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Research papers

Harmonizing human-hydrological system under climate change: A scenario-based approach for the case of the headwaters of the Tagus River

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ABSTRACT

Conventional water management strategies, that serve solely socio-economic demands and neglect changing natural conditions of the river basins, face significant challenges in governing complex human-hydrological systems, especially in the areas with constrained water availability. In this study we assess the possibility to harmonize the inter-sectoral water allocation scheme within a highly altered human-hydrological system under reduction in water availability, triggered by projected climate change applying scenario-based approach. The Tagus River Basin headwaters, with significant disproportion in the water resources allocation between the environmental and socio-economic targets were taken as a perfect example of such system out of balance. We propose three different water allocation strategies for this region, including two conventional schemes and one imposing shift to sustainable water management and environmental restoration of the river. We combine in one integrated modelling framework the eco-hydrological process-based Soil and Water Integrated Model (SWIM), coupled with the conceptual reservoir and water allocation modules driven by the latest bias-corrected climate projections for the region and investigate possible water allocation scenarios in the region under constrained water availability in the future. Our results show that the socio-economic demands have to be re-considered and lowered under any water allocation strategy, as the climate impacts may significantly reduce water availability in the future. Further, we show that a shift to sustainable water management strategy and river restoration is possible even under reduced water availability. Finally, our results suggest that the adaptation of complex human-hydrological systems to climate change and a shift to a more sustainable water management are likely to be parts of one joint strategy to cope with climate change impacts.

1. Introduction

During the visit of the EU commissioners to the headwaters of the Tagus River Basin on the 9th of February 2016 the local stakeholders described the river to them as "practically dead" (ABC, 2016). Here, nearly all available water resources are allocated to the economic needs of the Southeast of Spain through the famous Tagus-Segura Transfer, leaving the Upper Tagus River itself (characterized by a high seasonal of flows in natural conditions) with the constant minimal flow throughout the year. This water management strategy has launched the so-called "la guerra del agua" or "war over water" between the local stakeholders, worried about the environmental state of the river, and the beneficiaries of the controversial Tagus Segura Water Transfer, interested mainly in economic profits. The EU commissioners expressed their high concerns regarding the state of the Tagus river, criticizing Spanish water management course, and underlined the necessity of a shift to the Integrated River Basin Management, to comply with the Water Framework Directive (WFD) requirements (European Parliament, 2016).

There is a historic tradition of water management practices in Spain due to endemic asymmetry between water demands and water availability across the country, characterized by strong seasonality and inter-annual variability. Over the whole 20th century the water management paradigm of the Spanish government was

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focused on satisfying water demands of key economic sectors and was largely ignoring the environmental concerns (Cazcarro et al., 2014). Up until now, the general management strategy of Spanish rivers clearly prioritizes the short-term economic interests (González Del Tánago et al., 2012) instead of having a long-term view of the economic, social, and environmental benefits of adopting a more integrated sustainable water management approach, as required by the WFD. Even though the allocation of the environmental flows was mentioned as the most important measure for river restoration in the Spanish National Strategy of River Restoration, which emerged after the WFD launch (MAGRAMA, 2010), there is a large social and cultural pressure against it. Assigning scarce and highly profitable water resources to the environment is perceived by the stakeholders as a misuse of a valuable resource (González Del Tánago et al., 2012).

Nowadays many rivers, like the Tagus River, cannot be considered as solely natural systems anymore, but as the coupled human-hydrological systems due to significant alterations in the hydrological dynamics imposed by humans. Such systems are characterized by a high complexity and reciprocal feedbacks of their components (Liu et al., 2007). Often, when management strategies of these systems are serving solely economic and social needs, as in the case of the Tagus River, the sustainable limits of the natural hydrological system have been exceeded (Savenije et al., 2014). This increases their vulnerability to the projected changes in climate, if a decrease in river discharge is projected and escalates the probability of the potential collapse of a hydrological system. This, in turn, would lead to strong adverse effects on humans (Savenije et al., 2014), and therefore the resilient functioning of the human-hydrological systems has to be ensured.

To tackle such problems, the Integrated Water Resources Management (IWRM) approach has been proposed as a way to harmonize multiple social, economic and ecologic goals while accounting for the risks related to climate change (Döll et al., 2014; Pahl-Wostl, 2007). The IWRM approach, among other aspects, implies sustainable re-allocation of the water resources among water users and harmonization of the water demands of the system, including the allocation of water resources to the environment (Marston and Cai, 2016). The IWRM approach is also aligned with the Sustainable Development Goals (SDGs) spearheaded by the United Nations, in particular the goal on 'Life on Land' designed to protect, restore and promote sustainable use of terrestrial ecosystems, and stop land degradation and biodiversity loss (United Nations, 2016).

