Groundwater Management in the MENA Region: Challenges and Opportunities for the Future

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Overview

Part A:
- Fresh, brackish, saline and brine/hyper-saline groundwater
- Requirements for “marginal” groundwater use

Part B:
- SubSol - Coastal SUBsurface water SOLutions
- Preventing / remediating saline water intrusions through MAR

Conclusions & Recommendations
Groundwater Resources / Arab League

**WHYMAP** – **W**orld-wide **HY**drogeological **MAP**ping and **A**ssessment **P**rogramme (BGR/UNESCO, 2008)

[Website URL: www.whymap.org]
Saline Groundwater / Global

Global Overview of Saline Groundwater Occurrence and Genesis (draft, IGRAC, 2009)

Saline and brackish groundwater by genesis
Occurrences at shallow and intermediate depths (less than approximately 500 m)

- Marine origin
- Transgression
- Flooding
- Lateral seawater intrusion & up-welling
- Combination of carbonate, transgression and recent flooding
- Natural terrestrial origin
- Evaporation
- Dissolution
- Igneous activity hydrothermal mineral water
- Combination of evaporation & dissolution
- Irrigation
- Pollution
- Unspecified origin
Fresh, Brackish, Saline and Brine/Hyper-Saline Groundwater

- **Classification (after Freeze & Cherry, 1979)**
  
<table>
<thead>
<tr>
<th>Class name</th>
<th>Class limits (TDS range, in mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh water</td>
<td>0 - 1,000</td>
</tr>
<tr>
<td>Brackish water</td>
<td>1,000 - 10,000</td>
</tr>
<tr>
<td>Saline water</td>
<td>10,000 - 100,000</td>
</tr>
<tr>
<td>Brine</td>
<td>&gt; 100,000</td>
</tr>
</tbody>
</table>

- **National Brackish Groundwater Assessment (USGS, 1965/2013)**

WSTA 12th Gulf Water Conference
Bahrain, 28-30 Mar 2017
Groundwater Salinity in Western Asia

http://waterinventory.org

WSTA 12th Gulf Water Conference
Bahrain, 28-30 Mar 2017
Socio-Economic Cost-Benefit Analysis

- **Cost:**
  Sum of transport and production cost

  **Option 1:**
  *Seawater (≥ 35 g/l)* desalination transported from nearest sea coast inland and up to elevation
  - Higher costs for location of desal plant, due to competing land use in coastal areas

  **Option 2:**
  *Local brackish water (1-10 g/l)* desalination transported from source up to elevation
Socio-Economic Cost-Benefit Analysis

2.5 kWh/m³, State Water Project, CA

0.35 kWh/m³, GWRIS, Orange County, CA

0.53 kWh/m³, Desalination Ashkelon, Israel

UNESCO (2014)
Socio-Economic Cost-Benefit Analysis

Salinity (g/l) of Seawater in Red Sea and Gulf

WSTA 12th Gulf Water Conference
Bahrain, 28-30 Mar 2017
SubSol –

Coastal SUBsurface Water SOLutions

- Sophisticated MAR applications
- Improve water management in coastal areas
- Developed in the Netherlands
- Operational on pilot or full-scale
- Subject of further study in the EU financed project SubSol

- Managed Aquifer Recharge (MAR):
  The *purposeful* recharge of water to *suitable* aquifers under *controlled* conditions for *subsequent* recovery or *environmental* benefit

WSTA 12th Gulf Water Conference
Bahrain, 28-30 Mar 2017
Managed Aquifer Recharge – Global MAR Inventory

- [Link](https://www.un-igrac.org/special-project/global-mar-inventory)

WSA 12th Gulf Water Conference
Bahrain, 28-30 Mar 2017
Saline Groundwater in Coastal Settings

- Urbanization & industrialization - Increasing water demand
- Seawater intrusion into aquifers - Water unsuitable

Example:
Marine saltwater intrusion due to overpumping
Post (2016)
Saline Groundwater in Coastal Settings

- Understanding Freshwater Lenses,
  Freshwater Injections
  ASR Sand Tank Experiments

- **FLIN** – Freshwater Lens INvestigations:
  [www.bgr.bund.de/EN/Themen/Wasser/Projekte/laufend/F+E/Flin/flin_projektbeschr_en.html](http://www.bgr.bund.de/EN/Themen/Wasser/Projekte/laufend/F+E/Flin/flin_projektbeschr_en.html)
Seawater Intrusion in Coastal Areas

