Integrated Coastal Aquifer and Coastal Zone Management Strategies

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ABSTRACT

The majority of coastal aquifers are endangered by saltwater intrusion and pollution as a consequence of overexploitation and mismanagement. In fact, coastal zones are more and more intensely urbanized and groundwater of good quality is not sufficient to match the growing demand, especially in the dry areas of southern Mediterranean coasts, reliant on groundwater resources for their domestic, agricultural, irrigation and industrial water supplies (Figure 1).

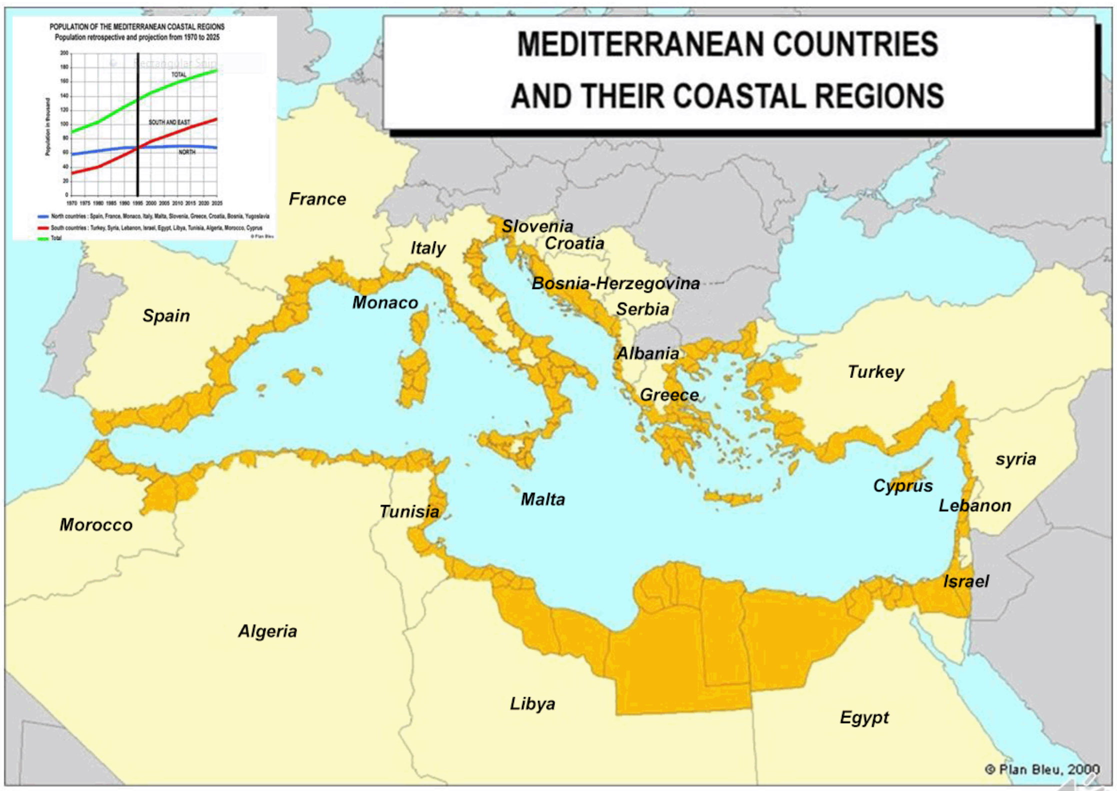

Figure 1. The total water resources of the Mediterranean area are estimated at 1.060 km^3, of which 107.4 km^3 (84.2% of the total) are in the south, 62.4km^3 (5.8% of the total) in the east, and the remaining 894.6 km^3 (84.2% of the total) in the north (*data derived and map modified from EUWI MED 2007, Plan Bleu 2000, and UNEP MAP 2012*).

