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## Research Article

# Climate Change Impacts in Soil- Water Balance in Semi-Arid Region, Southeast of Spain: The use of Eco- Hydrological Model

## Abstract

Predictions of climate change have a high interest in semiarid regions like the province of Alicante (SE Spain). It is expected that the decrease of precipitation and the increase of air temperature according to climate change forecasts, could impact on the recharge to aquifers. In this context, the aim of this study was explore the possible impact of climate changes forecasts on recharge in a small aquifer southeastern Spain. Air temperature and precipitation data in two climate change scenarios, B2-low and A2-high have been coupled to HYDROBAL model. The HYDROBAL software is a useful eco-hydrological model with daily resolution for assessing water balances in different vegetation types in a semiarid region of south-eastern Spain. Based on two models, HYDROBAL and DISRUM, water balance was calculated on two scales (vegetation plots and watershed). Over the latter period (2071-2099), we expect reduced average annual groundwater recharge, of up to 17% (49 mm), if compared to the baseline period (1961-1990).

## Introduction

Global climate change will produce a strong impact on the hydrologic cycle and therefore on water resources in many regions of the world, especially in semiarid regions, which seems to be a general agreement for academics and governments. The latest Assessment Reports of the Intergovernmental Panel on Climate Change [1], projects increase in precipitation on northern Europe indicate from 1-2% per decade, while in southern Europe shows a decrease up to 1% per decade (it may be up to 5% in summer). On the other hand, the frequency and duration of very wet periods have significantly decreased in recent decades in many regions. These general simulations have been specified for Spain as it will be an increase of the mean annual temperature of 2.5 °C and a decrease of the annual rainfall, range from 2 % in the basins of the North to 17% in the South basins. This study was carried out in the Ventós-Castellar aquifer (Figure 1) located in the Municipality of Agost, Alicante Province, southeast Spain (38° 28'N, 0° 37'W). In this context, the aim of this study was assessing the impact of climate change forecasts on soil water balance and natural groundwater recharge in a semiarid area (SE, Spain) Air temperature and precipitation data in two

climate change scenarios, B2-low and A2-high, were predicted using downscaled climate data from the HadCM3 Global Climate Model. These databases were coupled to a HYDROBAL hydrological model to determine the soil water balance and aquifer recharge.

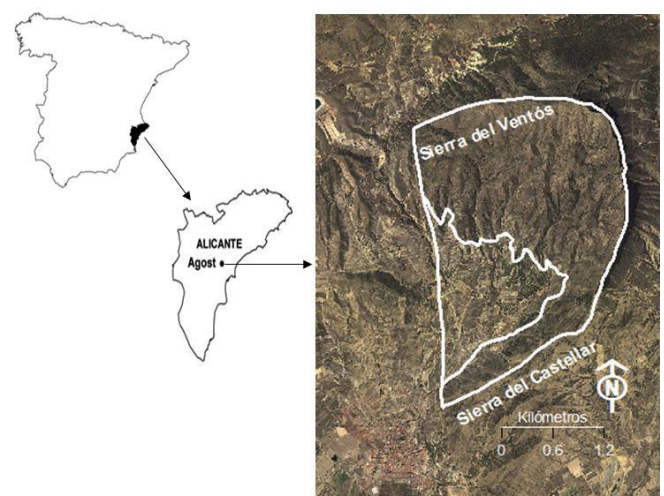


Figure 1: Geographical location of the study area.

## Methodology

### Climatic data source

The climatic data (from 1961 to 2099) were obtained by the Spanish National Meteorological Agency (AEMET) from the meteorological stations closest to the study area. Two weather stations were selected to model the climatic conditions at Ventós-Castellar aquifer, and they hold the longest climate records available for this area. The observed daily precipitation data from (1961–1990) were collected from the Agost-Escuela weather station (376 m a.s.l., 38° 26'N; 0° 38'W) which is about 1 km southwest of the aquifer. The maximum and minimum temperatures data were obtained from the Novelda weather station (241 m a.s.l., 38°23'N; 0°46'W). This weather station is located 15 km southwest of the aquifer.

