Monitoring and management of coastal karstic aquifers

Polemio M.

CNR - IRPI, Bari
Our general purpose

• To study complex phenomena on risks for groundwater resources of quality and quantity degradation offering:
  – Synthetic view on ongoing trends
  – As simple as possible tools to quantify degradation effects
  – Solutions to improve the groundwater quality and promoting durable sustainability of groundwater resource utilisation
Quantity and quality degradation of Groundwater Resources (GR)

GR OVEREXPLOTATION

SHORTAGE OF WATER RESOURCES
• DROUGHT AND CLIMATE CHANGE
• INCREASING WATER DEMAND

AQUIFER VULNERABILITY AND WIDESPREAD POLLUTION

SALT POLLUTION BY SEAWATER INTRUSION (SAPSI)

QUALITY DEGRADATION


Bari, 25/10/2016
Main Mediterranean coastal groundwater affected by quality degradation due to seawater intrusion and/or anthropogenic contamination


M. Polemio, Gruppo di Idrogeologia, http://hydrogeology.ba.cnr.it

Bari, 25/10/2016
A simple coastal aquifer


M. Polemio, Gruppo di Idrogeologia, http://hydrogeology.ba.cnr.it

Bari, 25/10/2016
Downward trend of Pleistocene sea-level sequence

Frenzel, 1973
Coastline during previous glacial maximum (22 ka BP)

On the basis of Italian geomorphological map (Climex maps, Vai & Cantelli, 2004), it can be seen the sea level was -149 m during last glacial maximum (LGM, about 22 thousands year before present). The mean temperature was about 4÷5 °C lower than today.
Relationship freshwater – saltwater: the effect of variable recharge or fresh groundwater flow (confined aquifer)

A) The freshwater flow is enough to allow the sea discharge. A saline wedge is observed below fresh groundwater.

B) The freshwater potential is very high and the saltwater wedge does not exists.

C) The freshwater pressure is low and not enough to be discharged to the sea (again the saltwater wedge does not exists).
Schematic Italian hydrogeological map and coastal karstic aquifers

- Lakes
- Recent sedimentary successions - stratified aquifers of coastal/alluvial plains
- Aquifers in volcanic or pyroclastic successions
- Terrigenous Cenozoic successions - Mainly low permeability
- Carbonate aquifers – mainly karstic aquifers
- Crystalline or metamorphic successions – low permeability and shallow aquifers

More coastal karstic aquifers (Sardinia, Sicily, Friuli and Apulia): the largest one’s are in Apulia
The schematic hydrogeological map and section

Gargano
Tavoliere
Murgia
Salento

Maggiore e Pagliarulo, 2002

Pleistocene medio - Olocene superiore
Plio - Pleistocene
Miocene
Mesozoico

Fresh water
Saltwater

>500 m
400 km

M. Polemio, Gruppo di Idrogeologia, http://hydrogeology.ba.cnr.it
Bari, 25/10/2016
Polemio, M., Degradation risk owing to contamination and overdraft for Apulian groundwater resources (southern Italy), in Proceedings Water resources management in a vulnerable environment for sustainable development, Perugia, November 1998 2000, Grifo Publishers, Perugia, p. 185-194
General purpose

Reducing the risk of **Groundwater quality Degradation** due to the **Seawater Intrusion (GDSI)** with

- the management of the resource and the control of GDSI effects using tools as simple as possible to be utilized by each kind of public institutions
  - spatial and multi-temporal analyses of usual chemical and physical data (threshold approach)
  - Definition of management criteria
Pallucchini summarised the Italian situation during thirties.

About Apulia:
- 87 monitoring wells (unused wells) of shallow (nowadays secondary) aquifers (Tavoliere and Salento)
- very few deep or bored wells, all in the porous Tavoliere aquifer

The level of Apulian karstic groundwater utilisation was null inland and almost low near the coast, due to low depth to water, until the end of the Second World War.

A continuous increasing trend of groundwater discharge started about from the second half of fifties; this trend is still observed.
Apulia groundwater utilisation and regulation

- From fifties groundwater discharge is increasing as an effect of social and economical improvements, population increase and availability of new boring technologies to realize very deep wells.
- The current number of wells is not well known due to high percentage of abusive wells; in any case, the number should be measured as many tens of thousands.
Apulia groundwater utilisation and regulation

Water Protection Plan I (WPP-I or PRA, 1984)

- The groundwater discharge in Apulia (and roughly in Italy) was regulated by law only from an administrative point of view until 1984.

