Sub-chapter 2.3.5

Changes in Mediterranean groundwater resources

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Introduction

The strong variability in space and time of all components of the hydrological cycle is a fundamental feature of the Mediterranean region (e.g. Cudennec et al. 2007). Its most visible marker is the succession of droughts and floods that deeply affects environment and societies. Impacts of such events on groundwater are obvious but there are countless drivers of hydrological changes that act under multiple forms.

Among them, irrigation is of primary importance. For millennia, Mediterranean populations developed strategies of adaptation to water scarcity and exploited groundwater to secure crops against seasonal and interannual irregularity in rainfall and river flows. Ancient Mediterranean civilizations have left many traces of their hydraulic mastery from the tapping and transfer of spring water to the drainage of aquifers or the digging of deep wells (e.g. Remini et al. 2010).

But the 20th century represented a complete disruption because technical advances allowed massive access to groundwater. Irrigation now represents between 50% and 90% of the total Mediterranean water demand (UNEP/MAP-Plan Bleu 2009) and has based its “silent revolution” on intense groundwater exploitation. This has led to critical drops of groundwater levels of up to several hundred meters in a few decades (e.g. Custodio et al. 2016). Many other human interventions have consequences for groundwater quantity and quality including changes in land use and land cover, hydraulic works, artificial inflows and outflows. These often interact at different scales of time and space, which makes the current state of groundwater a complex combination of multiple processes.

Original features of groundwater resources

Sedimentary aquifers are by far the largest regional reservoirs in the Mediterranean region. Most are small or medium in size, i.e. a few hundreds or thousands of square kilometers. They represent the last stage of an eventful geological history that still influences the present, especially active tectonics and variations in sea level since the Miocene. The apparent opposition in water circulation processes between fissured carbonates and porous media often plays a secondary role in comparison with more important properties like storage capacity and resilience to external stresses.

The first driver of their recharge is the heterogeneous distribution of rainfall, which is largely influenced by topography, particularly apparent by the contrast between relatively humid hinterlands and drier littorals. Recharge depends mainly on the intensity and distribution of rainfall events in space and time, and on vegetation and soil surface conditions: monthly and annual amounts of rainfall are only insignificantly linked with the real recharge reaching aquifers. The role of water towers played by upstream areas is illustrated by the Haouz plain of Marrakech whose groundwater originates from upstream catchments and not from direct infiltration of rainfall over the plain (Boukhari et al. 2015). The weakness or even complete lack of diffuse recharge and the major role of focused recharge are very common in the Mediterranean region.

Groundwater also comes from exchanges with rivers, especially during the highest floods. Depending on the event, infiltration can vary by one or two orders of magnitude. This implies that aquifer dynamics has to be analyzed simultaneously at several scales, from the event up to the millennium: the largest confined aquifer systems contain information dating back to the last humid period in the Holocene (e.g. Zuppi and Sacchi 2004).

Because of climatic surface conditions, a regional geology rich in carbonates and evaporites, and easy contact between the sea and the littoral aquifers, Mediterranean groundwaters are often highly mineralized. For instance, only one fifth of Tunisian groundwaters have a salt content lower than 1.5 $g.L^{-1}$ while another fifth exceed 4 $g.L^{-1}$ (Besbes et al. 2014). A significant proportion of the theoretically available Mediterranean groundwater resource is in fact not exploitable for human use without treatment.

Climatic change and groundwater

Apart from the few last centuries when direct observations have been made, climatic variations are reconstituted from proxies. As humans have been highly active in the Mediterranean for millennia, it is necessary to disentangle the climatic and human origins of apparent modifications of the socio-environments in the Holocene, and also to differentiate local and regional phenomena. Temperature reconstructions in the north-western part of the Mediterranean region by Camuffo et al. (2010) indicates that past cycles already reached current measurements. The resulting sea level rise is a potential threat for littoral aquifers, but far behind the threat represented by their modern exploitation. Regarding past variations in rainfall, the wide range of proposals in the scientific literature mirrors the wide range of data, methods and objectives of the authors concerned. According to careful analyses (e.g. Reiser and Kutiel 2011) no coherent regional trend can be identified over the 20^{th} century. At a longer perspective of several centuries, some consistencies and also significant discrepancies appear in climatic reconstructions between eastern and western sub-basins or even between north-western and south-western sub-basins.

In recent decades or centuries, spectacular events that may have marked infiltration are attributable to the usual great variability of the Mediterranean climate. And today, the multiple forms of anthropization of the hydrological cycle completely dwarf the climatic signal.

Anthropization of groundwater resources

Expansion of irrigation highly exploits groundwater resources whatever their renewal rate. Cases of severe overexploitation are numerous and widespread throughout the region: in Libya, the demand for water for irrigation is about ten times higher than renewable water resources. Even worse, overexploitation in fragile aquifers leads to rapid social and environmental disasters like in the coastal Chaouia of Morocco (Moustadraf et al. 2008). But cases also exist where the development of irrigation leads to an increase in the superficial groundwater resource because of a significant return flow of excess irrigation water, pumped from deeper aquifers or imported by large channels, like in the Spanish Cartagena aquifer (e.g. Baudron et al. 2014) or the Moroccan Tadla aquifer (e.g. Bouchaou et al. 2009).