Overexploitation of freshwater lenses

Low efficiency of conventional ASR systems

Upcoming of brackish/saline water

Freshwater supply under pressure

Modified after KWR (2015)
SubSol Project

**Freshmaker**
Management of freshwater lenses

**ASR Coastal**
ASR with partially penetrating wells

**Freshkeeper**
Well configurations to prevent upconing

Implementing subsurface solutions

Modified after KWR (2015)
SWS in Different Coastal Settings

ASR Coastal
Modern coastal cities

Freshkeeper
Local shallow or deeper aquifers

Freshmaker
Artificial islands

Modified after KWR (2015)
Freshmaker - Concept

2 horizontal directional drilled wells (HDDW) – shallow and deep

**Injection phase**
Freshwater injection in shallow HDDW1
Saltwater abstraction in deep HDDW2

**Abstraction phase**
Freshwater abstraction in shallow HDDW1
Saltwater abstraction in deep HDDW2

→ Increase thickness of the freshwater lense; prevent upconing during abstraction
ASR Coastal - Concept

Infiltration, storage and recovery of freshwater using multiple partially penetrating wells (MPPW) to deal with *buoyancy effects*

**Injection phase**
Freshwater injection in deeper wells

**Abstraction phase**
**Option 1:** Freshwater abstraction in shallow wells
**Option 2:** Additional brackish water abstraction in deeper wells; RO treatment
Freshkeeper - Concept

1. The freshwater wells inland are protected by interception of the intruding seawater.
2. The intercepted water is desalinated with reverse osmosis (RO)
3. The membrane concentrate is disposed to the underlying saline aquifer

Raat et al. (2015)
Conclusion & Recommendations

- Groundwater can be fresh, brackish or saline: Brackish and saline groundwater can provide important marginal water resources in local situation
- Need for better mapping of fresh, brackish and saline groundwater laterally and in depth
- Improve socio-economic cost-benefit assessments for potential use of brackish and saline groundwater
- MAR/ASR can offer solutions in coastal settings to prevent and remediate saline water intrusion
- SubSol proven subsurface solutions for coastal settings potentially also for GCC and Arab countries

WSTA 12th Gulf Water Conference
Bahrain, 28-30 Mar 2017
Acknowledgement & Links

- **FLIN** – *Freshwater Lens INvestigations:*
  Dr. Georg Houben, Dr.-Ing. Leonard Stöckl
  [www.bgr.bund.de/EN/Themen/Wasser/Projekte/laufend/F+E/Flin/flin_projektbeschr_en.html](http://www.bgr.bund.de/EN/Themen/Wasser/Projekte/laufend/F+E/Flin/flin_projektbeschr_en.html)

- **SubSol** - *Coastal SUBsurface water SOLutions:*
  Dr. Maike Gröschke and SWS team, [www.subsol.org](http://www.subsol.org)

- Desalination, brackish and saline waters:
  Dr. Armin Margane
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http://gripp.iwmi.org
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Saline Groundwater / Global

- Global Overview of Saline Groundwater Occurrence and Genesis (draft, IGRAC, 2009)
Status of Groundwater Resources

- Global Overview of Saline Groundwater Occurrence and Genesis (draft, legend, IGRAC, 2008)

**Saline and brackish groundwater by genesis**

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Freshmaker - Challenges

Depth of HDDW2 is important design parameter

- if too shallow this HDDW can abstract costly freshwater
- if too deep it provides insufficient protection of the upper HDDW

→ SEAWAT modelling to find optimum depth of HDDW2
Freshmaker - Pilot
Ovezande, Southwest Netherlands

Freshwater is scarce due to the surrounding estuaries and saline seepage. Resources are limited to rainwater and local fresh groundwater lenses in sandy creek ridges.

Zuurbier et al. (2015)
ASR Coastal - Option 1

Zuurbier et al. (2013)
ASR Coastal - Option 2

Recovery Phase:

- Freshwater abstraction in shallow wells
- Brackish water abstraction in deeper wells feeding an RO system
- Injection of RO brines into deeper saline aquifer or disposal in sea/ocean

Zuurbier et al. (2015)
SubSol - Project

EU project SUBSOL
“bringing coastal subsurface solutions to the market”

- Continue with scientific evaluation of the full-scale systems (reference sites)
- Demonstrate applicability in different settings (replication sites)
  - Denmark, Greece, Mexico
  - Pilot scale studies
- Assess applicability worldwide (target regions)
  - Europe, Gulf of Mexico, China, Brazil, Vietnam
  - Pre-feasibility studies