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An accurate evaluation of water availability in sub-arid Mediterranean watersheds through SWAT: Cega-Eresma-Adaja

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ABSTRACT

Simulation of flow processes in hyper-regulated Mediterranean watersheds is critical when examining general water demand and established ecological flows of River Basin Management Plans. Weather dynamics in the Mediterranean zone in recent decades have been characterised by a natural variation of drought cycles. In addition, exacerbated climate change proves that water fluxes must be estimated with more exhaustive models. The aim of this study is to assess the water balance of the Cega-Eresma-Adaja (CEA) watershed, including a detailed assessment of land uses and management practices to quantify agricultural water demand for the time period 2004–2014. We used the Soil and Water Assessment Tool (SWAT), given that it is a widespread tool that involves complex processes of the water cycle on a basin scale, providing information on water dynamics related to land use as a fundamental characteristic for water balance calculation. The Nash-Sutcliffe coefficient efficiency value, the main index of calibration and validation performance, was 0.86 for the Eresma-Adaja River and 0.67 for the Cega River. This presents a good result considering the large-scale watershed studied. Analysing dry hydrological years, we found that the estimation of ecological flows for sub-arid zones needs to consider the shallow aquifer-river relationship. During spring-summer periods, with very low flow, monitoring the shallow aquifer levels ensures a good ecological status. The study reveals that aspects such as crop rotation, soil management and their associated measures in Mediterranean basins are key factors for water resource management during drought periods. These results are expected to serve stakeholders and river basin authorities in conducting better-integrated water management practices in the watershed.

1. Introduction

Water availability in the Mediterranean zone has been a subject of research in recent decades, and its assessment on a basin scale is a priority to secure water availability for different users, including fresh water, industry, agriculture and hydropower in southern Europe (Calbó, 2010; Giorgi and Lionello, 2008; Rafael et al., 2010). Agriculture is the major water user in Europe, accounting on average for 32% of total freshwater abstractions (EUROSTAT, 2017). In southern Europe, agricultural abstractions are greater, accounting for an average of 52% of total freshwater abstractions (EUROSTAT, 2017). In sub-arid climates, agricultural water extractions can reach 80%, and often become a source of disputes amount water users (European Comission, 2012). The usual implementation of flow regulation strategies in these areas to meet increasing water demands, through reservoirs and artificial recharge of aquifers, captures the majority of the surface flow of rivers and results in a low flow system affecting riverine ecosystems and water availability (Tharme, 2003).

In Mediterranean watersheds of southern Europe, irrigated agriculture is a common strategy to ensure crop production and is considered a key driver in water scarcity (Psomas et al., 2016). Because of this, agricultural water demand must be reformulated, based on an integrated land use management approach, considering both irrigated and rainfed crops. Specific mitigation and adaptation measures for water resources management are needed to reconcile water demands from multiple users, as outlined in the River Basin Management Plans (RBMPs) (European Comission, 2012; European Environment Agency, 2015). The EU 2020 strategy and the Water Framework Directive (WFD) have been promoting several policies for water savings and its protection. Additionally, the Programme of Measures (PoMs) aims to achieve a satisfactory status for surface and groundwater bodies. Several tools, such as remote sensing, are used to identify land uses and the

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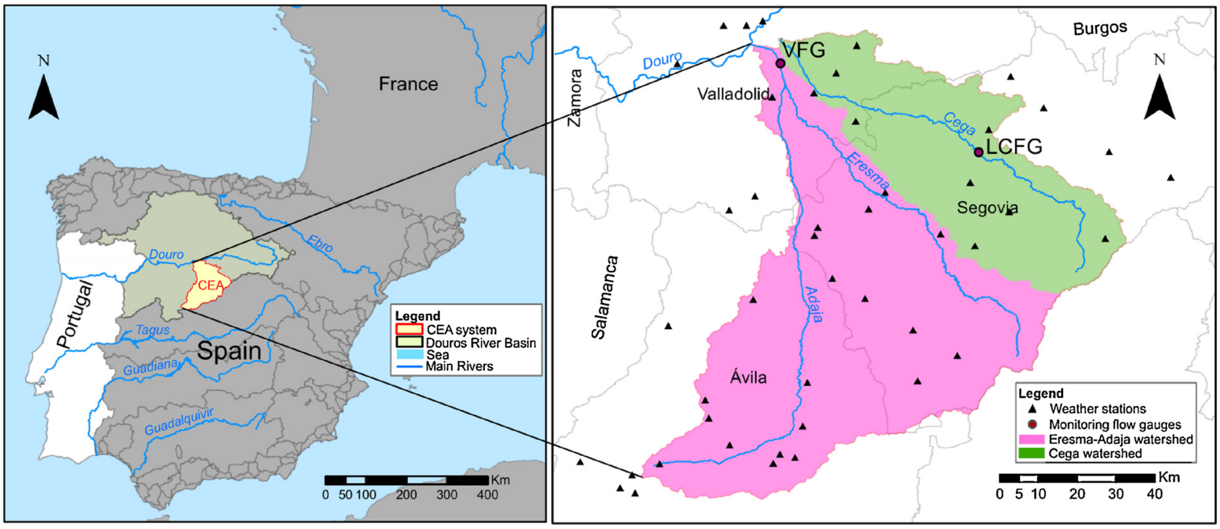

Fig. 1. Location of the study area in Douro's River basin, river network and flow gauges.

application of hydrological models to quantify real and potential water demand for agriculture.

