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Water supply sustainability and adaptation strategies under anthropogenic and climatic changes of a meso-scale Mediterranean catchment

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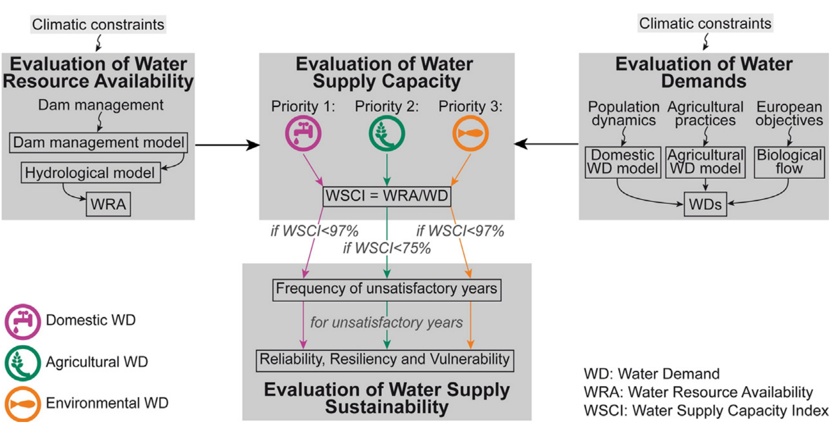
GRAPHICAL ABSTRACT



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ABSTRACT

Assessing water supply sustainability is crucial to meet stakeholders' needs, notably in the Mediterranean. This region has been identified as a climate change hot spot, and as a region where water demand is continuously increasing due to population growth and the expansion of irrigated areas. The Hérault River catchment (2500 km^2, France) is a typical example and a negative trend in discharge has been observed since the 1960s. In this context, local stakeholders need to evaluate possible future changes in water allocation capacity in the catchment, using climate change, dam management and water use scenarios. A modelling framework that was already calibrated and validated on this catchment over the last 50 years was used to assess whether water resources could meet water demands at the 2030 horizon for the domestic, agricultural and environmental sectors. Water supply

Abbreviations: AWD, agricultural water demand; CO, climate only; DWD, domestic water demand; EWD, environmental water demand; FUY, frequency of unsatisfactory years; GCM, General Circulation Model; INSEE, Institut National de la Statistique et des Etudes Economiques; MEEDDM, Ministère de l'Ecologie, de l'Energie, du Développement Durable et de la Mer; PACC, Plan d'Adaptation au Changement Climatique; PET, Potential Evapotranspiration; R, reference; REL, reliability; RES, resiliency; SDAGE RMC, Schéma Directeur d'Aménagement et de Gestion des Eaux du bassin Rhône-Méditerranée et Corse; SMBFH, Syndicat Mixte du Bassin du Fleuve Hérault; UAC, water use and climate; UO, water use only; VUL, vulnerability; WD, water demand; WRA, water resources availability; WSCI, water supply capacity index.

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sustainability was evaluated at the sub-basin scale according to priority allocations using a water supply capacity index, frequency of unsatisfactory years as well as the reliability, resilience and sustainability metrics. Water use projections were based on the evolution of population, per-unit water demand, irrigated areas, water supply network efficiency, as well as on the evaluation of a biological flow. Climate projections were based on an increase in temperature up to 2 °C and a decrease in daily precipitation by 20%. Adaptation strategies considered reducing per-unit water demand for the domestic sector and the importation of water volume for the agricultural sector. The dissociated effects of water use and climatic constraints on water supply sustainability were evaluated. Results showed that the downstream portions would be the more impacted as they are the most exploited ones. In the domestic sector, sustainability indicators would be more degraded by climate change scenarios than water use constraints. In the agricultural sector the negative impact of water use scenarios would be stronger. The environmental sector would be hardly satisfied especially in summer with low resilience levels. The adaptation strategies considered in this study would not be sufficient to cope with both anthropogenic and climate changes. Other strategies were discussed based on known examples in the Mediterranean context.

