HYDROLOGICAL IMPACTS OF CLIMATE CHANGE AND ADAPTIVE WATER GOVERNANCE IN THE IBERIAN PENINSULA

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Abstract - Hydroclimatic extremes such as droughts and intense precipitation events are expected to intensify in the Iberian Peninsula (IP) under climate change, posing major risks to water resources, agriculture, and infrastructure. This study uses three precipitation-based indices—Consecutive Dry Days (CDD), number of dry spells (CDDn), and very wet days (R95pTOT)—to quantify projected changes under three CMIP6 scenarios (SSP1-2.6, SSP3-7.0, SSP5-8.5) and three future periods (2041–2060, 2061–2080, 2081–2100). Results show pronounced drying in southern and central basins, with annual precipitation decreasing by 25–40 % and CDD length exceeding 90 days per year under SSP5-8.5 by 2081–2100. R95pTOT rises by up to 45 % in Atlantic-facing catchments, signaling a shift toward more intense rainfall events. These patterns indicate higher drought persistence alongside growing flood risk, emphasizing the need for integrated adaptation measures in water management and planning.

Keywords - Water Management; Climate Change; Iberian Peninsula

I. INTRODUCTION

The Iberian Peninsula is a recognised climate-change hotspot where droughts, water scarcity, and extreme precipitation are projected to intensify throughout the 21st century. The region's climatic heterogeneity—from humid Atlantic zones to semi-arid Mediterranean basins—produces strong spatial contrasts in water availability and vulnerability.

Prolonged dry spells and heavy rainfall increasingly occur in the same hydrological year, compounding management challenges [1–3]. This study aims to assess future hydroclimatic stress across Iberia by analyzing standardized precipitation indices (CDD, CDDn, R95pTOT) under various Shared Socioeconomic Pathways (SSPs). The results provide a spatially consistent picture of evolving drought and precipitation extremes relevant for basin-scale governance, agricultural resilience, and infrastructure adaptation.

II. MATERIAL AND METHODS

The Iberian Peninsula (IP), located in southwestern Europe, encompasses Spain and Portugal and covers approximately 580,000 km² (Fig. 1). It features a pronounced climatic and topographic diversity, ranging from humid Atlantic regimes in the northwest to semi-arid Mediterranean systems in the south and east. Mountain chains such as the Pyrenees, Cantabrian Range, Central System, and Sierra Nevada strongly influence precipitation patterns through orographic effects, creating steep spatial gradients in rainfall and temperature.

Hydrologically, the peninsula is structured around several major river basins — including the Ebro, Tagus (Tejo), Douro (Duero), Guadiana, and Guadalquivir — which are critical for agriculture, hydropower, and urban water supply. Many of these are transboundary systems, shared between Spain and Portugal, and are managed under joint agreements such as the Albufeira Convention.

The southern and southeastern basins (Guadalquivir, Guadiana, Segura, and Júcar) are the most water-stressed, exhibiting recurrent droughts and limited natural recharge. In contrast, northern and Atlantic-influenced basins remain comparatively humid and resilient.

This complex interplay of climate, topography, and water demand makes the Iberian Peninsula a key hydroclimatic hotspot in Europe and an ideal case study for assessing the impacts of projected climate change on water availability and extremes.

Daily precipitation data from nine CMIP6 Global Climate Models (CanESM5, CNRM-CM6-1, CNRM-ESM2-1, EC-Earth3, IPSL-CM6A-LR, MIROC6, MPI-ESM1-2-LR, MRI-ESM2-0, and UKESM1-0-LL) were downscaled using CHELSA v2.1 to ~1 km resolution [4–5]. Historical simulations (1991–2010) and projections for 2041–2060, 2061–2080, and 2081–2100 were analyzed for SSP1-2.6, SSP3-7.0, and SSP5-8.5.

