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Impact assessment of combined climate and management scenarios on groundwater resources and associated wetland (Majorca, Spain)

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SUMMARY

Climate change impact on a groundwater dependent wetland and natural recharge has been investigated in the Inca-Sa Pobla coastal aquifer for the year 2025. Temperature and precipitation based on the downscaled output from a general circulation model (GCM) was coupled to a groundwater model to estimate the impacts of climate change and management practices on groundwater. Management practices were based on changes in the volume of water extracted for agricultural and domestic purposes. Climate change impacts on the hydrogeological system were based on downscaled HadCM3 outputs for future medium–high (A2) and medium–low (B2) greenhouse gas scenarios developed by the IPCC [IPCC, 2001. Climate change 2001: the scientific basis. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Van Der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A. (Eds.), Contribution of Working Group I to the Third Assessment Reports of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp]. Assessment of the impacts on the water level of the wetland were carried out by estimating the flow rate of springs discharging from the aquifer obtained by changes of agricultural land use and water supply allocation and variation of recharge according climate scenarios. The greatest reduction in recharge was observed in scenario A2 (−21%), while recharge in scenario B2 remained relatively unchanged (−4%). However, as uncertainties arising from GCM outputs maybe greater than the differences simulated here results are only indicative of the system response. In order to preserve the spring discharge at its current level (17 Mm^3/yr), which successfully prevents the wetland from drying up, a decrease in groundwater extraction is needed. In addition, the reallocation of agricultural wells is recommended under both scenarios. Spring discharge was affected the most by agricultural wells located near the wetland, as indicated by the sensitivity analysis.

Introduction

Water management in the Mediterranean area, particularly in the islands (e.g. Sicily, Cyprus, and Majorca), is currently under significant threat from increasing variability in seasonal and inter-annual rainfall patterns. This leads to an unbalanced distribution of water resources and increases conflict among users (e.g. domestic supply and natural ecosystem replenishment). A rising population, particularly during the high tourist season, and a culture of irrigated agriculture further increases the demand for water. The islands' scientific community and population as a whole are becoming increasingly concerned about the impacts of climate change on their natural resources and are starting to consider how their management practices can be adapted to cope with the effects.

According to the output of current coupled atmosphere–ocean general circulation models (GCMs) for the 2080–2100 time slice, the Balearic region (western Mediterranean) is forecasted an increase in temperature of between 1.5 and 3.6 °C and a decrease in precipitation of between 10% and 20% (IPCC, 2001, A1B storyline). Climate change projections also indicate an increased probability of drought (Kerr, 2005) and variability of extreme events. This situation is likely to aggravate the future availability of water resources.

Over the last decade, an extensive amount of research has been published on how climate change might influence different aspects the hydrological cycle (precipitation, runoff, evapotranspiration, etc.) (Kundzewickz and Somlyódy, 1997; Kracauer Hartig et al., 1997; Arnell, 1998; Bouraoui et al., 2004; Cuculeanu et al., 2004; Wilby et al., 2006; Burns et al., 2007; Hagg et al., 2007; Ruth et al., 2007; among others). Although the majority of the research published focuses on surface water impacts, the effect on groundwater

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resources is receiving greater attention (Zekster and Loaiciga, 1993; Allen et al., 2004; Brouyère et al., 2004; Green et al., 2007a,b; Hsu et al., 2007; Scibek et al., 2007; Serrat-Capdevila et al., 2007). This is also true for integrated approaches (Scibek et al., 2007) as well as recharge and discharge conditions under climate change scenarios (Bouraoui et al., 1999; Rosenberg et al., 1999; Kovalevskii, 2007; Woldeamlak et al., 2007). Despite the increasing amount of literature on groundwater impacts (Green et al., 2007a,b), as far as the authors are aware, there is limited information on impacts on groundwater dependent ecosystems derived from a combination of climate change and management scenarios (Risbey et al., 2007).

A review of published papers shows that predictions are generally based on coarse GCM outputs, which are not primarily designed for climate change impact studies, and are therefore not suitable for addressing concerns over regional hydrologic variability (Prudhomme et al., 2002). To address such concerns, GCM outputs relevant to hydrologic studies must be downscaled. A number of approaches can be adopted to achieve such needs (Hewiston and Crane, 1996; Dehn, 1999; Prudhomme et al., 2002), which include stochastic weather generators. As many authors such as Bates et al. (1994), Bouraoui et al. (1999), Wilks (1992) and Aronica et al. (2005) have reported, stochastic weather generators are widely used for downscaling values at the catchment level.

Numerical models can be used to determine which inputs are critical for model performance, especially for complex problems in which there are many potential inputs and the availability of prior knowledge is limited. Moreover, sensitivity analysis (SA) techniques based on local or global methodologies can be used to assess the effect of climate change and water management interactions on groundwater dependent ecosystems. By applying a sensitivity analysis to a groundwater model that tests different recharge scenarios, it is possible to identify which input data and model parameters most influence the piezometric level and spring discharges (Mehl and Hill, 2001; Barth and Hill, 2005; Jyrkama and Sykes, 2006; Candela et al., 2006; Elorza et al., 2006). In this specific application, sensitivity represents the degree to which a system is affected by climate-management related stimuli.