- The effects of seawater intrusion and the application of hydrogeological management criteria were completely neglected until 1984.

- In the 1984, Apulia Regional authorities defined by law the Water Protection Plan, called PRA
  - determining the quality zonation of Apulian groundwater and the regulation of groundwater and aquifer utilisations as a qualitative function of the risk of groundwater degradation.


M. Polemio, Gruppo di Idrogeologia, http://hydrogeology.ba.cnr.it
Apulia groundwater utilisation and regulation

Water Protection Plan II (WPP-II or PTA, 2009)

1) low quality groundwater by salt degradation (new fresh discharge permission not provided, NOD zone)

2) qualitative and quantitative protection zone (QQP zone, regulated new discharge)

3) quantitative protection zone (QP zone, new discharge permission suspended)

Authorization extension (existing well):
- well bottom (-m asl) less than 20-30 piez. head (m asl)
- drawdown (m) of max discharge yield less than 30-50% piez. head (m asl)

New wells are possible if:
- If unconfined, well bottom (-m asl) less than 20-25 piez. head (m asl)
- drawdown (m) of max discharge yield less than 30-60% piez. head (m asl), TDS<1 g/l, CC<500 mg/l

M. Polemio, Gruppo di Idrogeologia, http://hydrogeology.ba.cnr.it

Bari, 25/10/2016
Surface watered with groundwater in Apulia region

- BARI: 89% in 1971, 92% in 1982, 82% in 1990, 89% in 2000
- BRINDISI: 125% in 1971, 22% in 1982, 18% in 1990, 18% in 2000
- FOGGIA: 23% in 1971, 18% in 1982, 23% in 1990, 18% in 2000
- LECCE: 46% in 1971, 70% in 1982, 46% in 1990, 46% in 2000
- TARANTO: 10% in 1971, 4% in 1982, 4% in 1990, 4% in 2000
Apulian annual net rainfall and trend
Standardized 5-year moving average [(yr-Mean)/St.Dev]

- The annual net rainfall ranged from 52 to 675 mm
- Negative net rainfall trend
  - ranging from -3.52 to -0.23 mm/yr,
- In the whole period decrease from 22 to 42% of the mean net rainfall
  - percentage range much higher than similar actual rainfall percentage range

Monitoring network

- hundreds of wells and secondly springs were considered
- Study period from 1929 to 2008
- Monthly data if available
- Variables used:
  - salinity (TDS), Chloride ion Concentration (CC), Rainfall (R) and atmospheric Temperature (T), chemical data (CD), piezometric head (H), spring yield (Q)
- “Time series” approach to low density and high frequency data
- Spatial and multi-temporal geostatistical approach to low frequency and high density data
Wells and Time Series used for the Apulian piezometric trend analysis (1924-2003)


MURGIA AND SALENTO: WN 27 (BRINDISI)
MONTHLY RAINFALL, PIEZOMETRIC HEIGHT AND TREND

### Piezometric trend analysis summary

<table>
<thead>
<tr>
<th>HS</th>
<th>DATA</th>
<th>AC(m/month) Minimum</th>
<th>More probable spatial trend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>From</td>
<td>to</td>
<td></td>
</tr>
<tr>
<td>GARGANO</td>
<td>1975</td>
<td>1978</td>
<td>-0.034</td>
</tr>
<tr>
<td>TAVOLIERE</td>
<td>1929</td>
<td>2008</td>
<td>-0.060</td>
</tr>
<tr>
<td>MURGIA</td>
<td>1965</td>
<td>2008</td>
<td>-0.240</td>
</tr>
<tr>
<td>SALENTO</td>
<td>1965</td>
<td>2008</td>
<td>-0.120</td>
</tr>
</tbody>
</table>

Annual mean of chloride monthly data and trend well 264 - Salento

Statistics and chloride concentration trend (Annual average of monthly data, mg/l)

<table>
<thead>
<tr>
<th>HS</th>
<th>Murgia</th>
<th>Salento</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well</td>
<td>302</td>
<td>303</td>
</tr>
<tr>
<td>Min</td>
<td>25.7</td>
<td>28.2</td>
</tr>
<tr>
<td>Mean</td>
<td>35.6</td>
<td>63.0</td>
</tr>
<tr>
<td>Max</td>
<td>40.4</td>
<td>80.9</td>
</tr>
<tr>
<td>EY</td>
<td>1998</td>
<td>2000</td>
</tr>
<tr>
<td>G</td>
<td>-0.08</td>
<td>-0.16</td>
</tr>
</tbody>
</table>