1. Introduction

1.1. Integrated approach on water supply assessment for future impact studies

The conclusions of the fifth IPCC report AR5 show that since AR4 the awareness of human influence on global warming since the mid-20th century has grown. This influence is being now considered as “extremely likely” (IPCC, 2013). Moreover even if greenhouse gas emissions are stopped now the impacts of past and present emissions, on the water cycle among others, will continue in the next centuries. This highlights the urgent need to evaluate the possible impacts of climate change on water resources management and to investigate how policy-makers and the general public may mitigate and adapt to these changes. The Mediterranean is one of the most vulnerable regions to climate change (Giorgi, 2006) as in the second half of the 20th century streamflows decreased by half in many basins (García-Ruiz et al., 2011) while water demand doubled (Blinda and Thivet, 2009). Subsequently the water stress index that was already high to very high in various basins of this region could increase in the future under the constraint of climate and anthropogenic changes (Milano et al., 2013b).

Integrative water management approaches have been developed to allow the analysis of climate change impacts, as well as the co-evolution of water uses related to these changes in the past, present and future periods (see e.g. Yates et al., 2005; Quilbé and Rousseau, 2007; Sun et al., 2008; Bhadwal et al., 2013). These approaches have been used to explain and represent the combined dynamics of climate, hydrosystems and anthroposystems and help the decision-makers to evaluate the sustainability of their water management systems. Arnold (2013) underlined the difficulties in developing such approaches that gather together data from diverse disciplines, especially on meso-scale catchments (considered here for catchments from 1000 to 10,000 km^2). At this scale, water stakeholders need to identify the limits of water supply capacity that could arise on their territory. Moreover the temporal scale of integrative approaches should be representative of the hydro-climatic variability as well as the evolution of anthropogenic constraints on time periods long enough so that the modelling chain can be tested for its robustness and used for future impact studies. One of the main constraints at this spatial scale relies on the generally poor available datasets for water withdrawal and socio-economic series over several decades (Hannah et al., 2011; Grouillet et al., 2015).

In this context, Collet et al. (2013b) presented an integrative water management approach developed on a meso-scale catchment in the French Mediterranean. This modelling framework was applied at a semi-distributed scale over a long period of time, based on the compromise between (i) the aim of evaluating the long-term evolution of water supply capacity and (ii) the availability of hydro-climatic and socio-economic data series with an appropriate time step. This study was part of a wider project on this catchment that aims at evaluating possible future changes in water supply capacity and sustainability under climatic and anthropogenic constraints. It was thus developed in order to be used in a prospective impact study.

1.2. Context for building future complex scenarios

Future impact studies imply building complex future scenarios that rely on the variation of numerous variables such as population, per-unit water demand, crop types, water network delivery efficiency, temperature, precipitations, etc. Water use scenarios should take into account policy constraints related to climate change at various decision-making levels. At the European Union scale, the Water Framework Directive advocates that water bodies attain a good ecological status by 2015. At the French scale, the December 2006 law on water and aquatic environments transcribes these European objectives to the national scale. In parallel, the August 2009 law allows the implementation of measures decided at the Grenelle Environmental Summit through a national climate change adaptation plan. This plan was defined in 2011 and sets a quantified target of reducing the water withdrawals by 20% by 2020. At the basin scale, the authority for water management in southeast of France is SDAGE RMC (Schéma Directeur d'Aménagement et de Gestion des Eaux du bassin Rhône-Méditerranée et Corse). For the period 2011–2015, one of the main objectives of SDAGE RMC is the return to a quantitative equilibrium between water resources and demands, by improving water resource sharing and the anticipation of the future. Meso-scale basins presenting quantitative water management troubles, such as the Hérault River catchment, were identified and a Water Development and Management Plan was developed for each of them to define concrete decisions that would allow the basin, French and European water management objectives to be reached.

Using a wide range of General Circulation Models (GCMs) outputs is generally recommended to estimate a set of possible futures in impact studies, as well as the probability of occurrence of these future scenarios (Wilby, 2010). With this approach, uncertainty of climate models outputs should be characterised and sensitivity and performance of impact models should be evaluated. However as reported by Ludwig et al. (2014) the use of these simulations add numerous uncertainties in future water availability estimation, related to the GCMs model structure that generates large biases in simulation, especially precipitation. Moreover, great uncertainty remains around regional projections in the Mediterranean basin (e.g. Palatella et al., 2011). This can lead to a multiplication of results and of result ranges, which make them more complex to interpret and used by decision-makers. Moreover the physical and chemical constraints implied in rainfall formation processes occur at a spatial scale largely smaller than GCM resolution (Planton et al., 2005). It makes GCM local estimation of precipitation unreliable, especially in regions where precipitation events occur sparsely and can vary greatly in intensity in a very short time. This study does not seek to estimate a wide range of possible futures in water management