 25 Mm$^3$ sediments / year
- Loss of 0.5% of storage capacity
- Clogging of hydraulic infrastructure
- Sedimentation of wadi’s beds
Implementation of the radioactive source and the NaI detector in the probe

\[
\frac{I}{I_0} = \exp\left(-\rho_m \times [\mu_s C + \mu_w (1-C)]\right)
\]

- \(I\): intensity of radiation through a thickness of water with a concentration \(C\).
- \(I_0\): intensity of the emitted radiation.
- \(\mu_s\): sediment mass attenuation coefficient
- \(\mu_w\): Water mass attenuation coefficient
- \(\rho_m\): density of the water-sediment mixture

\[
\rho_m = \frac{\rho_s \rho_w}{\rho_s - C(\rho_s - \rho_w)}
\]

- \(\rho_s\): density of sediments
- \(\rho_w\): density of water
Determination of level of water in river

\[ H(m) = \frac{mA - 4}{1.49} \]

Level of water in river depending on the pressure

\[ y = 0.1517x^{1.849} \]
\[ R^2 = 0.99 \]

Determination of flow rate in river

Gauging Curve at Slouguia station
Determination of the concentration of suspended elements

\[ y = -3919x + 24383 \]
\[ R^2 = 0.99 \]

Nal detector converts into electrical impulses recorded radioactivity in CPM

\[ C(g/l) = \frac{24383 - CPM}{3919} \]

Counting & concentration of SE Relationship
Determination of solid flow $G_s$ of suspended elements Crossing the section of the river

$$G_s (Kg / s) = Q \times C$$

with $Q$: flow rate ($m^3 s^{-1}$)

$C$: concentration of suspended elements ($kg m^{-3}$)
Example of hydrological parameters over 2005 at Slouguia Station

Big fluctuation of the sediment concentration

Concentrations vary from 0.1 to 6 g/l

The amount of sediment during this period was estimated at 780,000 T.
Profile across the wadi Medjerda at Slouguia station

Continuous sedimentation of Medjerda since entry into service of the Sidi Salem dam
• **Activities with IAEA:**

  • RAF/0/038: *Promoting Technical Cooperation Among Developing Countries (TCDC) in Africa through Triangular Partnerships*: Use of geochemical and isotope techniques to improve water resources management of coastal aquifers in Senegal and Tunisia. (2014-2015)


  • IAEA Project Counterpart TUN/8/017


  • *Course Director of IAEA training in Isotope Hydrology with particular emphasis on Dam Safety, 22-26 April 2002, Tunisia


  • *Participation in the TC project TUN/5/017: Nuclear Techniques to improve Water and Soil Management of Kairouan plain.
Visit of IAEA Director General Yukiya Amano

to the Isotope Hydrology Laboratory

CNSTN, Tunisia, 25 June 2012.
Isotope Ratio Mass spectrometry Lab
Carbon 14 for Groundwater Dating Lab
GEOCHEMISTRY LABORATORY
ATLAS - Presents summary information of about 10,500 water samples - 26 countries and 79 IAEA projects.
Thank you!