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Climate change impacts on irrigated agriculture in the Guadiana river basin (Portugal)

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ABSTRACT

This study evaluates climate change potential impacts on irrigated agriculture in the Guadiana river basin, in the south of Portugal, by running long-term soil water balance simulations using the ISAREG model and taking into consideration the maximum potential yield. The ISAREG simulations were focused in a set of the most locally representative crops to assess the evolution of net and total water requirements, considering a monthly time step for two 30-year future periods, (2011–2040) and (2041–2070). Reference evapotranspiration was estimated using the temperature-based Hargreaves–Samani equation, and the simulations were performed using, as inputs, a combination of five climate change scenarios built using the Ensemble-Delta technique from CMIP3 climate projections datasets to set different alternative climate change bracketing conditions for rainfall and air temperature. Water balance outputs for different climate scenarios were combined with four agricultural scenarios allowing for the estimation of total irrigation requirements.

A general increase in crop irrigation requirements was estimated, mainly for those crops as maize, pasture, and orchards that are already big irrigation water consumers. Crops as olive groves and vineyards, well adapted to the Mediterranean conditions, show less sensitivity to climate change. The combined results of crop irrigation requirements for climate change and agricultural scenarios allow for the expectation of sustainability for the agricultural scenarios A and C, essentially defined by the complete use of the irrigation network and systems currently being constructed with the Alqueva project, but not for the ambitious irrigation area expanding scenario B.

1. Introduction

The Guadiana river basin, situated in southern Portugal, with a rich and diversified natural patrimony, presents important potential vulnerabilities in terms of physical and human desertification. In the Guadiana river basin region, socio-economic development has been, traditionally, highly dependent on the agricultural sector due to the lack of other valuable natural resources. Climate change and its related environmental local impacts are likely to be high, specifically in the agricultural and irrigation water availability domains.

Climate change has become universally recognized, based on scientific results backed by historically observed data, and also acknowledged by public perception in the last decades. Institutions like the Intergovernmental Panel on Climate Change (IPCC, 2014) and the European Environment Agency (EEA, 2012) have regularly reported works on observed and future climatic change and respective impacts and risks, and also mitigation and adaptation measures as policy requirements for a sustainable development. Climate change was already a strong concern in the Medalus project (Mairota et al., 1998). Within this project, Corte-Real et al. (1998) noted that “the Mediterranean is one of the areas where the impacts of climate change may be particularly severe” and that “a general decrease in rainfall for the western-central Mediterranean region in recent decades has been reported”. The same authors observe that during the three decade period 1961–1990 rainfall has decreased sharply in March, reflecting in spring totals 23% less rainfall in the case of the Alentejo region, “with a detrimental effect on the growth of cereal crops”.

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Within the same project Goodess et al. (1998) estimated future climates using GCM models with increasing CO_2 contents in the atmosphere, coupled with statistical models for sub-grid scale results, compensating for the large (300 km) grid elements typical to GCM models. These authors conclude that "effects on agriculture, for example, may be better described by looking at changes in the availability of water for crop growth". For the same authors, potential evapotranspiration (*ETo*) cannot be estimated from GCM. "Rather more confidence can be placed in GCM estimates of temperature, which can be related to *ETo* by an empirical formula. . .".

One of the remarkable aspects of climate change over the Mediterranean region is the increasing frequency of extreme climatic events as droughts. A recent example of a drought event occurrence was in the hydrological year of 2004/2005, one of the most severe and spatially extensive on record in Portugal (Botelho and Ganho, 2010). More recently, within the first 5 months of 2012, the Portuguese territory experienced a situation of severe drought due to low rainfall in the winter months, inspiring public and governmental concerns on climate change.

One of the most complete reports on climate change in Portugal, SIAM II (Santos and Miranda, 2006), underlines that the 6 warmest years in the period between 1931 and 2000 occurred in the last 12 years of the twentieth century. The SIAM II report also performed a thorough and relevant climate change characterization in Portugal, confirming the rising trends of mean air temperature and decreasing rainfall. Within the project SIAM II, Cunha et al. (2006), reporting on climate change impacts on water resources availability, concluded that "the tendency for reduction both on surface and groundwater is evident, especially in the centre and south regions of Portugal, with increasing non-symmetric distribution during the year, the rainfall concentrating in winter and reducing in spring, summer and fall. The same authors conclude that flow reduction in the rivers of south Portugal and Spain should deserve a particular attention on the strategy for adapting to climate change.