The combined pressures of climatic change and an increasing population, together with the requirements of the EU water framework directive (WFD) illustrate the importance of effective long-term strategies for water management. The objective of the present paper was firstly to investigate the impacts of climate change on groundwater resources recharge in a coastal aquifer. Secondly, we aimed to analyse the impact of combined climate and management scenarios on the hydrogeological system, in particular on the groundwater discharge into the existing wetland connected to the aquifer. The first aim was addressed by linking changes in groundwater recharge to the downscaled CGM output. The second objective was addressed by modelling groundwater flow and evaluating the system sensitivity to different management scenarios. Finally, we assessed different policy options aimed at developing adaptation strategies to address the impact of climate changes on water resources management.

Study area

The Inca-Sa Pobla Plain (Fig. 1) covers an area of over 415 km^2 and is located in the Central Plains of the Island of Majorca (Balearic Islands, Spain). From the 1970s onwards, the region has seen a new trend in the demand for water to support a growing tourist population and an important culture of irrigated agriculture. No industrial demand exists. Despite a decrease in agricultural activities over the last 30 years, water is still extracted from wells mostly in the Sa Pobla area to irrigate crops such as potatoes and forage (4300 ha). In the study area surface water is reduced to ephemeral streams, which may show important flow rate during a short period of time, and water demand is met mainly by intensive groundwater abstraction.

The Sa Pobla study area was specifically selected based on several criteria such as increasing water demand (particularly during seasonal periods when the population can double), irrigated agricultural activity, conflicts in water management between users, and a growing concern for the deterioration of the S'Albufera coastal wetland. S'Albufera is included in the Ramsar list of wetlands of international importance.

There are seven meteorological stations in the area (Fig. 1), which cover a rainfall time period since 1940–1941. It is important to note here that series are irregular in both space and time. Daily air temperature data for the same period were only available at the B-691 meteorological station. Mean annual temperature is 17 °C. Mean annual precipitation is around 600 mm/yr, and approximately 60% of precipitation occurs during spring and autumn. Monthly Penman–Montheit potential evapotranspiration estimated for the 1980–2005 period accounts for 1025 mm/yr.

From a geological perspective, the Inca-Sa Pobla catchment area is a northeast/southwest tectonic subsiding sedimentary basin, filled with sub-horizontal post-tectonic Tertiary and Quaternary materials. The basin is constituted by three sub-basins from South to North (PHIB, 1999): Inca (southwest) and Sa Pobla (northeast) separated by the Llubi–Muro threshold, and S'Albufera where the wetland is developed, near the Mediterranean sea. Due to the number of abrupt lateral facies changes, the stratigraphy of the basin is rather complex.

From the hydrogeological point of view, the sedimentary infill of the basin, which comprises the three above-mentioned sub-basins, is composed by high permeability materials (carbonate rocks, gravels, and conglomerates) that constitute the aquifer material, and interlayered detritic low permeability sediments (marls). The surface aquifer extension (360 km^2) and a geologic cross-section showing the geometric relationships are presented in Fig. 1. Marls of the middle Miocene are the impervious bottom. The NW part is limited by the Tramuntana mountain range composed by highly fractured Lias limestone and dolostones, which constitute an unconfined aquifer overlying impervious clay materials. Along the border, lateral hydraulic connexion to the Plio-Quaternary and Miocene formations of the Sa Pobla Plain occurs when the clays are absent. At the SE it is limited by sedimentary formations with no hydraulic connexion (marls) and to the SW the boundary is a hydrogeological divide. The NE border is the Alcudia sea.

The hydrogeologic system is constituted by four hydrostratigraphic aquifer units and three hydrostratigraphic aquitard units from top (Holocene) to bottom (Middle Miocene). Despite of its multilayer configuration, permeable layers are hydraulically connected in a greater or lesser extent.

In the Inca basin a lower confined aquifer of Messinian and Tortonian age (limestones) and a Plio-Quaternary water table aquifer (sands, silts and gravels, and calcarenites) exist separated by an aquitard of grey marls. The lower aquifer, Messinian limestones (upper Miocene) constitutes a confined or semi confined aquifer, with a maximum thickness of 100 m. The Tortonian thickness varies from a few metres to more than 200 m. Their transmissivity generally ranges between 500 and 5000 m^2/d or in places, greater than 10,000–15,000 m^2/d. Quaternary sands and gravels, and Pliocene calcareous sandstones constitute an unconfined aquifer hydraulically connected to all geologic basin formations. Its thickness ranges between several metres to 50 m; the thickest part is found in the centre of the two basins. Hydraulic conductivity ranges between 8 and 15 m/d to up to 300 m/d near the S'Albufera area (Table 1). Pliocene calcareous sandstones are covered by quaternary deposits and only outcrop