Science of the Total Environment 584–585 (2017) 219–233

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Combined impacts of climate and socio-economic scenarios on irrigation water availability for a dry Mediterranean reservoir

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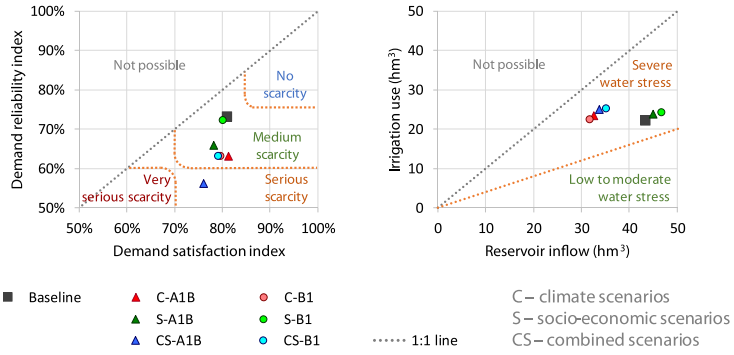
HIGHLIGHTS

- We studied the impacts of future climate and land-use on a Mediterranean reservoir.
- Lower supply reliability results from less rainfall and higher irrigation demands.
- Worsening trophic conditions result mostly from agricultural intensification.
- Future problems are essentially an aggravation of present-day problems.
- The characteristics of water supply systems are essential to assess vulnerability.

GRAPHICAL ABSTRACT



Water scarcity index (left) and water exploitation index (right) for baseline conditions and the six future scenarios; dashed lines represent water scarcity and water stress thresholds.

ARTICLE INFO

Article history:
Received 12 October 2016
Received in revised form 19 January 2017
Accepted 20 January 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Mediterranean region
Climate change
Land-use change
Irrigation water supply
Water scarcity

ABSTRACT

The impacts of climate and associated socio-economic changes on water availability, including supply and demand, quality, and storage volume, were evaluated for the Vale do Gaio reservoir in southern Portugal, located in a dry Mediterranean climate and already under drought stress. The SWAT model was applied with 6 scenarios for 2071–2100, involving two storylines (A1B and B1) with individual changes in climate (−9% rainfall, increasing in winter by +28 to +30%), socio-economic conditions (an increase in irrigation demand by 11%, and a replacement of cereals and pastures by sunflower), and a combination of both. Most future scenarios resulted in lower water availability, due to lower supply (−19 to −27%) combined with higher irrigation demand (+3 to +21%). This resulted in more years with limited irrigation supplies (presently: 28%; scenarios: 37 to 43%), although limitations were mitigated by lower losses to excess discharge. Land-use changes also decreased quality by increasing P concentrations (+29 to +93%). Impacts were more severe in scenario A1B than in B1, and in combined changes than in climate or socio-economic changes only. Water availability was resilient to climate change, as impacts led only to a moderate aggravation of present-day conditions. Lower future water availability could be addressed by supply and demand management strategies and, in the most extreme scenario, by water transfers from regional water reserves; water quality issues could be addressed through land-use policies. Results also highlighted the importance of taking the characteristics of water supply systems into account when designing adaptation measures for future changes.

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http://dx.doi.org/10.1016/j.scitotenv.2017.01.131
0048-9697/

1. Introduction

Water resources management in the Mediterranean rim of Europe faces several challenges due to variable rainfall patterns and high irrigation demand (EEA, 2012; Iglesias et al., 2011). Future climate in this region is expected to change towards warmer and drier conditions, decreasing available water resources (Collins et al., 2013; García-Ruiz et al., 2011; Kovats et al., 2014). This could be combined with land-use changes as farmers adapt to these drier climate conditions, for example by converting rain-fed to irrigated crops, possibly enhanced or countered by policy measures (Iglesias et al., 2011; Kovats et al., 2014). Such land-use changes could create new challenges for water management, especially as this region is already under water stress conditions (EEA, 2012; Iglesias et al., 2011).

Most research on future water availability in the Mediterranean has focused on the impacts of climate change, addressing water quantity alone (Garrote et al., 2016; Iglesias et al., 2011; López-Moreno et al., 2014; Majone et al., 2016; Mereu et al., 2016; Mourato et al., 2015; Piras et al., 2014; Pulido-Velazquez et al., 2015a; Sellami et al., 2016; Stefanova et al., 2015; Stigter et al., 2014) or combined with water quality (Bangash et al., 2013; Bussi et al., 2014; Carvalho-Santos et al., 2016; Molina-Navarro et al., 2014; Nunes et al., 2013, 2009, 2008; Rodriguez-Lloveras et al., 2016; Serpa et al., 2015; Simonneaux et al., 2015). In general, these studies pointed towards decreasing water availability, a greater seasonal contrast between wet and dry seasons, and, in cases of decreased vegetation cover, increasing sediment and nutrient exports. Models have also been used to examine the impacts of land use change on these parameters (Buendia et al., 2016; Rodriguez-Lloveras et al., 2015). More recently, research began to look into the combined impacts of climate change and associated changes in land use (Carvalho-Santos et al., 2016; López-Moreno et al., 2014; Molina-Navarro et al., 2014; Rodriguez-Lloveras et al., 2016; Serpa et al., 2015; Simonneaux et al., 2015). A key finding of these studies was that land-use changes could have a greater impact on sediment and nutrient exports and, hence, water quality, than changes in climate conditions alone. Ludwig and Roson (2016) introduced the current state of research on these topics. Research on the impacts of combined climate and land use changes has also been performed for other regions of the world (Bussi et al., 2016a, 2016b), and has been pointed as a pressing research need (Li and Fang, 2016).

