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Strategies to reduce water stress in Euro-Mediterranean river basins☆

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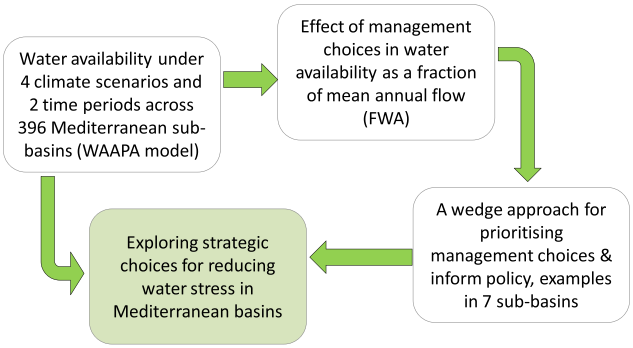
HIGHLIGHTS

- We model water scarcity accounting for reservoir operation and water management.
- We apply the high resolution model to the Euro-Mediterranean region.
- We show that increasing resolution increases the quality of the assessment.
- Incorporating water management will define more appropriate policy choices.
- A portfolio of management strategies illustrated regional policy choices.

GRAPHICAL ABSTRACT



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ABSTRACT

A portfolio of water management strategies now exists to contribute to reach water demand and supply targets. Among them, integrated water resource management has a large potential for reducing water disagreement in water scarcity regions. Many of the strategies are based on well tested choices and technical know-how, with proven benefits for users and environment. This paper considers water management practices that may contribute to reduce disagreement in water scarcity areas, evaluating the management alternatives in the Mediterranean basins of Europe, a region that exemplifies other water scarcity regions in the world. First, we use a model to compute water availability taking into account water management, temporal heterogeneity, spatial heterogeneity and policy options, and then apply this model across 396 river basins. Second, we use a wedge approach to illustrate policy choices for selected river basins: Thrace (Greece), Guadalquivir, Ebro, Tagus and Duero (Spain), Po (Italy) and Rhone (France). At the wide geographical level, the results show the multi-determinant complexities of climate change impacts and adaptation measures and the geographic nature of water resources and vulnerability metrics. At the local level, the results show that optimisation of water management is the dominating strategy for defining adaptation pathways. Results also show great sensitivity to ecological flow provision, suggesting that better attention should be paid to defining methods to estimate minimum ecological flows in water scarcity regions. For all scales, average water resource vulnerability computed by traditional vulnerability indicators may not be the most appropriate measure to inform climate change adaptation policy. This has large implications to applied water resource studies aiming to derive policy choices, and it is especially interesting in basins facing water scarcity. Our research aims to contribute to shape realistic water management options at the regional level and therefore provide information to climate change, agricultural and water policies.

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1. Introduction

Humans are deeply integrated into the water cycle and their actions strongly determine the availability of water resources (Vörösmarty, 2002). This is especially true in Mediterranean Europe. The human influence in water supply in Mediterranean European countries is one of the oldest influences in the world. Water infrastructure to deliver water supply and sanitation was implemented in Greece in IV B.C. and irrigation systems were developed in Spain in IV B.C. At the same time, Mediterranean societies have developed a great culture of water management. As a result, Mediterranean Europe follows a continuous adaptation process. When more water is available the demands rise while in scarcity situations the demands are restricted. I.e. water use is balanced with water availability. The main adaptation process has been to regulate water, so water availability is defined by regulation.

From Greece to Spain, the Euro-Mediterranean region has sustained his people for millennia. But rapid changes in population, lifestyle and climate change are turning the region into disagreement over water and land. The last ten years were the hottest on the global record and in many areas of Southern Europe were also the driest, resulting in crop failures and water imbalances that caused instability in many rural areas and, to a lesser extent, in cities. During these years the water resource community has made exceptional efforts in expanding the scope of research to include aspects of vulnerability that could be linked to social choices and has made a great collective effort to address the water vulnerability problem. But some issues remain unsolved. First, little is known about how vulnerability indicators of water scarcity respond to water management choices. Here we use a water adaptation policy model to contribute to the understanding of vulnerability in a region where water is intensively managed. A second unsolved issue is the prioritisation of adaptation strategies. Here we use a wedge approach to understand quantitatively the additive effect of management choices and illustrate the results with local examples.