Consequently, a sustainable management vision of water resources at watershed scale requires the inclusion of some measures at plot scale. Hence, through modelling, the cumulative effect of detailed land operations could be assessed for the watershed water fluxes. Hydrology models that include water fluxes related to land use can help decision makers formulate strategies in the water-energy-land-food nexus (Dodds and Bartram, 2016; Hoff et al., 2012). Furthermore, the water balance model alone is not enough; the environmental situation, the inclusion of hydrological dynamics in changing environments (Wang et al., 2016), climate change (Narsimlu et al., 2013), land use (Zhao et al., 2016), crop practices (Ullrich and Volk, 2009) and reservoir operation schedules (Kalogeropoulos et al., 2011) are also required to achieve an integrated water management scheme.

River basin authorities (RBA) use water management models as a tool to assess and guarantee water demands. Those models serve to manage water fluxes based on predefined and estimated water demands (e.g. water supply, irrigation and industry) and the associated regulatory infrastructure. Nevertheless, water balance is dynamic in time and space. Hence, to improve water management, more variables must be included to achieve a more accurate water balance. The water balance must include land use dynamics and cropland practices. The sensitivity of water availability in the catchment could be modified due to land use change for future water demands. This is why detailed hydrological models can be very useful tools for planning purposes.

As in any modelling exercise, hydrological models assume simplifications of a real-basin system and some degree of uncertainty is thus unavoidable. Therefore, the assumed simplifications should be considered cautiously, as they could affect the results. For example, if water demand by land use is expected, as a result, simplifications of this subject must be fully described by the model.

The SWAT is a spatially, semi-distributed and physically-based eco-hydrological model, developed by the USDA Agricultural Research Service. The application of SWAT, unlike other hydrological water management models, includes the viability of agricultural water demand in space and time. The model is largely used to evaluate the impact on land management over extended periods of time (Arnold et al., 1998). The use of SWAT as a tool to assess daily stream flows helps improve the general water balance, providing a new modelling trend for RBMPs. This water balance is influenced by crop rotations and farm practices, obtaining a better quantification and understanding of land management decisions in the watershed hydrology (Seeboonruang, 2012). At the same time, governments make an effort collecting accurate data from remote sensing and surveys. These have recently been used for the SWAT model setup (Ashraf Vaghefi et al., 2015; Guzinski et al., 2014; Laurent and Ruelland, 2011).

The aim of this study is to assess the water balance of the Cega-Eresma-Adaja (CEA), a Mediterranean watershed currently facing serious water stress, mainly as a result of a growing water demand for irrigation, compounded by increasing urbanisation. During the period from 2010 to 2016, the CEA was considered one of the most profitable areas for farming in Spain due to the expansion in horticultural production (Antequera et al., 2014). However, the growing demand for water is rapidly deteriorating the status of existing water bodies and threatening the sustainability of the basin and its economic activities. The situation may be worsening, as the RBMP (2015–2021) forecasts an increase of 18% (equivalent to 7000 ha) in the current irrigated area by 2027, despite the existing water gap. The purpose of this research is also to establish a comparison between RBA estimates for agricultural water demand, and model results will be provided to study the sustainability of the irrigated area expansion in the catchment.

2. Materials and methods

2.1. Study area

The CEA is located in the central north of the Iberian Peninsula, and consists of two adjacent sub-basins that are jointly defined as a hydrological management system by the Douro River Basin Authority (DRBA) (Fig. 1). The stream network defined by the Eresma and Adaja sub-basins represents 67% of the total CEA area, while the watershed defined by the Cega comprises 33%. The former are regulated at the upper river network, while Cega is not yet regulated.

The Eresma and Adaja sub-basin, with a total discharge of 407 hm^3 yr^{-1}, equivalent to 63% of the total discharge capacity of the CEA and the Cega sub-basin, provides the remaining 37% of CEA discharge (238 hm^3 yr^{-1}). Most of the rivers in the CEA system are directly connected to the aquifers (IGME, 2008). The frequent descent of the water table level, due to overexploitation, is causing a disconnection between the riverbed and the aquifer. This situation is exacerbated in dry periods, where most of the rivers have very low flows (CHD, 2015).

Nine major soil groups could be found in the area: Cambisols (34%), Luvisol (26%), Arenosols (19%), Leptosol (11.5%), Fluvisols (4%), Regosol (3%), Solonetz (1%), Solonchak (1%) and Gleysol (0.5%). The soil genesis is typically developed from moorland limestone in the northeast, Mesozoic carbonates in the headwater area and is detritic in the basin landfill (IGME, 2009). Sandy soils are the representative