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Water resources and environmental change in a Mediterranean environment: The south-west sector of the Duero river basin (Spain)

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Summary In the present work we analyse the temporal trend of water supplies to a network of basins, representative of the Mediterranean climate and plant cover, and its relationship with the evolution of temperatures, precipitation, and the changes that have occurred in the plant cover with time. The results point to an important decrease in water supply, with a high degree of dependence on precipitation ($r = 0.85$; p-value < 0.001). Important changes are also seen in the monthly distribution of water discharges due to modifications that have occurred in the intra-annual distribution of precipitation and an increase in temperatures in spring and summer. The rivers studied are losing their snow regime, with very important reductions in the winter and spring discharges. The results show that to date the changes detected in the forest have not affected the water discharges of the rivers. This absence of effect is probably because the changes observed in the plant cover are currently below the threshold after which it is possible to detect the effect of the forest on water discharges and because the interannual variability in rainfall and discharge in Mediterranean environments is so high that it masks other time-dependent changes. The planning and management of water resources should take these changes into consideration with respect to the functioning of hydroclimatic systems.

Introduction

Several studies published over the past 10 years or so have highlighted the increasing concern about the present and future availability of water reserves, which in the future will

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have to meet ever greater demands (PNUMA, 2000; IPCC, 2001a,b; Milly et al., 2005). This reality can be seen in a plethora of debates of politico-social, economic and environmental nature concerning the availability, management, and use of water in countries such as those in the Mediterranean area, where water is a scarce resource (Parry et al., 2000). In this context Spain is no exception (MIMAM, 2000), and in recent years the country has suffered droughts and water reserves across large parts of the territory have remained at less than 20% over many months of the year. In general, the water resources of a given territory depend on the interaction among three main factors: climate, water management and land use, and/or plant cover.

Management is a key element as regards the volume of water necessary to cope with increasing demands (Iglesias et al., 2005). The supply to the general population and that destined for several specific activities such tourism, agriculture and the energy sector, which depend directly on water resources, must be guaranteed through technical management. This factor is crucial in countries like Spain, with a Mediterranean climate and agricultural practices that consume about 80% of the water spent and with new demands for water concentrated in the summer (i.e. tourism, irrigation...), when water levels are at their lowest.

The influence of climate variables such as precipitation, temperatures, and evapotranspiration is crucial for a proper understanding of the availability of water in any given territory (Dunne and Leopold, 1978). Loaiciga et al. (1996) warned that planetary warming is likely to increase the variability of the hydrological cycle at global scale, which will force many countries to increase their resources destined for the control of floods and the storage and supply of water. Regarding analyses of the link between climatic and hydrological processes, Europe is clearly representative of the changes recorded at global scale (Shorthouse and Arnell, 1999), with a clear contrast between northern and southern (Mediterranean) Europe. In northern Europe, works such as that of Arnell (1998) and Kiely (1999), in the British isles, and that of Xu and Halldin (1997), in Nordic countries, point to an increase in the flows of rivers due to increased precipitation. In southern Europe, studies such as those of Mimikou et al. (2000) in Greece, or Ayala-Carcedo and Iglesias (2000) in Spain predict a decrease in rainfall and water supply, accompanied by an increase in the spatio-temporal irregularity of both variables.

Finally, in order to understand the water resources of a region, which are intimately related to the production of runoff, the role of the whole tributary basin should be taken into account (Gupta and Waymire, 1990; Loaiciga et al., 1996), especially as regards land use and the plant cover. One environmental aspect that is currently arousing the interest of the scientific community is the analysis of the relationship between the recovery of forest mass, propitiated by the abandonment of rural areas and palliated by the policies of the European Union and lower water availability in the ecosystem (Andréassian, 2004). A dense forest mass, as compared with a deforested area, always involves a reduction in surface runoff owing to the interception of the rain by leaves and the actual water demands of the trees themselves (Rambal, 1987; Joffre and Rambal, 1993; Zhang et al., 2001; Brown et al., 2005; Llorens et al., 2005). In the case of Spain, general analyses, such as those of Gallart and Llorens (2002), have underscored the key role of the forest in the reduction of water resources in some Iberian basins. More detailed analyses, such as that of Beguería et al. (2003) in the case of the Pyrenees, have estimated that the reduction in water supplies due to the spreading of forested areas is 30%.

The general aim of this work is to analyse the temporal evolution of water supplies in a network of basins representative of the Mediterranean climate and plant cover that occupies slightly more than 13,000 km^2, and to relate this to the behaviour of the main climatic variables (temperatures and precipitation) and to the changes undergone by the plant cover. In the present work, we selected a zone representative of the Mediterranean rainfall gradient and hence of the typical variety of Mediterranean plant formations (sclerophyllous and semi-deciduous forest) with a network of thermal, pluviometric and gauging stations sufficient for a regional analysis representative of the whole zone to be made. We complete this analysis with a discussion — from different points of view — of the effects of the observed changes on a series of environmental processes related to Mediterranean ecosystems.

Study area

The area chosen for the study is located in the south-western quadrant of the Duero basin, with a network of four direct tributaries to this major river that occupies a total drainage surface of 13,250 km^2. The tributaries are the Águeda, the Huebra, the Uces and the Tormes (Fig. 1). Altitude ranges between 2224 m a.s.l. in the Sierra de Gredos, close to the Tormes headwater, and 116 m at the confluence between the rivers Huebra and Duero, and there is a predominance of land located above 700 m a.s.l.

The territory is characterised by a certain lithological diversity: (i) Precambrian shales and sandstones, together with granites deriving from hercynian plutonism in the mountainous sectors and old erosion surfaces; (ii) Tertiary sediments (conglomerates, sandstones and lutites) and Quaternary fluvial sediments in the lowest-lying areas.

Mean annual rainfall ranges between 1500 mm in the mountainous area of the Sistema Central and slightly less than 400 mm in the most continental sector, following a clear southwest—northeast gradient with respect to the entry of frontal systems from the west—southwest of the Iberian Peninsula. Regardless of the annual amount of rainfall, the recording of at least two dry months in the summer points to the marked Mediterranean character of the overall territory. The lowest mean annual temperatures are found at the weather stations located at the highest altitudes (>1000 m), with values of about 9 °C, not surpassing 20 °C in the hottest month, and values of around 2 °C in the coldest month. In the case of the weather stations located at lower altitudes (<200 m), the mean annual temperature is 16 °C, with fairly hot summers (>26 °C in the hottest month) and very gentle winters (around 9 °C in the coldest month). Most of the territory is encompassed within an annual isotherm of 12 °C, with temperatures of about 4 °C in the coldest month and not more than 22 °C in the hottest one.

Approximately half of the surface of the study area is occupied by forest, with a predominance *Quercus pyrenaica* in the cooler and more humid zones and *Quercus ilex* sp.