Water resource vulnerability has been evaluated with indicators at the global scale (Alcamo et al., 1997; Wallace, 2000; Sullivan, 2002; Hanasaki et al., 2013), and at smaller scales (Meigh et al., 1999; Vörösmarty et al., 2000; Boithias et al., 2014). Commonly used indicators include the Falkenmark Index (FI, defined as the average per capita water available per year, Falkenmark, 1986) that indicates social water stress, and the Criticality Ratio (CR, is computed as the ratio of mean water use to availability) that indicates technical water stress. These indicators are extremely useful for an overview of the vulnerability levels and they influence the decision-making process in the planning and management of the water resource systems (UN, 2003). Recent works have proposed indicators for assessing water scarcity problems under climate change (Chávez-Jiménez et al., 2013) and have developed methodologies that are based on these indicators to allocate water resources under demand constraint scenarios (Chávez-Jiménez et al., 2015). However, indicators do not analyse the causes behind real water scarcity challenges (Ludwig et al., 2011; Victoria et al., 2005). In practice, however, water shortages often differ due to three major characteristics of water resource systems that are not included in these first order assessments: spatial heterogeneity, climatic variability and regulation. To overcome these limitations we present a study for the entire Euro-Mediterranean region carried out at high spatial and temporal resolution accounting for reservoir operation and water management strategies under different climatic scenarios. Furthermore, practical planning and management of water resources require models with greater local real representation; these models provide improved estimates of the reasons behind vulnerability levels and how these might change as actions are implemented (Schewe et al., 2014). Here we use the WAAPA model (Garrote et al., 2011, 2015) that responds to these three determinants to understand the choices that could mitigate water shortages in the Mediterranean region.

In 2004 Pacala and Socolow provided an analysis and clarification of how current mitigation options could contribute to the stabilising atmospheric CO_2, creating the concept of stabilisation wedges (Pacala and Socolow, 2004). This concept has been used widely ever because it provides a clear-cut way to link science to policy. Wada et al. (2014) applied a 'water wedges' concept as a framework to examine policies to mitigate the negative effects of water scarcity. In all cases, the wedge concept reflects on the understanding that a suite of management alternatives has to be used since none of the alternatives could provide a unique solution alone.

The water management choices necessary to achieve the EU good environmental status target depend on the quantitative details of water saving potential of the strategies and the water policy that influences behaviour of the stakeholders that need to implement them. Water scarcity areas in Southern Europe are approximately one half of the total water scarcity of the entire Mediterranean region, which in turn represents the global region that sustains the largest amount of population with water stress (Iglesias et al., 2007). The environmental targets for this area include those collective for all the European Union and those of individual member States committed to focus his climate change adaptation plans on water resources (Quevauviller et al., 2005). In the global effort to reduce water scarcity, the potential of the Mediterranean region can significantly help to meet adaptation targets that exemplify other regions at risk (UN, 2003; Iglesias et al., 2011).

The role of water resource management to provide solutions was recognised since the early 1990s (Gleick, 2003) and has been a major area of research in the last decades (Boithias et al., 2014; Garrote et al., 2015; Quevauviller et al., 2005). Water management has a large, cost-competitive adaptation potential to meet short to medium term targets for reducing water scarcity risks (UN, 2013; Iglesias et al., 2012). The inefficient use of water by poor management is exacerbated by climate variability, which could produce severe impacts on future water resources in Europe. Thus there is a need to increase the implementation of strategies which maintain water availability and, in turn, optimise good ecological status. Many researchers agree on a set of specific strategies, measures and technologies which have potential to increase efficiency, improve the environment, maintain the water services of rural populations, and contribute to adaptation to climate change (Gleick, 2003; Ludwig et al., 2011). This set of strategies can include among others, a more coherent integrated management and the implementation of policies that make urban water systems more efficient.

Effective options, and their costs, are the main focus of recent research to facilitate governments' better understanding about the implementation of specific sets of strategies at the regional and local levels (IPCC, 2014). But the information on the cost of strategies is still limited and fragmented and remains a topic of disagreement (IPCC, 2014).

The literature on adaptation of water resources includes a diverse array of options and some very large estimates of the global potential (IPCC, 2014). Here we restrict our attention to the strategies that are relevant to semiarid environments and have linkages to climate change adaptation. About two thirds of the volume of water used in Euro-Mediterranean countries is managed inappropriately, up to one-half of the water is under poor ecological status, primarily due to the inter-annual climatic variability (Garrote et al., 2015). About half of the agricultural land suffers from water scarcity every year. Strategies such as improved management are not quantified at the local level or tested against other alternatives, and choices are often made without data to support them. By 1995, water reuse was well established in the region, and irrigation with water reused has been adopted in about one tenth of the agricultural land. This trend has a large potential for being implemented in 20% of the irrigated cropland (Garrote et al., 2015). A combination of options could be extended to most of the basins with water stress, accompanied by a verification programme that enforces the adoption of strategies that actually work as advertised, a good case could be made for the European Union Water Framework Directive