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Assessment of the water supply:demand ratios in a Mediterranean basin under different global change scenarios and mitigation alternatives

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HIGHLIGHTS

- The supply:demand S:D ratio is used to valuate the water supply ecosystem service.
- The S:D ratio is calculated for 9 global change scenarios and at 5 spatial scales.
- Basin-scale water demand may not be met by the supply under the worst case scenario.
- The S:D ratio provides similar values than a monetary metric, the price of water.
- It can be used as a spatially explicit metric to valuate water provisioning service.

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ABSTRACT

Spatial differences in the supply and demand of ecosystem services such as water provisioning often imply that the demand for ecosystem services cannot be fulfilled at the local scale, but it can be fulfilled at larger scales (regional, continental). Differences in the supply:demand (*S:D*) ratio for a given service result in different values, and these differences might be assessed with monetary or non-monetary metrics. Water scarcity occurs where and when water resources are not enough to meet all the demands, and this affects equally the service of water provisioning and the ecosystem needs. In this study we assess the value of water in a Mediterranean basin under different global change (i.e. both climate and anthropogenic changes) and mitigation scenarios, with a non-monetary metric: the *S:D* ratio. We computed water balances across the Ebro basin (North-East Spain) with the spatially explicit InVEST model. We highlight the spatial and temporal mismatches existing across a single hydrological basin regarding water provisioning and its consumption, considering or not, the environmental demand (environmental flow). The study shows that water scarcity is commonly a local issue (sub-basin to region), but that all demands are met at the largest considered spatial scale (basin). This was not the case in the worst-case scenario (increasing demands and decreasing supply), as the *S:D* ratio at the basin scale was near 1, indicating that serious problems of water scarcity might occur in the near future even at the basin scale. The analysis of possible mitigation scenarios reveals that the impact of global change may be counteracted by the decrease of irrigated areas. Furthermore, the comparison between a non-monetary (*S:D* ratio) and a monetary (water price) valuation metrics reveals that the *S:D* ratio provides similar values and might be therefore used as a spatially explicit metric to valuate the ecosystem service water provisioning.

1. Introduction

Among all provisioning ecosystem services, supply of clean water has the highest value (Costanza et al., 1997). Its value is even higher in situations of water scarcity, that is where and when there is not enough water resource to meet all the demands, including those needed for ecosystems to function effectively (Brisbane Declaration, 2007; Meijer et al., 2012; Rolls et al., 2012). Unlike drought, which describes a natural hazard due to climate variability, water scarcity is typically a management issue related to the long-term unsustainable use of water resources, i.e. more water is being used than that structurally available (Barceló and Sabater, 2010; Van Loon et al., 2012). Water scarcity is common in semi-arid regions, such as the Mediterranean (López-Moreno et al., 2010), but it also occurs in other temperate regions when resources are over-committed (Stahl et al., 2010). Overall, water scarcity depends on both water availability and consumption (supply and demand), and is a fundamental economic problem of having humans with unlimited wants in a world of limited resources (Fisher et al., 2009; Paetzold et al., 2010; Syrbe and Walz, 2012; TEEB,

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2010). Supply and demand are defined in this study according to Burkhard et al. (2012): the supply of ecosystem services refers to the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period that is available for human enjoyment; the demand for ecosystem services is the sum of all ecosystem goods and services currently consumed or used in a particular area over the same time period.

As human population densities increase, there is often a spatial mismatch between the places where humans use services derived from ecosystems and the locations of the ecosystems that produce these services (Brauman et al., 2007; Kroll et al., 2012). This spatial mismatch between service production and the enjoyment of its benefit is a common feature within ecosystem service assessment (Fisher et al., 2009; Hein et al., 2006; Verburg et al., 2012; Willaarts et al., 2012). Furthermore, spatial differences in the supply and demand of services may imply that the demand for ecosystem services cannot be fulfilled at the spatial scale at which management decisions take place (Hein et al., 2006).

The balance between water supply and demand therefore needs to be defined in space and time, as the results might differ depending on the considered spatial and temporal extensions (Syrbe and Walz, 2012). For example, water scarcity might be identified at the seasonal scale when demand is much higher than supplied or stored water, but not at the annual scale, as wetter seasons might counteract dry seasons (Wada et al., 2011) or reservoirs may recover their water reserves. The same applies for space, as the balance between supply and demand might change considerably depending on the considered area in a heterogeneous basin. These changes in space and time can be expressed by the supply:demand (S:D) ratio. This metric summarizes the balance between the maximal potential service provisioning of the ecosystem service with the actual use of the service (Vörösmarty et al., 2000) within a particular time period. Thus, S:D ratios above unity imply that not all the provisioned water is used, while ratios below unity imply that not all the demand can be satisfied. Therefore, the S:D ratio can also be used as a water scarcity index.