The total population of the Mediterranean countries grew from 276 million in 1970 to 412 million in 2000 (a 1,35 % increase per year) and to 466 million in 2010. The population is predicted to reach 529 million by 2025. More than a third lives in coastal administrative entities totalling less than 12 % of the surface area of the Mediterranean countries. The population of the coastal regions grew from 95 million in 1979 to 143 million in 2000. It could reach 174 million by 2025 (UNEP/MAP 2012). The concentration of population in coastal zones is heaviest in the western Mediterranean, the western shore of the Adriatic Sea, the eastern shore of the Aegean-Levantine region, and the Nile Delta. Overall, the concentration of population in the coastal zone is higher in the southern Mediterranean countries, where the variability of the population density is highest, ranging from more than 1000 people/km^2 in the Nile Delta to fewer than 20 people/km^2 along parts of coastal Libya. Many coastal areas are so heavily urbanized that the need for freshwater is even more acute and increasing.

Coastal areas represent the final part of the hydrogeological catchments, where the fragile interface equilibrium between fresh, brackish, and saltwater may be easily jeopardized also by natural processes, such as sea level variations due to climate cycles and subsidence, floods and tsunamis, and anthropic activities developed also inland upstream. Owing to sea level variations in time, the structure of major deltaic plains is rather complex, and fossil freshwater and salt water aquifer layers are interbedded in depth below sea level (Barrocu, Dahab 2010). Saltwater intrusion processes and their effects are quite well known and described in literature, particularly in previous SWIM proceedings. Saltwater intrusion is generally produced by overexploitation, due to excessive fresh groundwater development with respect to effective natural recharge, land-use change, climate variations, and sea level fluctuations. Short- and long-term climatic fluctuations influence the amount of recharge and consequently the groundwater resource available for use (Post 2005; Ferguson, Gleeson 2012; Werner et al. 2013).

Well pumping in coastal aquifer systems modifies hydrodynamic levels producing lateral saltwater ingression when their radius of influence, depending on terrain K rate, trespasses the fragile interface between fresh groundwater, coast saline water bodies, and the sea, even when aquifer recharge is higher than the yield extracted. It also produces upconing of seawater trapped in deep layers formed in geological past, such as syndepositional connate saltwater and dense brines, sometimes connected to salt domes, evaporitic deposits in thin beds or disseminated geologic formations. The upconing of brackish and saltwater, often consisting of fossil waters, caused by well drawdown, produces water-rock interactions difficult to control, affecting groundwater quality and aquifer hydraulic parameter values. Soil and groundwater salination may be due also to sea water spray and anthropogenic salt released from industries, roads, etc. Coastal aquifers may be particularly endangered by mining activities, industrial facilities, and unsuitable engineering works. Retoxification processes may be observed where accumulation of heavy metals in sediments and changes of the environmental conditions take place. Alluvial sediments act as long-term skins storing heavy metals, and through chemical processes of desorption and dissolution, they can revert into large sources of heavy metals in bioavailable form (Sodde, Barrocu 2008).

Under natural conditions, sea level variations due to surges, tides, and tsunamis determine temporary low coast land submersion, so that salt water infiltrates and produces groundwater and soil salination. Tsunamis effects on urbanized low areas may be counteracted by protecting them with physical barriers.

Floods, typical of arid and semiarid areas like the Mediterranean coasts, may be conveniently moderated by stocking them in reservoirs so as to mitigate excessive erosion effects, produce hydroelectricity, and surface water may be conveniently transferred downstream to match different demands when and where necessary. 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 generally affect river discharge and aquifer recharge.

Inland pollutants transported by floods partly outflow directly into the sea and are partly deposited with deltaic sediments. Floods and tsunamis may heavily devastate urbanized low coastal areas, where they generally mobilize pollutants of different diffused and point sources so that they infiltrate and endanger groundwater and soil, at grades depending on their vulnerability. Interaction effects of salination and pollution, depending on temperature, pH and Eh, are not easy to control. Inland pollution of transboundary aquifers, typical of karstic areas like Slovenia, Croatia, Bosnia and Herzegovina, Albania, Greece, Montenegro, Turkey, Israel, Palestine, and North-African countries, may affect costal aquifers, where large volumes of water are discharged from the aquifer system through terrestrial and submarine springs.

Surface water and groundwater body boundaries to be considered in coastal land planning and management should be determined by the hydrogeological catchment, collecting both surface waters and groundwater, often different from the surface water basin. Such case is 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"*. The concept of integrated water resource management implies an international approach to river conservation of entire river systems considering hydrogeological catchments irrespective of political borders. No other way is possible than the agreement between different water authorities and land administrators to find the best fitting method to rule land and water resources in an integrated way.