### HYDROBAL model

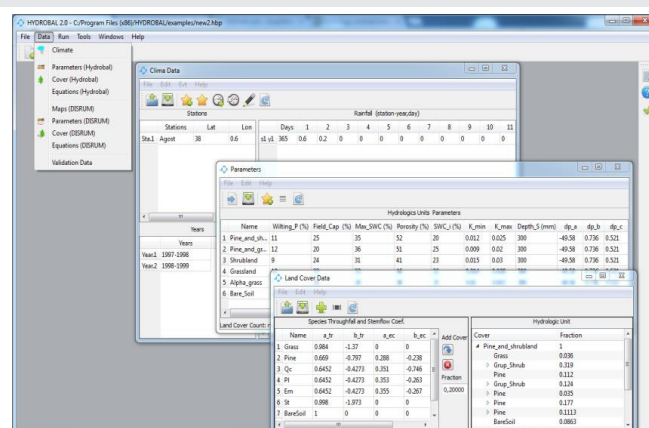
Hydrological simulations were performed with the HYDROBAL model (Bellot and Chirino, 2013) [2]. HYDROBAL is a model that integrates meteorological conditions, vegetation characteristics and soil processes to simulate water balances in ecosystems dominated by different vegetation types. The model estimates daily water flows across vegetation canopy and soil water balance using a simple mass balance equation calculated at a daily time step. This equation estimates the groundwater recharge (R) by considering precipitation (P) to be input, less output by rainfall interception, actual evapotranspiration (Eta), runoff (Roff) and change in soil water storage ( $\theta$ ). A brief description of the model is presented herein, but a more detailed description and discussion of it can be found in Bellot and Chirino and Touhami et al. [2,3].

The HYDROBAL software allows the determination of the water balance on different vegetation cover types using the HYDROBAL and DISRUM models. The HYDROBAL software is divided into three main menus: (1) Data menu (Database module). This menu is structured according to two models: HYDROBAL and DISRUM. Both models present a subsection with several premade templates (climate data; vegetation data, soil data; Figure 2), which must be filled in or loaded with the data required to run the models. For the DISRUM model (raster model), besides the previously indicated data and parameters, load several maps are needed (vegetation cover, slope, etc., Figure 3). Another template in this module is related with the equations used to calculate water flows. We can use the equations indicated by default or change them. (2) Run menu (Calculations module). In this module, the software runs the Hydrobal model on two scales (plots and watershed) and the DISRUM model, which determines the spatial distribution of runoff on the watershed scale using the input maps. (3) Tools menu. It presents a set of tools for the comprehensive use of the data and results: (a) calibration methods (by means of calibrating parameters min K and max K (HYDROBAL model) and the Curve number (CN) parameter (DISRUM model), (b) Generation Scenarios (generation of new scenarios of land use, impact of wildfires, etc.), (c) Validation (allows the comparison of observed data vs. estimated data by the model and its graphic representation, (d) Calculation of reference evapotranspiration

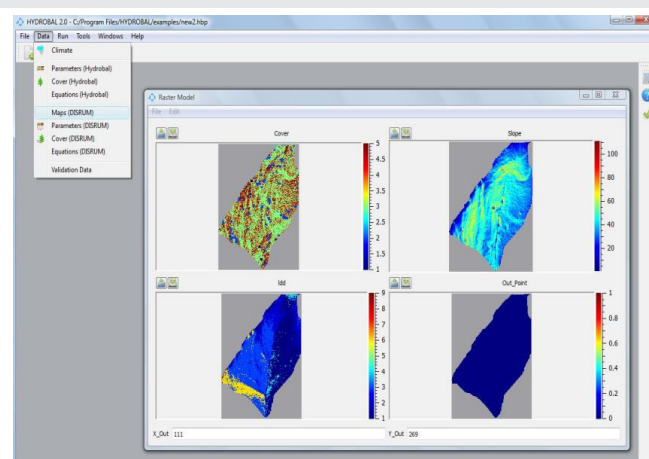
by two methods (Penman–Monteith and Hargraves and Samani), and (e) Summary of the model's output variables as results tables (Tools Menu, options: Plot report, Summary plot report and Report all).

