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ESSAY

# Topical Collection: Groundwater-based agriculture in the Mediterranean

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**Abstract** This essay introduces a collection of articles that explore the future of groundwater-based agriculture in the Mediterranean from an interdisciplinary perspective, in a context of declining water tables due to intensive groundwater use. The imminent crisis that many groundwater economies face due to very rapid and intense global change may have severe irreversible social, economic and environmental consequences, but could also be the opportunity to make a clear break with current agricultural development models and move towards more sustainable agricultural practices. The Mediterranean region is, therefore, an interesting case for the future of intensive groundwater use, as innovative ideas and practices may emerge and inspire similar groundwater-based agricultural systems around the world.

**Keywords** Over-abstraction · Agriculture · Groundwater management · Socio-economic aspects · Mediterranean

This article is part of the topical collection "Groundwater-based agriculture in the Mediterranean"

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## Introduction: revealing the fragility of groundwater-based agriculture

Groundwater is a major component of human development, especially in areas where the marked seasonality and the inter-annual variability of rain distribution are a severe constraint on agriculture. Despite being exploited for millennia, groundwater is still often a hidden resource. It took decades for hydrogeologists to make it more visible and to pinpoint the vulnerability of groundwater systems to global change (Gleeson et al. 2012). Climate variability affects groundwater dynamics, but the various forms of anthropization are more important drivers of immediate hydrological changes, including changes in land use and vegetation or agricultural practices (e.g. increased use of fertilizers and pesticides), the construction of dams, and intensive pumping (Leduc et al. 2017, this issue). The apparent abundance of groundwater and its relative ease of access have led to numerous cases of critical water table decline and groundwater shortage, particularly in semi-arid regions (Wada et al. 2010). Such crises have called public attention to the fragility of groundwater resources and to the need for more sustainable management.

In parallel, the political, social and economic importance of groundwater-based agriculture worldwide has become visible over the past decades. More than a third of the world's irrigated area (113 out of 300 million ha) is fed with groundwater thanks to millions of wells and tube-wells (Siebert et al. 2010). Flexible use of groundwater allows the intensification and diversification of cropping systems, strengthens farmers' economic conditions, and is usually available at relatively low cost (Bouarfa and Kuper 2012). Intensive groundwater use thus led to the development of a 'vibrant wealth-creating agriculture', referred to as the *groundwater economy* (Shah 2009). Interestingly, within this strand of literature, the signs of a coming crisis due to groundwater overdraft have also

been pinpointed. Likewise, most groundwater users are well aware of this and some even anticipate their *exit* from groundwater-based agriculture (Bekkar et al. 2009). Groundwater overexploitation is therefore no longer an issue only recognized by specialists, but has become common discourse among users, government agencies and international donors. It has become so common that confusion persists as to what overexploitation really is (Custodio 2002), how it began, who is affected by it, and what the implications of groundwater overexploitation represent for the resource and for the users who depend on it.

Hence, the objective of this topical collection is to explore the future of groundwater-based agriculture in a general context of concern about declining water tables. This collection of interdisciplinary articles concerns the Mediterranean region, with a particular focus on North Africa, due to the intensive development of groundwater use and the very rapid and intense environmental, political, social and economic changes that have already taken place and are still underway. Groundwater-based agriculture in North Africa, like elsewhere in the Mediterranean region, has expanded at a remarkable pace—for example in Algeria, irrigated land increased from 228,000 ha in 1985 to slightly over a million ha in 2011 thanks to groundwater (Kuper et al. 2016). The general expansion of groundwater-based agriculture affects the whole range of Mediterranean aquifers, whatever their size, renewal rate and intensity of exploitation. This is true for the large Saharan sedimentary basins, which are among the biggest aquifers in the world (MacDonald et al. 2012), but whose recharge rate is much lower than current pumping rates. This is also true for other regional aquifers located closer to the Mediterranean Sea that are smaller in size but whose recharge is higher. Among them, coastal aquifers are particularly threatened by the seawater intrusion that is caused by intensified pumping.