The issues, associated with water allocation and re-allocation for sustainability, were thoroughly discussed by Marston and Cai (2016). The process is associated with many challenges and requires integrated and interdisciplinary approaches (Falkenmark, 2009) and it has to account for long-term hydro-climatic variations. While there is a large body of research on optimization of water allocation among users for maximization of the economic profits and benefits, the issue of water allocation to the nature still lacks enough attention. Among the recent assessments considering allocation of water to the environment are e.g. a study conducted by Cai and Rosegrant (2004), who assessed the water allocation scenarios for the Yellow River in China, and a study by Suen and Eheart (2006), who performed an assessment of the reservoir management strategies to meet the environmental and human demands in the Dahan River, in Taiwan. In Spain, Varela-Ortega (2008) performed a study of policy implication on the trade-offs between the water allocation to agriculture and environment. She engaged a hydro-economic and hydrological model to study policies for an aquifer in the Guadiana River Basin.

In Spain, where the regulation capacity of the rivers is almost exhausted, and many rivers can be classified as the "closed" type (Falkenmark, 2009) as practically all available water resources are already allocated, the expected changes in climate and associated decrease in water availability will make the management of such systems even more challenging (González-Zeas et al., 2015). The assessment of climate change impacts on water availability in Iberia was performed on the scale of the Iberian Peninsula, as well as for single river basins, or their parts (e.g. Kilsby et al., 2007; Morán-Tejeda et al., 2010b; López-Moreno et al., 2011; Guerreiro et al., 2014; González-Zeas et al., 2015; Lobanova et al., 2016). All studies agreed on decreasing trends in precipitation and reduced water availability in the Iberian Rivers, especially under high-end scenarios. These trends can be considered to be robust as the studies conducted employed different methodologies, hydrological models and global warming scenarios.

In this study we aim to investigate the opportunity to reallocate the water resources within a highly modified human-hydrological system, in order to ensure environmental restoration of the hydrological system while still supporting the socio-economic activities in the face of moderate and high-end climate change. Taking the headwaters of the Tagus River Basin as a critical example representative of a highly altered human-hydrological system, we explore the possibilities to impose a more sustainable operation of the reservoirs maintaining environmental flows in the river while still supporting the operation of the Tagus Segura Water Transfer employing a scenario-based approach. The Soil and Water Integrated Model (SWIM) (Krysanova et al., 1998), coupled with water allocation and reservoirs modules was applied to simulate the water allocation scenarios within the coupled human-hydrological system of the Tagus River headwaters in one integrated framework. We employed the latest climate change scenarios to assess the deviation in the water inflow, volumes of the reservoirs and water supplied to the Southeast Spain triggered by climate change under different management strategies. While our study accounts for the influence of humans on the hydrological pattern and environmental state of the Tagus River it should not be confused with the coupled human-nature system study, which can account for two feedback loop to represent the dynamics of the system: the influence of the humans on hydrological patterns and the influence of the hydrological patterns on the humans, while scenario-based approach applied in these paper only accounts for the influence of the humans on hydrological processes.

We show that current conditional management strategy of the Tagus headwaters, based on assumptions of the past has not only exceeded the limits of the hydrological system, but is also unsustainable in the face of moderate and high-end climate change. Our results point that a shift to the IRBM in the highly-modified human-hydrological systems is possible even under reduced water availability, triggered by climate change.

2. Case study

The Tagus River Basin is one of the largest and the most important rivers in the Iberian Peninsula (IP). With the catchment area covering approximately 80,000 km^2 and average annual discharge of 500 m^3/s at the outlet, the Tagus River is an important strategic water resource for Portugal and Spain. Approximately 15% of Spanish and 30% of Portuguese population depend on water resources provided by the Tagus River Basin, which are used for irrigation, domestic water supply and hydropower production. Due to that and significant inter-annual variability of flows, with the high flows in winter and low flows in summer, the Tagus River Basin is also one of the most regulated rivers in Europe. An extensive network of water abstraction channels and reservoirs emerged in the basin since the 1960s, ensuring the continuous and stable water supply for agricultural, hydropower and urban water demands throughout a year.