BY) Beginning Year of observations  
AF) End Year of observations  
G) Gradient, linear trend (mg/l yr), green for negative value

The basic or threshold criterion


- Need of a simple criterion, like as “absence-presence” of the salt groundwater degradation, or threshold approach
- On the basis of the of complete chemical analyses of more than 500 groundwater samples, the simplest grouping differentiated 2 groups:
  - absence or pure fresh groundwater, group F, “fresh”, including water types Ca-HCO3, Ca-Mg-HCO3 and Mg-Ca-HCO3, TDS mean, standard deviation and 75th percentiles equal to, respectively, 0.41, 0.13, and 0.47 g/L. 75% percentile or the mean value plus a standard deviation= TDS≤0.5 g/L,
  - presence or remaining water types, (group S, “saline”), fresh groundwater mixed with variable percentages of seawater= TDS>0.5 g/L

1) Fresh groundwater and variable % of seawater (group S);
2) Pure fresh groundwater (Group F); 3) sea water.
Spatial and multi-temporal approach: protected, vulnerable and hit areas to/from GDSI

To characterise the spatial trend of salt pollution due to seawater intrusion it can be useful to define the **Reference Salt Contour Line (RSCL)** simply considering the threshold between pure fresh groundwater and that contaminated by seawater intrusion, about equal to 0.5 g/L, to use with each available data and wells (also in the past)....

Spatial modification of RSCL (0.5 g/l)  
1989 referred to 1981

1) 1989 RSCL from 1981 to 1989
2) RSCL moves landward
3) RSCL moves seaward

Considering some years and periods from 1981 to 2003

Spatial modification of RSCL (0.5 g/l) 1997 referred to 1989

From 1989 to 1997

1) 1997 RSCL
2) RSCL moves landward
3) RSCL moves seaward

Spatial modification of RSCL (0.5 g/l)
2003 referred to 1997

From 1997 to 2003

1) 2003 RSCL
2) RSCL moves landward
3) RSCL moves seaward

GDSI spatial trend: Spatial multi-temporal modification of RSCL (0.5 g/l, 1981-2003)

In the whole period

1) TDS always >0.5 g/l

2) TDS always <0.5 g/l
Numerical model approach

- to show the capability of large-scale numerical model in the management of groundwater developing forecast scenarios to evaluate the impact of climate change on groundwater resources.

Qualitative and quantitative groundwater changes from 1930 to 2060 were modelled based on the effects of climate change, sea level rise and changes in sea salinity.
• The highest risks due to seawater effects are observed in Salento
• The boundary was defined using the coastline and the potenziometric surface
3D modelling of hydrogeological complexes

Conceptual model

Climate and net rainfall (steady period, 1925-1975)

- Study areas 2300 km², from 0 to 214 m asl
- Coastal length 175 km
- 16 climatic gauges
- GIS: 150-meter cells were used
- Altitude (DEM) and distance from the Adriatic Sea were considered

**Annual values**

- Temperature: from 15.5 to 17.5 C° (mean: 16.6 C°)
- Rainfall: from 544 to 946 mm (mean: 727 mm)
- Real evapotranspiration: from 476 to 601 mm (mean: 553 mm)
- Net rainfall: from 68 to 343 mm (mean: 173 mm)

Mean annual recharge equal to 150 mm (10.6 m³/s)
Piezometric results

First scenario
- steady drinking discharge
- increasing irrigation discharge

Second hypothesis
Steady irrigation discharge

Seawater Intrusion Simulation 2040-2060 (mg/l)

Salinity maps (mg/l) from -65 to -50 m asl (II hypothesis)

Steady state 1989 1999 2019

2040 2060

Salinity variations 2060-steady state
Main conclusions

- Both future scenarios are unsustainable
- Well design should be improved
  - Overlapping well effects should be considered
- The drinking use should be better designed
  - distributed on larger areas
  - as much as possible, reduced
- Adaptation measures are necessary, focusing on agricultural uses
- The artificial recharge should be pursued
- The use of brackish spring water should be pursued
- More efforts should be realised to test and optimise management proposals to be adopted by public authorities
For more details, all useful papers can be downloaded from the website of the Hydrogeology Research Group [http://hydrogeology.ba.irpi.cnr.it/](http://hydrogeology.ba.irpi.cnr.it/)

Thank you for the attention!