DROUGHT MANAGEMENT IN COASTAL AREAS

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COASTAL AREAS

Coastal areas are catchment final parts, where the fragile interface equilibrium between fresh, brackish and salt water may be easily jeopardized by

- Natural processes such as sea level variations, due to climate cycles, subsidence, floods, and tsunamis, and

- Human actions like freshwater overexploitation, drainage, and land reclamation, so that it may be strongly affected by droughts, conditioning aquifer recharge.
SCHEMATIC COASTAL AQUIFER SYSTEM
BARCELONA CONVENTION (2005)

- Scientific and technical analysis based on hydrogeological investigations may put in evidence that coastal groundwater pollution sources are not located in the coastal areas as defined by geomorphological and administrative criteria but are to be looked for even far upstream of coastal zones.

- Such cases are foreseen in the Article 8 of the Barcelona “Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols”, saying that the Contracting Parties shall endeavor to ensure that their national legal instruments include criteria identifying and delimiting, outside protected areas, open areas in which urban development and other activities are restricted or, where necessary, prohibited for the sustainable use of the coastal zone.
Freshwater-saltwater interface in unconfined coastal aquifer

(a) under hydrostatic conditions (Badon Ghijben, 1888/89 and Herzberg, 1901)
(b) under hydrodynamic conditions (Hubbert, 1940, Cooper 1959, Freeze and Cherry 1979).
INTERFACE ZONE INTERACTIONS

- Natural water quality in the interface zone is dependent on the interactions between rocks and water both, in the emerged and submerged parts of the coast, intended as the transition zone between continents and seas.

- In the long run, the dynamic equilibrium between solid and liquid phases is strongly affected by sea level variations due to subsidence, climate changing, and ocean dynamics.
SALINITY EFFECTS ON ROCK-WATER INTERACTIONS

- In coastal aquifers, the chemical status of groundwater is strongly influenced by seawater intrusion.

- Actual porosity and hydraulic conductivity, so far regarded as invariable, may change with increasing salinity, resulting in pH variations, element desorption from clay, and recontamination due to their mobilization.

- Mixing processes cause both, salinity increase and other chemical-physical parameters variation.
SALINITY EFFECTS ON HEAVY METAL MOBILITY

- Salinity variations affect the solubility of heavy metals by altering the ion-exchange equilibrium, increasing soluble complexation, and decreasing thermodynamic chemical activities in solution.
- Changes in the environmental conditions can suddenly mobilize toxic materials that become immediately available for biological uptake.
- As a consequence, in coastal aquifers heavy metal mobility may be subject to cyclic changes according to the dynamics of seawater intrusion.
Coastal aquifers affected by saltwater encroachment are particularly vulnerable to “retoxification processes”, which may be observed where both, accumulation of heavy metals in sediments and changes of the environmental conditions, take place.

Alluvial sediments serve as long-term skins for large stores of heavy metals, and through reverse chemical processes, such as desorption and dissolution, they can revert to large sources of heavy metals in a bioavailable form.

Salinity increase, pH, and Eh are the main activating factors of these processes owing to their influence on cation exchange equilibrium.
INTERFACE MORPHOLOGY

The morphology of the interface between surface waters and groundwater of different salinity, and the sea, strictly depends on the hydrodynamic balance, strongly affected by:

- Natural piezometric fluctuations due to natural inflow, runoff, and evapotraspiration;
- Groundwater drawdown, determining upconing and gradient inversion with seawater ingressions;
- Irrigation;
- Sea level variations due to
  - Waves, tides, coastal flooding, and tsunamis determining temporary coast submersion, so that seawater infiltrates and produces groundwater and soil salinization.
  - Climate changes
PHYSICAL EFFECTS OF SEA LEVEL RISE

- Erosion of beaches and bluffs
- Inundation of low-lying areas
- Salt intrusion into aquifers and surface waters
- Higher water tables
- Increased flooding and storm damage

Total water level = Storm surge + Tide + Waves + Rivers + other additional factors (*seasonal heating and cooling ocean dynamics, and tsunamis*)
The fresh groundwater resource $\Delta V$ is the water volume stored between the maximum and minimum level of the piezometric surface.

The groundwater volume between the minimum level and the underlying freshwater-saltwater interface is the reserve.
SALTWATER INTRUSION INCREASES WITH FRESHWATER WITHDRAWAL
WATER LEVEL VARIATIONS AND UPCONING IN PUMPING WELLS

(a) 
(b) 
(c) 
(d)
COASTAL AQUIFERS AT RISK

- A large proportion of the world’s population (about 70%) dwells in coastal zones.