Other authors within the same project (Pinto et al., 2006) referring specifically to climate change impacts on Portuguese agriculture, used GCM (large scale) and regional (intermediate scale) climate change models and the FAO CERES models for crop yields. These authors conclude that drastic reduction on yields is predicted for crops like wheat and maize (up to 50% loss), and even more (up to 75%) for rice. Pasture and fodder crops are the only group of crops that may increase yields (up to 75%) on the future.

Within the present project, Valverde et al. (2014) analysing the CC impacts on crop yields over the Guadiana river basin during the historical period 1960–2010, observed similar in sense but less in absolute values tendencies for decreasing crop yields due to decreasing rainfall and increasing irregularity of precipitation and the values of temperature.

For the Guadalquivir basin in south Spain, next to the Guadiana basin, Rodríguez Díaz et al. (2007) in a study of climate change impacts on future crop irrigation requirements, stated that ". . . climate change threatens to exacerbate the current supply-demand imbalance" and modelled an increase in irrigation water requirements between 15 and 20% by the year 2050.

The consequences of global warming impacts on agriculture, water resources management and ecosystems pose particular concern in the Mediterranean climates in the transition zone between the arid climate of North Africa and the temperate climate of central Europe. The Mediterranean region, characterized by desert-climate transition features is potentially highly vulnerable to existing adverse trends of warming and rainfall reduction and will likely be the region within Europe to firstly experience severe economical and sociological consequences from climate change. Management and allocation of water are thus particularly sensitive issues in the local agricultural context.

The Alqueva dam is one of the biggest dams and the largest artificial lake (250 km^2) in West Europe, retaining water from the Guadiana river basin, with a total storage capacity of 4150 hm^3, of which 3150 hm^3 are usable during regular operation (EDIA, 2013). The Alqueva dam and its irrigation network was a project ambitioned for many decades and planned so as to counteract the poor water availability in the region. It has been, since its implementation in the first decade of this century, the major driving force for the development and expansion of irrigated agriculture in the region, providing a steady source of water supply and lessening the vulnerability of local farming, traditionally limited by water availability and the typical variability that characterizes the Mediterranean climate.

The intensification of irrigation is susceptible to a build-up of soil degradation processes, causing a reduction in overall soil water storage capacity and an increase in surface runoff, resulting in a significant loss of soil fertility. Irrigation management practices will therefore have to be planned to balance short-term economical returns with long-term sustainability, avoiding the effects contributing to the enhancement of the desertification processes.

Climate change, water availability and farming practices are indirectly interwoven with each other and many of the future challenges of a sustainable agricultural activity in the Guadiana river basin rely on both soil and water conservation practices to cope with the inevitable pressure of climate warming and rainfall reduction and irregularity.

Crop sensitivity to climate change is an important regional issue to be taken into account as adverse climate conditions can lead to considerable differences in overall basin-scale water consumption. Crop choices and irrigation management have a considerable effect in agriculture economic and environmental sustainability, and crop choice is frequently mentioned as one potential adaptation strategy to climate change. However, farmers often choose crops (woody perennial or herbaceous annual) based on a host of contextual factors such as crop revenue, water availability, soil conditions and government policies, disregarding climate change as a secondary concern.

Looking at this context, the main specific objectives of the present work can be described as to evaluate climate change for the Guadiana river basin and its impacts on the irrigation requirements of chosen crops within appropriate agricultural scenarios, as well as to evaluate the sustainability of such scenarios according to the water resources availability in the basin, holding policy decisions on water resources management integrating agricultural and other uses within the basin.

2. Materials and methods

2.1. Description of the study area and crop distribution

The study area is the Portuguese part of the Guadiana river basin, in southern Portugal. To allow an enhanced spatial resolution of climatic heterogeneities and, therefore, to provide a better assessment of the crop water use impacts, the Guadiana river basin was divided into six main units of analysis (UA) defined by the main sub-basins of the tributaries of the Guadiana river. This spatial definition was adopted from previous works carried out under a pilot project for the development of a Portuguese Drought Forecasting and Management System (Serralheiro et al., 2010; Vivas et al., 2010; Vivas and Maia, 2010). Two additional spatial units (7 and 8) were added to those referred, representing areas located outside the Guadiana river basin – one (7) in the Sado river basin (Alentejo region) and the other (8) in the eastern part (Sotavento) of the southern Ribeiras do Algarve river basin (Algarve region) – but irrigated with water abstracted from it, as shown in Fig. 1.