Coast urbanization implies soil consumption and should not endanger land safety and ecosystems. Agriculture practices are compatible with recycled and brackish water irrigation, the only available in areas with scanty water resources, considering real free global market requirements, as in the long run producers might not be able to rely on high public incentives. Aquaculture may be developed depending on water quality available and different type of fish exigencies.

A minimum stream flow including sediment transport is to be granted to preserve riparian and coastal areas ecosystems, and induce groundwater recharge. Natural recharge may be conveniently integrated with diffused and intensive artificial recharge. Saltwater intrusion and interface morphology may be modified and controlled by hydrodynamic and physical barriers so as to develop coastal aquifers in the best way.

Desalinization methods may be the only solution to grant water supply especially in small islands with scanty fresh water resources. A number of desalination plants are functioning in Mediterranean coasts, particularly in Israel, Spain, Algeria, Egypt, etc., mainly for the production of drinking water but also for agriculture demand. Production costs are variable, depending on local energy costs. In some countries, like Italy, desalination plants are not favoured by local rules on account of the impacts due to byproduct concentrates released into the sea, soil salination caused by saltwater upconing when tapping saline groundwater from coastal aquifer wells, and high energy costs.

Conflicts among different users may not be resolved rationally and effectively only with technical remedies aiming at controlling saltwater intrusion from the sea and due to upconing.Major efforts are necessary to convince decision makers and users to evaluate and manage available groundwater and surface waters, land capability and susceptivity, human resources in an integrated way, so as to grant a real sustainable economic development for present coastal areas inhabitants and future generations. It is a responsibility of all scientists and professionals of disciplines involved in coastal aquifer and zone management are responsible for emphasizing the relevance of their activities. 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.

Research and university courses should be finalized to prepare high profile land managers.

REFERENCES

Barrocu, G., Dahab, K. 2010. Changing climate and saltwater intrusion in the Nile delta, Egypt, Proc. XXXVI IAH Congress, Toyama, Japan, Eds. M. Taniguchi, I.P. Holman, IAH Selected Papers, 16, Groundwater Response to Changing Climate, Chapt. 2, pp. 11-25, CRC Press Taylor & Francis Group, Balkema Book, ISBN: 978-0-415-54493-1 (Hbk), ISBN: 978-0-203-85283 (Ebook)

EUWI MED.2007. Mediterranean Groundwater Report.
http://www.semide.net/initiatives/medeuwi/JP/GroundWater
http://forum.europa.eu.int/Public/irc/env/wfd/library?l=/framework_directive/groundwater_library&vm=detailed&sb=Title

Ferguson, G., Gleeson, T. 2012. Vulnerability of coastal aquifers to groundwater use and climate change. Nature Climate Change 2: 342-344.

Margat,J., Vallée D. 2000. Water resources and uses in the Mediterranean countries. Blue Plan for the Mediterranean. Sophia-Antipolis: Regional Activity Centre.

Sodde, M., Barrocu, G. 2008. Seawater intrusion and arsenic contamination in the alluvial plain of the rivers Quirra and Flumini Pisale, south-eastern Sardinia. Ed. Barrocu, Proc.1st SWIM-SWICA, Cagliari-Chia Laguna, Sept. 24-29, 2006, University of Cagliari, UNESCO, Regione Autonoma Della Sardegna, IAEA, IAH, Tipografia 3 ESSE, Serramanna (CA), pp. 165-173, ISBN 88-902441-2-7

UNEP/MAP .2012. State of the Mediterranean Marine and Coastal Environment, UNEP/MAP – Barcelona Convention, Athens, 2012.

Werner, A.D., Bakker M., Post, V.E.A., Vandenbohede A., Lu C., Ataie-Ashtiani, B., Simmons, C.T., Barry, D.A. 2013. Seawater intrusion processes, investigation and management: Recent advances and future challenges. Advances in Water Resources 51: 3-26, doi: 10.1016/j.advwatres.2012.1003.1004.

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