Changes in water consumption for irrigation are far more influenced by technical (e.g. drip systems), economic (e.g. energy cost), social (e.g. local knowledge) and political (e.g. subsidies) drivers than by increasing temperatures modifying crop water demand. There is evidence for a wide range of illicit but tolerated groundwater exploitation practices in many Mediterranean countries, which are sometimes even encouraged by national authorities. Two emblematic cases are widespread unauthorized boreholes and unauthorized plants for desalinating brackish groundwater.

Apart from irrigation, agriculture modifies land uses and land covers in many ways (areas covered by rangelands, forests and fields; crop intensification; etc.) that modify the proportion of blue and green water, and consequently the flux and location of groundwater recharge.

Hydraulic works are another major component of the modification of the groundwater regime, either by a direct impact or by an intermediate effect on surface water that subsequently modifies recharge. Hydraulic works include a very wide range of sizes and construction modes from big and small dams to soil and water conservation works, and traditional bench terraces. Their number considerably increased in the 20th century, and only a very few of them were built with the explicit intent of modifying recharge (e.g. Martin-Rosales et al. 2007), probably less than cases of unexpected losses that contribute significantly to new groundwater inflows (e.g. Leduc et al. 2007). The efficiency of the recharge of these different hydraulic works varies considerably over time, depending on siltation, maintenance, etc. This non-exhaustive list can be completed with pumping and refuse from quarries and mines, losses of long distance water transfer, drainage of wetlands, plots for artificial recharge, etc.

Groundwater is also intensely exploited for the supply of drinking water, which has rapidly increased as a consequence of population growth, the improved ratio of the population supplied, and higher standards of living. The concentration of population in Mediterranean coastal areas results in an ever increasing demand for drinking water in areas where groundwater of good quality is often naturally rare and sources of quality degradation numerous (e.g. seawater intrusion, waste water). To the fundamental priority of drinking water is added the provision of groundwater for tourism and industry, which are usually present in the same areas as cities and increase the spatial and temporal disequilibrium of groundwater exploitation.

Consequences of changes for groundwater

Anthropization of the Mediterranean environment directly affects the location, temporality and intensity of groundwater fluxes in both recharge and outflow (e.g. limitation of floods in alluvial plains, increased vertical fluxes under irrigated schemes, leakage inversion). It also affects groundwater quality, in nearly all cases leading to its degradation: increased mineralization of water stored for a longer time at the surface before infiltration (e.g. in irrigated fields, in dam reservoirs), pollution by fertilizers and pesticides used in agriculture, advance of seawater intrusion, uncontrolled discharge of wastewater, artificial mixing of groundwaters in defective or multiscreened boreholes, etc. The qualitative consequences of groundwater anthropization are often less perceptible (i.e. less visible and/or less surveyed) than drops in groundwater level, which partly explains the inertia of decision makers before implementing costly remediation actions that have to be continued over long periods.

The progressive superseding of natural processes by anthropized ones increases the complexity of both hydrodynamics and geochemistry, at multiple scales of space and time (Fig.1). The consequence should be a supplementary effort to densify survey and analysis whereas in practice, most observation networks have worsened under financial constraints in the last two decades. Some are no longer appropriate for the new emerging issues, and large territories remain almost unknown.

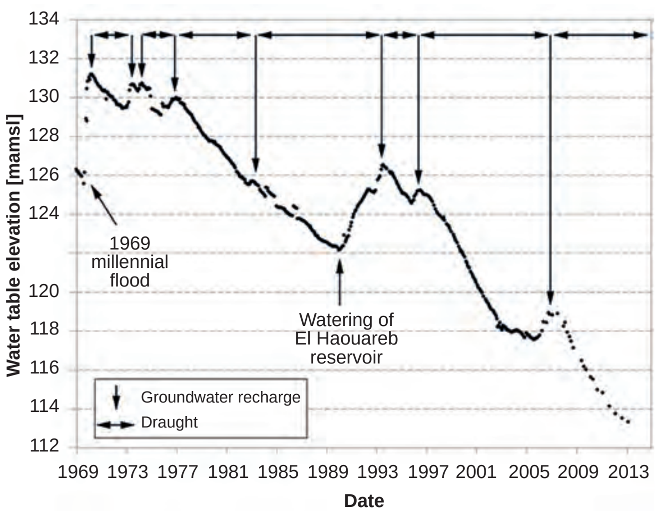

Figure 1
Changes in the water table depth in the Kairouan plain. The two biggest rises are due to the catastrophic floods in 1969 and the construction of the big El Haouareb dam; other rises due to wet years are much smaller. But the major trend is the severe long term drop caused by the ever increasing pumping for agriculture.