## Groundwater overexploitation: beyond the groundwater budget

The term 'groundwater overexploitation' is widely used to qualify any water table decline or deterioration of groundwater quality. It is frequently assumed that groundwater overexploitation has a consensual definition in the community of hydrogeologists, which is actually not the case. Groundwater overexploitation is not only related to the imbalance of the water budget (see for instance the discussion on the so-called water budget myth in Bredehoeft 2002). The concept extends well beyond hydrogeological considerations because it is related to all prejudicial effects of groundwater exploitation. Resource specialists, institutions and users perceive these effects differently and their perceptions change over time. Some scholars therefore suggested that an "aquifer is overexploited when the balance between the benefits and costs of a certain level of groundwater abstraction is negative considering long-term values" (Hernandez-Mora et al. 2001). Groundwater overexploitation often embodies complex situations, in which the decline in the water table is interlinked with a decline in water quality and unequal access to groundwater or where the state juggles with conflicting objectives, for instance, agricultural development versus environmental protection (Massuel and Riaux 2017, this issue). Conflicting objectives may lead to declaring an aquifer overexploited for environmental reasons in one place, based, for example, on the observation that rivers or springs are drying up, whereas in another context with similar signs, groundwater development will continue to favor agricultural dynamics. There is therefore a need to look at groundwater overexploitation from a wider interdisciplinary viewpoint by taking into account how groundwater is used and by whom.

Several difficulties await the scientist interested in exploring the future of groundwater-based agriculture in a context of declining water tables. The conceptual contribution of Mukherji and Shah (2005) advocating the use of three complementary perspectives (resource, institutional and user perspectives) to understand the challenge of sustainable groundwater management may be useful here. First, knowledge of the dynamics of aquifers in the Mediterranean region under various forms of anthropization, "whose impacts occur at multiple scales of time and space", is heterogeneous and incomplete (Leduc et al. 2017, this issue). Developing a thorough *resource perspective* is even more challenging due to the "complete upheaval of groundwater exploitation in the 20th century" with the very rapid development of scattered agricultural pumping (Leduc et al. 2017). Making sure the knowledge base keeps up with the rapid pace of global change is, therefore, a major challenge.

Second, the increase in groundwater use for irrigation over the last few decades has mainly been taking place below the radar of managers and researchers (El-Agha et al. 2017, this issue). The problem is not only that tube-wells are generally neither registered nor monitored by state services, but also that groundwater use is largely driven by informal arrangements with little direct state involvement. This does not mean that the role of the state in current groundwater use dynamics is not important. Quite the contrary, in the Mediterranean region, the state often actively encourages groundwater-based agriculture (Kuper et al. 2016). However, the influence and role of the state cannot be determined solely on the basis of formal state-sanctioned rules, but rather by analyzing the interface of formal regulations and informal practices of groundwater use. An *institutional perspective* on groundwater use will, therefore, have to focus on field-based evidence of the (in)formal institutional arrangements under which the resource is appropriated and used.

Third, individual groundwater withdrawals, the main groundwater outputs, are closely linked to irrigation practices,

which are themselves driven by countless factors, including land use, the farmers' underlying logic, access to natural resources, public policies and markets (Massuel et al. 2017, this issue). It was shown, for example, in a case study in North Africa, that the irrigation volumes applied by two farmers growing the same crop can vary in the ratio of one to four (Benouniche et al. 2014). Simply counting the number of tube-wells or determining the land use to estimate groundwater use is therefore insufficient. Adopting a *user perspective* makes it possible to investigate the behavior of groundwater users. This is obviously time consuming, but appears to be the only way to understand current and future trends of groundwater use in relation to complex aquifer dynamics. A user perspective also allows pinpointing some of the larger issues of social justice and rural development (Hoogesteger and Wester 2015).

## On the difficulty of preparing for a decline in groundwater-based agricultural systems

The contributions of this topical collection provide insights into the current dilemma facing the different actors of the groundwater economy in the Mediterranean region. As the title of their paper somewhat provocatively suggests, Petit et al. (2017, this issue) raise the specter of the possible 'collapse' of groundwater economies with severe and irreversible social, economic and environmental consequences. However, collapse can also pave the way for new opportunities and changes, for example downscaling farming systems with a particularly large water footprint, which is why it is important to prepare for collapse. This result is of interest beyond the Mediterranean, as an increasing number of semi-arid regions in the world are confronted with the decline and possible collapse of existing groundwater economies (see for instance Leblanc et al. (2012) on the Murray-Darling basin in Australia or Massuel et al. (2013) on the Krishna basin in India).