### Data processing

We selected regional projection precipitation and air temperature (maximum and minimum) data based on the HadCM3 model database of the PRUDENCE and ENSEMBLES projects. These data were obtained from the closest meteorological stations to the study area. Two weather stations were selected to modelling the Ventós-Castellar aquifer. Both of them are the most representative to determine the climatic conditions of the study area, and hold the longest climate records available for this area. The daily precipitation data of the baseline period (1961–1990) and three future periods (2011–2040; 2041–2070; 2071–2099) for emission scenarios A2-high and B2-low were collected from the Agost-Escuela weather station (376 m a.s.l., 38° 26'N; 0° 38'W). The maximum and minimum temperature data were collected from the Novelda weather station (241 m a.s.l., 38° 23'N; 0° 46'W). In order to analyse the temporal variation of the microclimatic variables (precipitation, minimum and maximum air temperature) throughout the study period (from 1961–1990 and 2011–2099),



**Figure 2:** menu. Templates of climate data, vegetation data and soil data, which must be filled in or loaded with the data needed to run the HYDROBAL and DISRUM models.



**Figure 3:** Data menu. Maps of several variables to run the DISRUM model.

a General Linear Model univariate analysis was performed. Data were analysed by two-way ANOVA using two factors: (1) the period's factor (1961–1990, 2011–2040, 2041–2070 and 2071–2099) and (2) the emission scenarios factor (A2-high and B2-low). Annual precipitation (Figure 4a) and mean annual air temperature (maximum and minimum; Figure 4b) were used as the dependent variables.

## Results

After applying the HYDROBAL model's water balance (Table 1) to the Ventós–Castellar aquifer, the results show a decreasing

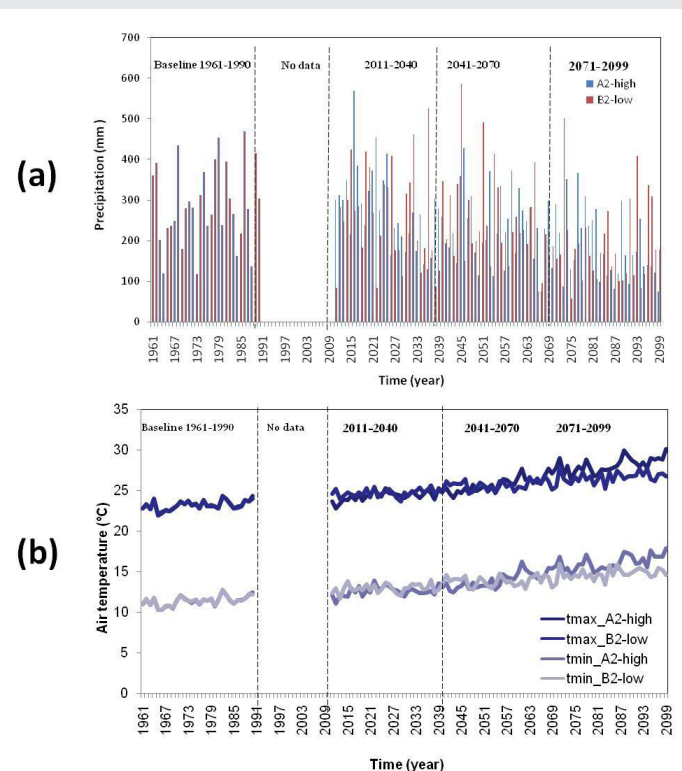


Figure 4: (a) Annual precipitation and (b) means annual temperature (max and min) during baseline period (1961-1990) and future period (2011-2099). Data from output of HadCM3 model for A2-high and B2-low scenarios.