The capacity of water managers to inform their decisions with groundwater knowledge diminishes with time, in parallel with the higher pressure on groundwater resources, the higher vulnerability of socio-hydrosystems, and the much stronger claim of citizens to play an active role in the decision process. In addition to individual requests, collective welfare and long-term sustainability must also be taken into consideration. This is particularly important for environmental water demand, often taken as an adjustment variable, and sacrificed to needs that are considered to be more urgent, at the risk of causing irremediable damage. This addresses the more general issue of the role of states and their ability to enforce law.

The rapid evolution of Mediterranean socio-environments is a major challenge for scientists and managers. The intricacy of technical, societal and biophysical drivers is progressively increasing and taking new forms. Among these multiple drivers, climate change currently has less impact than many other drivers. Whatever their relative importance in the future, beyond traditional disciplinary and/or technical studies, holistic approaches will have to be developed, and anticipating major crises will largely depend on our ability to imagine possible futures outside traditional thought frameworks. Most Mediterranean groundwater resources have been considerably reduced in quantity and degraded in quality in recent decades, preserving their resilience capacity is an absolute necessity to withstand the projected increase in the frequency of extreme events.

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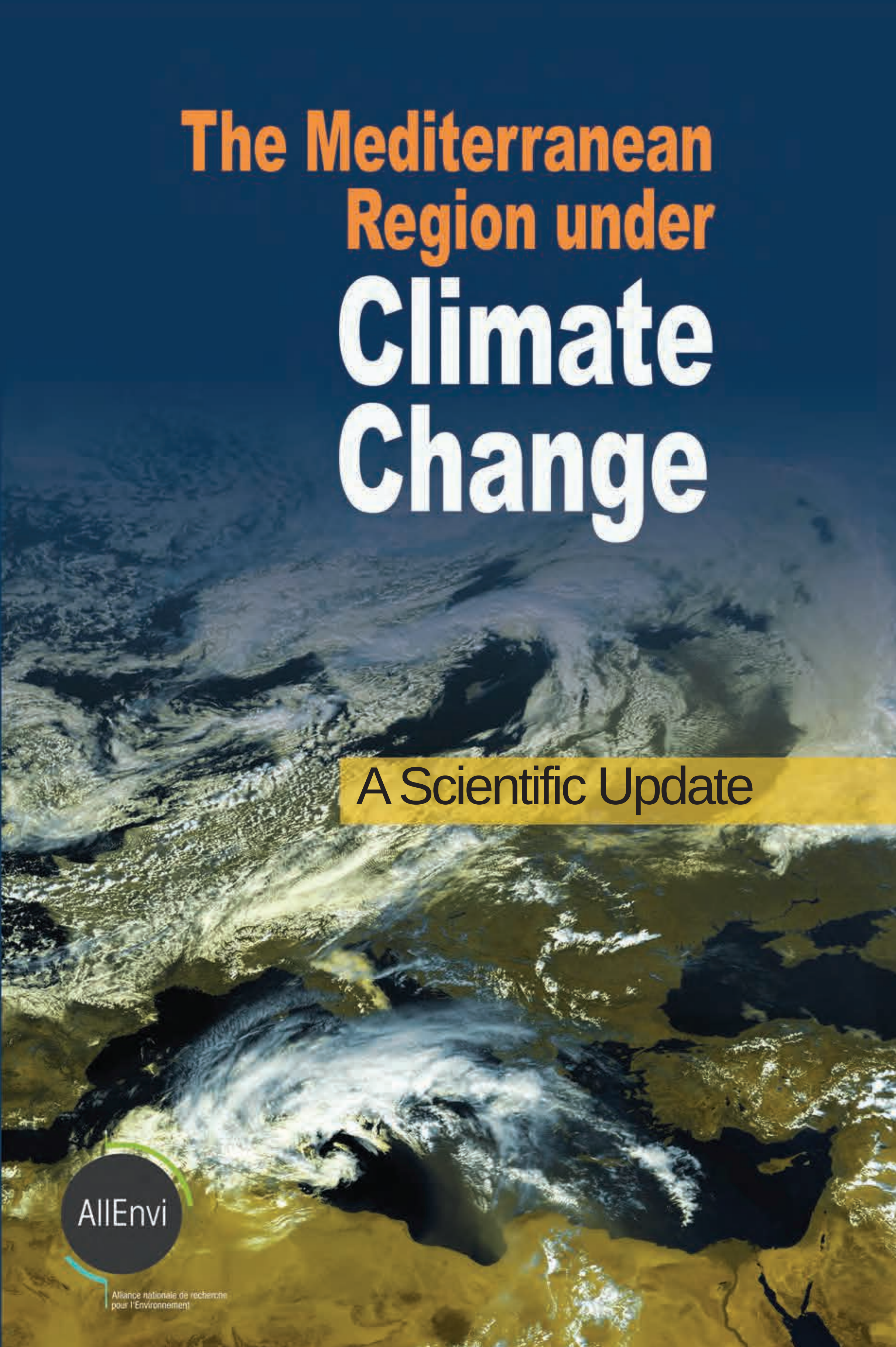

The Mediterranean Region under Climate Change

A Scientific Update

AllEnvi

Alliance nationale de recherche pour l'Environnement

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