Models have also been applied to examine Mediterranean water supply systems, taking socio-economic scenarios into account (Paredes-Arquiola et al., 2010; Paredes et al., 2010). Some of these studies have done a combined analysis of water supply vs. demand under climate change scenarios, taking into account the characteristics of the water supply infrastructure. Iglesias et al. (2011) demonstrated an evaluation framework in eastern Spain, using a simple water balance model with management policies to assess the capacity of existing water supply systems to satisfy demand in future climate scenarios and to propose policy recommendations for adaptation. Garrote et al. (2016) expanded a similar analysis to rivers in the Mediterranean rim of Europe, concluding that regional water infrastructures and management policies could be more determinant for climate change vulnerability than future climate scenarios. Girard et al. (2015), Mereu et al. (2016) and Stigter et al. (2014) used similar water balance approaches, applied in more detail, to examine the balance between supply and demand for specific supply systems in respectively southern France, Sardinia, and across Spain, Portugal and Morocco. These studies pointed to a decrease in water supply combined with an increase in irrigation demand, with the vulnerability of a system depending more on its characteristics and on the current balance between supply and demand than on future climate. Finally, López-Moreno et al. (2014) and Pulido-Velazquez et al. (2015b) applied complex process-based modelling approaches in Spain, to a reservoir and an aquifer respectively, concluding that land-use changes could have similar impacts on the demand-supply balance as climate change alone. Both studies conclude that socio-economic changes could be the sufficient for adaptation, the former by a modification to the water supply infrastructure and the latter by land-use change incentives to decrease nitrate leaching.

Not many studies have addressed future changes to water quality in supply infrastructures in the Mediterranean region, resulting from changes in sediment and nutrient inputs, even though such changes could present additional challenges for water supply infrastructures. For a Spanish reservoir, Bangash et al. (2013) applied a simple model based on water production and erosion indices to assess the impacts of climate change on water and sediment inputs, finding a decrease in streamflow as well as sediment input and, hence, reservoir siltation. In contrast, Molina-Navarro et al. (2014), using a complex process-based modelling approach for another Spanish reservoir, found that a synergistic effect between climate and land-use changes could lead to lower water and sediment input and, at the same time, to a deterioration of water quality. Neither study considered the additional impacts of an increased demand for irrigation water in the future.

The results of existing studies point to the importance of the characteristics of the water supply infrastructure and, in particular, its capacity to capture, store and supply sufficient water to meet demands, in determining the vulnerability of water resources to future conditions and in defining adaptation policy options. Similar conclusions have been reached in other regions of the world with a Mediterranean-type climate (Connell-Buck et al., 2011; Medellín-Azuara et al., 2011). Therefore, studies such as that of Garrote et al. (2016) are required, comparing different types of water supply systems (small reservoirs, integrated reservoir networks, aquifers…), different types of water uses (irrigation, domestic or industrial consumption, hydropower production…), and distinct environmental settings (climate, geology…) to evaluate common trends and future challenges.

This work presents an integrated approach to the assessment of the impacts of climate and land-use changes on a Mediterranean irrigation system, the Vale do Gaio reservoir in southern Portugal, where water resources are already under stress from high irrigation demands, mostly during severe drought years. The approach was tested using a subset of existing climate projections for the region. A process-based hydrological model was used, following calibration under present-day conditions, to estimate changes to water supply and demand as well as to sediment and nutrient inputs, caused by: (i) two scenarios of climate change; (ii) two associated scenarios of socio-economic change, each including increased irrigation demands, land-use changes, and lower population; and (iii) two scenarios combining climate and socio-economic changes. Results were evaluated in terms of supply provisioning and reliability, compared with vulnerability thresholds proposed by Iglesias et al. (2011), while the changes in sediment and phosphorus inputs were analysed in terms of reservoir siltation and lifetime, and water quality regulations, respectively.

2. Methods

2.1. Study area

This work was applied to the case study of the Vale do Gaio reservoir, with a usable volume of 63 hm^3, located at the end of the Xarrama watershed (528 km^2) in the dry region of southern Portugal (Fig. 1). The study area is relatively flat and has shallow soils, mostly Luvisols and Cambisols, overlaying relatively impermeable bedrock of schist and granite (Cardoso et al., 1973). The climate is dry Mediterranean, with rainfall concentrated in autumn and winter. Annual precipitation averages 595 mm but it is highly variable, ranging from 330 and 1140 mm between 1981 and 2010, so that severe droughts occur regularly, the last two in 2003–2005 and 2011–2012. These factors make irrigation an attractive option for agriculture, especially for growing crops during the dry summer season but also to limit the impacts of possible droughts. However, current agricultural land use is predominantly rainfed, consisting of a combination of pastures and winter cereals on croplands, and pastures underneath