Yet, there are several difficulties involved in preparing for the decline of groundwater-based agriculture. The first is that informal groundwater economies are often invisible to policy makers. Revealing how a groundwater economy is working, and for whom, is certainly one important contribution of this collection of articles. For instance, Lejars et al. (2017, this issue) underline from an institutional perspective the important role of supply chain actors in the development of groundwater irrigation; they advocate involving these actors in groundwater governance as "vectors of innovations leading to more sustainable agricultural practices". Ameur et al. (2017, this issue) show that groundwater use is generally lumped in a single figure, groundwater abstraction, whereas a decline in water tables always has social consequences—in this case, the progressive exclusion of smallholders from groundwater use, which, in turn, favors groundwater overexploitation. Ameur et al. (2017, this issue) plead for a user perspective to groundwater use by identifying the relative contributions of different social categories of farmers to groundwater overexploitation. Thus, the rampant inequalities associated with groundwater use can be revealed, possibly also enabling those in charge of regulating groundwater use to better deal with the problem.

The second difficulty is the widespread view of researchers and policy makers on resource overexploitation as only a matter of (hydrological) inputs/outputs. The different contributions in this topical collection show that a change in perspective when analyzing resource overexploitation is helpful, as the classical view of overexploitation masks the different problems faced by the different stakeholders. This includes difficulties in accessing water, problems the authorities face in controlling a territory and individual abstraction practices, and complications for scientists qualifying hydrological situations (Massuel and Riaux 2017, this issue). Although the decline of groundwater-based agriculture may be linked to degradation in the quantity or quality of the resource, it may also be linked to socio-economic factors, in particular risky and volatile agricultural markets (Lejars et al. 2017, this issue), or to political intervention and heavy-handed regulation (Petit et al. 2017, this issue). An aquifer can therefore be considered as overexploited because of many prejudicial aspects, but in the absence of an immediate threat to the resource (Massuel and Riaux 2017, this issue).

The third difficulty is related to the scant knowledge of aquifer dynamics, linked to the socio-economic and political pathways of groundwater-based agricultural systems in the Mediterranean region. Monitoring these very diverse systems is a tough task given the pace and the complexity of the physical heterogeneity of basic processes and fluxes, the multiple interactions between natural and anthropogenic processes (Leduc et al. 2017, this issue), the limited knowledge on groundwater uses (El-Agha et al. 2017, this issue) and the difficulty of assessing individual groundwater withdrawals at regional scale (Massuel et al. 2017, this issue). The hidden nature of the underground resource, its frequent inertia to short-term shocks and the progressive deterioration of groundwater may lead to crises that extend over a longer period and attract less attention from the authorities. More skeptically, some political scientists question whether stakeholders are even interested in a knowledge-based groundwater policy in a context where users "pump water at rates that contradict the advice of groundwater scientists until the resource is exhausted. These practices reflect the assumptions of the region's water users and governments" (Allan 2007). Informing different stakeholders on the pathways of groundwater economies and on the dynamics of aquifers on which these economies are based is, therefore, an unceasing chore that should concern both the natural and the social sciences.

## Conclusion: decline as an interesting prospect for change?

There is certainly no easy way to promote alternative pathways to more sustainable groundwater-based agricultural systems in the Mediterranean region, but it is clear that such a redirection will require extending the debate far beyond the resource perspective and involving all actors, including not only direct users and managers, but also environmental lobbies and the civil society. The imminent crisis that many groundwater economies face due to global change may be an opportunity to make a clear break with current agricultural development models and move towards more sustainable agricultural practices. The Mediterranean region is, therefore, a very interesting case in point for the future of intensive groundwater use. Current dynamics should be closely monitored in the coming years, as innovative ideas and practices may emerge and inspire groundwater-based agricultural systems around the world.

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