- Many areas are so heavily urbanized that their need of freshwater for domestic, agricultural, and industrial supply is even more acute and increasing.

- Coastal aquifers are important sources of freshwater at risk, especially in deltas.

- Where alternative water resources are missing, the lack of good coastal water resource management schemes as well as mismanagement has led to groundwater overexploitation.

- Groundwater resources tend to be insufficient to meet increasing population water demand.
DROUGHT IMPACTS ON COASTAL LAND AND WATER BODIES

- Non-sustainable coastal urbanization & irrigation development
- Reduced GW recharge Decrease of GWD
- Impact on the emerged & submerged coast, & water bodies of different salinity
- Land cover and Land degradation → Erosion & loss in land productivity potential
- Loss of water resources, and wetland ecosystems
- Fresh GW depletion → Saltwater intrusion & Coastal land salinization
- Loss of coastal marine resources given by fishing, reproduction areas
VULNERABILITY TO DROUGHTS

- Coastal areas are particularly vulnerable to droughts, as the lack of precipitations causes a drastic freshwater outflow in rivers and aquifer systems, and in the long run, it upsets the fragile equilibrium between surface and groundwater of different salinity.

- Therefore, surface waters and groundwater are jeopardized by the combined effects of saltwater intrusion and pollution, with strong impacts on the emerged and submerged coast ecosystem.
SUSTAINABLE WATER RESOURCES MANAGEMENT CRITERIA

INTRINSIC VULNERABILITY
Aquifer, soil, geology, hydraulic conductivity, groundwater level, ground slope, effective infiltration, land cover

CONTAMINATION

SALTWATER INTRUSION

PHYSICAL AND CHEMICAL ROCK-WATER INTERACTIONS
K-rate variations, Retoxification processes, ...

INTEGRATED VULNERABILITY

PROTECTION AREAS
+ WATER RESOURCES MANAGEMENT
GROWING WATER DEMAND, CONFLICTS, AND INTEGRATED WATER RESOURCES

- The growing water demand, due to rapid population growth and socio-economic development, can be hardly satisfied with local resources mainly consisting of groundwater, which might be insufficient to supply water of good quality for drinking, domestic, agricultural, irrigation and industrial purposes.

- Conflicts may arise among different users, especially when there is a seasonal peak demand for irrigation and drinking purposes, also to match tourist sector needs.

- Conventional and non-conventional water resources should be assessed and managed in an integrated way, considering quantity and quality demands for different purposes and local hydrogeological and economic characteristics.
Floods, typical of surface water in arid and semiarid areas, may be conveniently moderated by stocking them in reservoirs upstream of coastal areas so as to

- mitigate excessive erosion effects, and prevent damages downstream,
- make surface water available to integrate groundwater to match demands for different uses, when and where necessary,
- grant the minimum river outflows needed to counteract surface seawater intrusion in final river stretches, which might induce downward saltwater movement into unconfined aquifers, and
- produce hydroelectricity.
IWRM POLICIES...

- The water supply system might need to be reorganized so as to face emergency situations. Considering the local delay time in aquifer recharge, groundwater should be preferably used in dry periods, when it reaches its maximum level.

- However, erosion cannot be completely blocked upstream without endangering coastal plains and beaches, whose dynamic stability depends on continental water outflow and sea movements, especially in deltas.

- Upland river channel fragmentation by dams and water regulation resulting from reservoir operation, interbasin diversion, and irrigation affect river discharge and aquifer recharge.

- Groundwater offers the advantage that can be extracted close to the place of final use, but some problems may arise due to its intensive use without public control, such as freshwater reserves depletion, interface land subsidence, contaminant mobilization, and impacts on aquatic ecosystems.

- Most of these problems can be avoided, corrected, or at least mitigated with an adequate control planning.
The criteria should be adopted that

- the mean rate of groundwater extraction should not exceed the safe yield, i.e. of the recharge,

- the volume of freshwater in storage should be great enough to ensure that no saline groundwater reaches the well screens,

- risk of salt water intrusion only under extreme circumstances must be acceptable, and

- the environmental impacts such as the effects on vegetation and soil must be acceptable.
MEASURES...