At large scale, the water supply mainly depends on climatic factors that cannot be influenced by management, whereas the role of management and policies are important on the demand side (Curran and de Sherbinin, 2004). Freshwater policies are mainly focused on decreasing the demand by improving efficient water use, adjusting land-uses to water availability, or setting water pricing. In Europe, the Water Framework Directive (WFD) (EC, 2000) calls for the full recovery of costs, including environmental and resource costs, in accordance with the "polluter pays principle", as one of the tools of an adequate and sustainable water resource management system at a river basin level. The actual price of water in a given area, when not subsidized, would be based on the law of supply and demand following market valuation rules (McDonald, 2009; Sagoff, 2011; Sutton and Costanza, 2002). However, water provisioning, just like most ecosystem services, is traditionally public goods. The price of its consumption is regulated, and includes the costs to build and maintain infrastructures that store and divert water to meet different human activity demands in various times and places (Quiroga et al., 2011).

Monetary valuation of ecosystem services, in particular water supply, can be a powerful tool for assessment and policy-making because it provides a common metric with which to make comparisons (Brauman et al., 2007; Everard, 2004; TEEB, 2010). Among the first examples of such efforts is the global monetary valuation done by Costanza et al. (1997) for a wide range of ecosystem services. However, this exercise was shown to be complex and not always efficient (Moran and Dann, 2008; Spangenberg and Settele, 2010; TEEB, 2010). The uncertainty in monetary valuation of many ecosystem services at the landscape scale stresses the need for a non-monetary valuation of ecosystem services in biophysical service units (e.g. cubic meters of water per year) (e.g. Burkhard et al., 2009; Kroll et al., 2012). Although biophysical service units are often unsuited for comparison between services and for trade-off assessment (De Groot et al., 2010), the relative indices, such as the S:D ratio have been widely used to value goods, as well as ecosystem services.

Global change, namely climate change and anthropogenic changes (Pronk, 2002), is expected to have dramatic impacts on global water availability for human uses (Foley et al., 2005). By 2030, half of the European river basins are expected to be affected by water scarcity (EC, 2012). The Mediterranean basin is one of the most vulnerable regions to climate change (Calbó, 2010; Schröter et al., 2005), and several studies have shown that it is already facing the impacts of climate change on water yields (García-Ruiz et al., 2011; López-Moreno et al., 2010; Ludwig et al., 2011). In the Iberian Peninsula, the demand for water in different watersheds ranges between 55% and 224% of water supply (Sabater et al., 2009). Climate change scenarios in that area predict extended droughts (García-Ruiz et al., 2011; Lehner et al., 2006; López-Moreno et al., 2010), that likely will impact ecosystem services such as water provisioning for agriculture, industry or human consumption (Burkhard et al., 2012; De Groot et al., 2010; TEEB, 2010). In the meanwhile, economic growth, and subsequent urbanization, industrialization and agriculture intensification, can substantially increase water demand (Farley et al., 2005; Gallart and Llorens, 2004), even outweighing the effects of climate change (Buytaert and De Bièvre, 2012; Vörösmarty et al., 2000).

To date, few approaches exist that deal with the spatial and temporal dependencies between ecosystem service and demand (Seppelt et al., 2011). In our multi-scale approach, we use a non-monetary metric, namely the supply:demand (S:D) ratio, to estimate the value of the service water provisioning. We applied the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs — Tallis et al., 2011) annual water yield model to the Ebro River basin. Our objectives were to (1) characterize the effect of the considered spatial scale on water scarcity, and define the scale at which water scarcity could be more pronounced; (2) assess the sensitivity of water supply to climate extremes; (3) assess the effect of mitigation land use policies by changing the extension of irrigated agriculture on water scarcity; and (4) assess the relationship between the S:D ratio values and the current water prices.

2. Material and methods

2.1. Study area

The Ebro River basin has a drainage size of 85,362 km^2. It is situated mostly in North-Eastern Spain (98.9% of the basin area), and partially in southern areas of France and Andorra (1.1% of the basin area). Altitude ranges between 0 m along the Mediterranean coast and 3404 m in the Pyrenees (Fig. 1). The climate is Mediterranean with continental characteristics in most of the catchment, which becomes semi-arid in the center of the valley (CHE, 2011). The western side (Pyrenees and Iberian mountains) has an oceanic climate. Mean annual precipitation in the catchment is 622 mm (averaged 1920–2000) with high monthly and annual variability. The rainfall mostly occurs in spring and autumn. It is irregularly distributed in the catchment, ranging from 900 mm yr^{-1} in the Atlantic headwaters to 500 mm yr^{-1} in the southern Mediterranean zone (Fig. 2(a)). Extreme values of 3000 mm yr^{-1} in the Pyrenees and <100 mm yr^{-1} in the central plain have been recorded (Sabater et al., 2009). In the most arid parts of the valley the water deficit is >900 mm (Cuadrat et al., 2007) regarding the evapotranspiration needs. Table 1 shows the average climate conditions in the Ebro basin (1991–2010), and values for wet (1994, 1995, 1998, 2001) and dry (1996, 1997, 2003, 2008) years. Across the basin, climate change models predict that (1) precipitation will decrease in most of the territory (up to −20%) and irrigation demand increases (Iglesias et al., 2007), and that (2) temperature is projected to increase (+1.5 °C to +3.6 °C in the 2050s). The likelihood of droughts and the variability of precipitation – in time, space, and intensity – will increase and directly influence water resources availability (Quiroga et al., 2011).