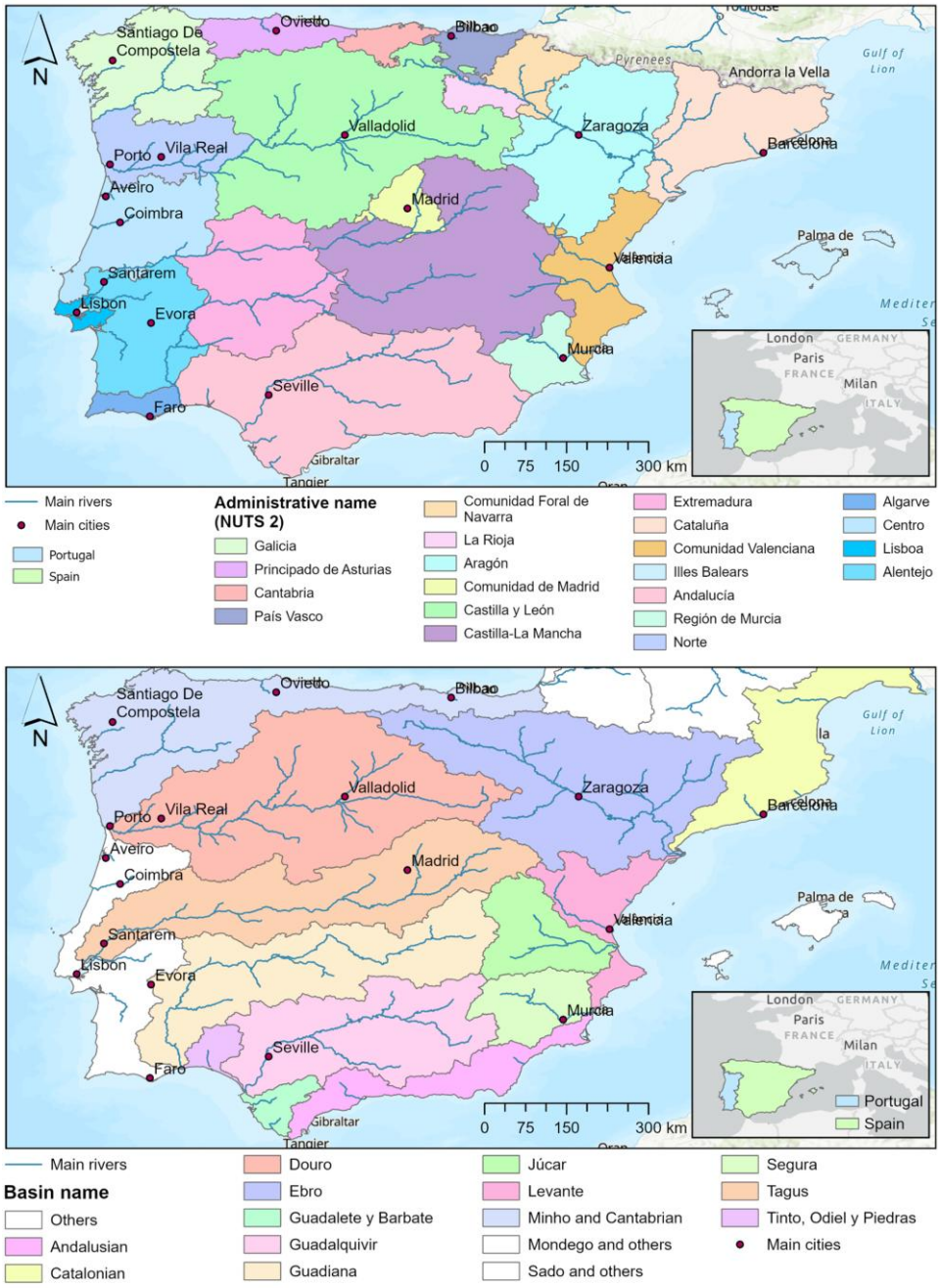


Fig. 1 Maps of the Iberian Peninsula. Top panel: NUTS 2 administrative regions of Spain and Portugal, with major cities (red dots) and principal rivers (blue lines). The inset shows the location in southwestern Europe. Bottom panel: Major hydrographic basins (labelled) overlaid on the same geographic domain, with basin boundaries color-coded and main cities for reference. Both panels include a 0–300 km scale bar and north arrow.

The indices were computed following ETCCDI guidelines [6]: (i) CDD = maximum consecutive days with P < 1 mm; (ii) CDDn = number of dry spells > 5 days; (iii) R95pTOT = percentage of annual rainfall from days above the 95th percentile. Ensemble means were derived to minimize model bias. Spatial analyses were conducted at 30-arc-second resolution and aggregated by major Iberian River basins (Tagus, Douro, Ebro, Guadalquivir, Guadiana, Júcar, Segura, and Minho) (Fig. 1).