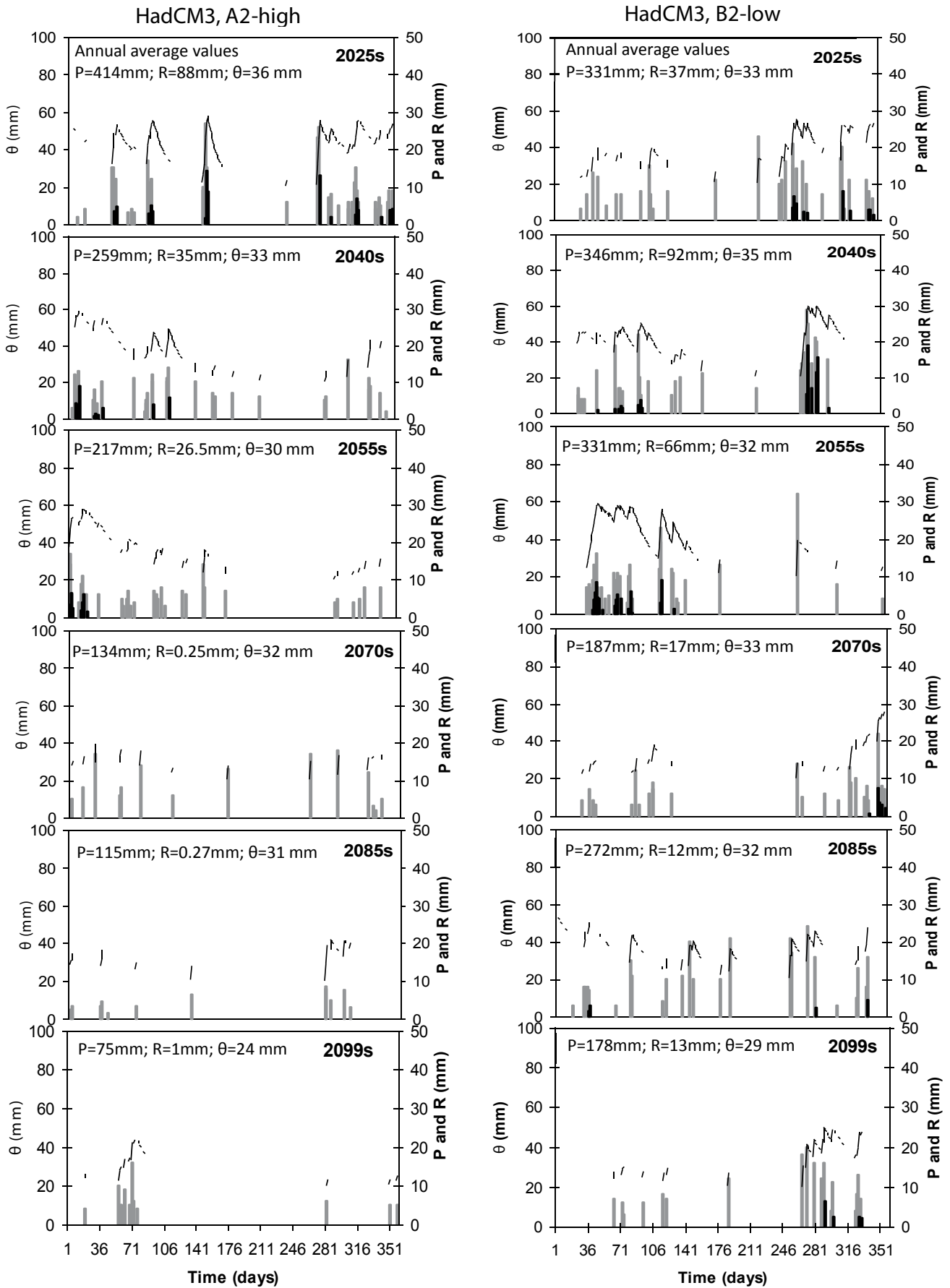
in the annual average of all the output variables of water balance at the end of this century, especially in the A2-high scenario. The average recharge during the last period, 2071–2099, will decrease by up to 17% if compared to the baseline period (1961–1990). Several previous studies have reported results that came close to the values observed in our study. On the Island of Majorca (Spain), Younger et al. [4] similarly estimated the same decrease in mean aquifer recharge of up to 16% during the future 100-year series if compared to the pre-1995 values. In the Almonte–Marismas aquifer (Doñana wetland), SW Spain, using the HadCM3 projections between 2071–2099 vs. the 1961–1990 baseline period, Guardiola Albert and Jackson [5], indicated that the mean annual recharge rates will decrease by 14%. The same reduction value for the emission scenario A2-high (14%) has been reported by Pulido-Velazquez et al. [6], in the Serral-Salinas aquifer in Altiplano, Murcia, SE Spain, after applying different Regional Climate Models (RCMs).