- Pumping rate reduction or time-share pumpage from some wells
- Relocating wells or redesigning of the well field
- Reconsidering land use type
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- Economic measures for over-pumping and over-use
- Different pricing scale for domestic, industrial, and agricultural consumption
- Aquifer recharge with surface water stocked in rainy periods
MEASURES

- Major fractures sealing and karst outlets damming to control freshwater runoff
- Pressure, hydrodynamic barriers, perpendicular to flow lines by injecting treated wastewater into wells, upstream of the interface, so as to build up a sufficient head of freshwater to block saltwater encroachment.
- Depression hydrodynamic barriers by extracting saltwater from scavenger wells before it reaches freshwater supply wells, so as to prevent saline water upconing through interface hydrodynamic stabilization.
- Physical barriers consisting of diaphragms obtained by grouting, slurry walls or sheet piles, to block shallow lateral saltwater intrusion.
- Plugging abandoned wells which can provide a conduit for leaking saltwater from the saline aquifer into fresh aquifers.
- Each of these methods can be applied to certain situations, and the method used will depend on the problem to be solved.
NATURAL AND ARTIFICIAL RECHARGE

- **Natural recharge** may be conveniently integrated with diffused and intensive artificial recharge, which is recommended when freshwater is available in reservoirs as a reserve for future use during periods of high demand.

- **Artificial recharge** is increasingly used for short- or long-term underground storage, where it has several advantages over surface storage, and in water reuse.

- Different cases may be foreseen for a reasonably predictable dry period.

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MANAGEMENT CRITERIA

- The recharge can be increased by **proper land use** and by artificial recharge if the permissible fresh groundwater extraction is insufficient to meet water demand.

- Providing surface water is available, the recharge should be increased if more groundwater is to be extracted, and the losses by the outflow of fresh groundwater to the sea should be reduced either by hydrodynamic barriers or by increasing the recharge.

- Possible actions are conditioned by the availability of surface water stocked in artificial reservoirs to recharge aquifers.

- Monitoring programs are needed (1) to predict long-term behavior of the interface in response to changes in population, water use and other actions which impact groundwater, and (2) to provide timely information on the existing conditions, a reasonably accurate assessment of interface changes, and to dynamically monitor its migration.
ALTERNATIVE SOLUTIONS

- The selection of alternative solutions typically involves making complex trade-offs and their economics remain subject to decide considering local conditions.
- Multicriteria evaluation techniques have proven to be an excellent decision support tool for evaluating IWRM alternatives.
- Models are required to consider the influence of these decisions on flows and downstream water availability, as well as the influence of flows on the productive, passive use and environmental values of water.
- Delineation and monitoring of saltwater intrusion rely on field observations; numerical modelling takes the observation results as the constraints for the boundary and initial conditions when one tackles a particular problem.
- For control and prevention of the intrusion, practical engineering work is needed, based upon the situation estimates from delineation, monitoring, and simulation.
CONCLUSIONS...

- Drought problems should be prevented by managing all water resources in an integrated way, so as to meet water quantity and quality demand for different uses.

- Conventional and unconventional water balance of the hydrogeological catchments, different areas of interest, and supply costs are to be considered in coastal areas. Promoting joint management of shared aquifers is a need. A common effort is to be made to converge towards common management criteria considering different scenarios in time under local conditions.

- Monitoring carried out by direct and indirect methods is essential to determine and predict groundwater deterioration, and assess other management activities in coastal aquifers.

- The management of coastal waters and areas requires interdisciplinary collaboration among different experts on water resources and land planning, agronomy, biodiversity, economy, water laws and directives.

- Science may give the right answers to plan the best actions necessary to manage land and water resources in a sustainable way so as to prevent conflicts among different users and in the respect of the Mediterranean environment.
CONCLUSIONS

- Coastal aquifers, representing the main sources of available freshwater, are at risk of degradation, especially in deltas, where population density in urban areas and straggling settlements is often highest, and pollution due to agriculture and industry may be very strong. As far as possible, fresh ground waters are to be considered strategic resources especially for drinking purpose whereas surface waters, treated used waters, and desalinized waters may be allocated to meet other users’ demand.

- Prevention and mitigation measures may be adopted to prevent groundwater degradation. Conflicts among different users cannot be rationally and effectively solved only with technical remedies aiming at controlling saltwater intrusion due to upconing and lateral inflow from the sea.

- All available groundwater and surface waters are to be managed considering land capability and susceptibility, and human resources in an integrated way, so as to grant a real sustainable economic development for present coastal areas inhabitants and future generations.
...CONCLUSIONS

- A common effort is to be made to converge towards common management criteria of sustainable resource development considering different scenarios in time under local conditions, so as to prevent conflicts, often due to overexploitation and mismanagement.

- The integrated management of surface waters, groundwater, and biotic and abiotic environment components is essential to prevent and mitigate interest conflicts between people resident in hydrogeological catchments and outside resource users.
Thank you for your attention
Merci pour votre attention
Grazie per l’attenzione