III. RESULTS

The baseline climatology (1991–2010) reveals a pronounced northwest–southeast gradient in precipitation across the Iberian Peninsula, with annual totals ranging from 1600 to 1900 mm in the humid, Atlantic-facing regions of Galicia and the western Pyrenees and falling below 300–400 mm in the semi-arid southeastern interior. This gradient reflects the combined influence of Atlantic westerlies, orographic uplift along mountain ranges, and the

progressive dominance of Mediterranean climate regimes toward the south and east (Fig. 2).

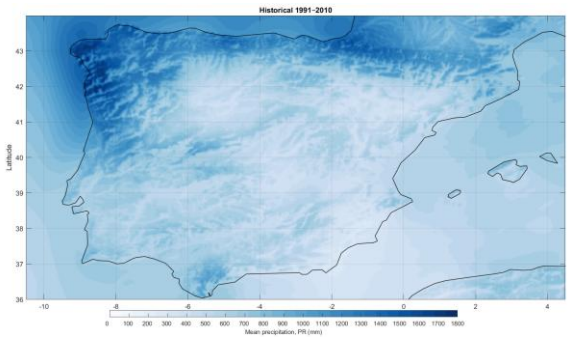


Fig. 2 Mean annual precipitation (in mm) over the Iberian Peninsula for the historical baseline period (1991–2010).

Dryness indicators show a parallel spatial structure. The mean number of Consecutive Dry Days (CDD) remains below 30 days yr^{-1} in the north and along the Atlantic coast, increasing to 80 days yr^{-1} or more in the southern and interior basins (Guadalquivir, Guadiana, and Segura) (Fig. 3). The number of extended dry spells (CDDn) averages 5–10 events yr^{-1}, with the highest frequencies in central and southeastern Spain. In contrast, very wet days (R95pTOT) contribute 50–60 % of total precipitation in northern and northwestern basins influenced by Atlantic frontal systems, but only 10–20 % in southern and Mediterranean regions dominated by convective rainfall.

Overall, the historical period is characterised by a sharp climatic and hydrological contrast between humid northern and arid southern Iberia, providing a robust reference for evaluating projected changes under future emission scenarios.

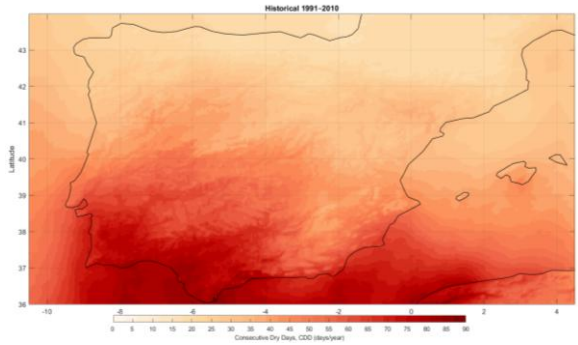


Fig. 3 Spatial distribution of the mean number of consecutive dry days (CDD) for the historical baseline period (1991–2010).

Future projections indicate a coherent drying trend across most of Iberia. Under SSP1-2.6, annual precipitation declines slightly (5–10 %) in southern basins, while SSP3-7.0 and SSP5-8.5 project reductions of 20–40 % by the late century. The CDD metric shows strong intensification, with southern basins experiencing over 80–90 consecutive dry days per year under SSP5-8.5. Dry-spell frequency (CDDn) roughly doubles across southern and central regions, suggesting more frequent and fragmented drought episodes. In contrast, R95pTOT increases across northern and Atlantic-oriented areas by 25–45 %, implying that rainfall will be more episodic and concentrated in extreme events. These combined shifts highlight the transition toward longer dry seasons punctuated by intense precipitation bursts.

IV. CONCLUSION

The Iberian Peninsula is projected to experience marked hydroclimatic intensification, characterised by prolonged dry periods and more intense precipitation events. Without mitigation, southern and inland basins face the greatest risks to water security and ecosystem stability. Adaptive strategies should prioritise water-use efficiency, reservoir optimisation, and nature-based solutions that enhance soil moisture and aquifer recharge. Results underscore the urgency of integrating climate projections into basin-scale planning and developing flexible governance to cope with increasing variability and uncertainty in Iberia's hydrological future.

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