The study area has a high potential vulnerability to climate changes. The changes projected in the precipitation and air temperature regime will significantly influence the average annual recharge of the Ventós–Castellar aquifer. We will observe that during the last 2071–2099 period, the change in the percentage of aquifer recharge vs. the baseline period (1961–1990) will considerably decrease by up to 17% (49 mm). This will imply a significant reduction in the groundwater level, and will affect the main drinking water source of the town of Agost (5000 inhabitants).

The temporal variation analysis of the HYDROBAL model's output variables indicated a significant decrease in water balance components (recharge, actual evapotranspiration, runoff and soil moisture;  $p < 0.01$ ) with different amplitudes. In both scenarios (A2-high and B2-low), a temporal decrease in the HYDROBAL model's output variables from the baseline period to the end of this century (Figure 5).

Table 1: The water balance results for climate change in the A2-high and B2-low scenarios from HadCM3 between the baseline period and future years.  $P$  precipitation;  $R_{off}$  runoff;  $E_t$  actual evapotranspiration;  $R$  groundwater recharge;  $\theta$  Soil moisture.

		A-2 High Scenario							
		1970	1990	2020	2031	2058	2066	2084	2096
<b>P (mm)</b>		279	303	323	200	220	249	167	141
<b><math>E_t</math> (mm)</b>		178	201	190	172	197	175.7	151	127
<b>R (mm)</b>		73	76	97	41	47	36	22	11
<b><math>R_{off}</math> (mm)</b>		4.0	5.0	5.3	3.8	4.6	4.0	3.3	2.2
<b><math>\theta</math> (%)</b>		13.8	13.6	14.2	13.9	14.2	13.5	13	12.4
		B2-low scenarios							
		1970	1990	2017	2033	2060	2068	2087	2098
<b>P (mm)</b>		279	303	285	201	259	216	167	178
<b><math>E_t</math> (mm)</b>		178	201	160	152	167	141	134	131
<b>R (mm)</b>		73	76	83	26	59	40	20	36
<b><math>R_{off}</math> (mm)</b>		4.0	5.0	4.2	3.2	4.1	2.8	2.5	2.9
<b><math>\theta</math> (%)</b>		13.8	13.6	13.8	13.4	13.6	12.6	12.9	12.8



**Figure 5:** Temporal variation of daily precipitation, soil moisture and aquifer recharge by means of HYDROBAL model by analysed years (2025, 2040, 2055, 2070, and 2085 y 2099), for A2-high and B2-low scenarios (P: precipitation, grey bar, R: recharge, black bar and  $\theta$ : soil moisture, black solid line).



## Conclusion

The present study analyses the impact of climate change on groundwater recharge by applying the HYDROBAL model, based on projections of downscaled precipitation and air temperature data in a semiarid region of SE Spain. The climate change projections computed by the HadCM3 model in the A2-high and B2-low emissions scenario for the Ventós-Castellar aquifer show a significant decrease in precipitation and a significant increase in air temperature by the end of the 21st century. The HYDROBAL model results revealed that during the last period (2071–2099), climate change will have a major impact on soil water balance in the study area, especially on groundwater recharge, of up to 17% if compared to the baseline period (1961–1990).

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