Analysis and forecast of crop's water demand among some irrigation districts across Southeastern Ebro's river basin (Catalonia, Spain): estimation of ET through Copernicus-based Inputs

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Introduction

Agriculture is the main user of freshwater, accounting for nearly 70% of total water consumption in the world. However, in addition to the already existing pressure on freshwater resources, the current climate change scenario, population growth and the industrial development, may further decrease water availability and make future perspectives pessimistic, especially in the semi-arid Mediterranean regions (Bisselink et al. 2020). The sustainability of irrigated agriculture is strongly linked to the improvement of water use efficiency. This can be primarily achieved by improving water management and use at farm and irrigation district (ID) levels, respectively (Playan and Mateos, 2006). In Spain, IDs have different water allocations and based on this, farmers decide which crops to plant. However, in a scenario of water scarcity, it may happen that the allocation of irrigation water to scheme may be below maximum crop water requirements. The key is to find an equilibrium between crop water demands and supplies in order to guarantee irrigation water for an entire growing season. To achieve it, a detailed and dynamic knowledge of crop water demands is necessary to support decision-making in planning and water management.

Remote sensing technologies have the ability to estimate spatio-temporal water demands of IDs and to analyze the inter-annual variations. Crop evapotranspiration (ET) is a major component of the water balance and represents crop water requirements. Recent advances in remote sensing for ET have been made during the past few decades by using surface energy balance (SEB) models. The great advantage of these models compared to optical methods such as crop coefficient algorithms is that they estimate the actual ET (ETa) instead of the potential ET, by the use of land-surface temperature (LST), and thereby accounting for the influence of crop water stress (Knipper et al. 2020). One of the applications that showcase this issue is the SEN-ET modelling framework (http://esa-sen4et.org) (Guzinski et al. 2020). High-resolution ET could be operationally derived daily at 20 m resolution by sharpening thermal observations from Sentinel-3 satellites (1km, daily) and optical observations from Sentinel-2 satellites (20m, every 5 days) (Guzinski et al. 2020).

The present study aims to take advantage of the SEN-ET modelling approach to quantify, compare, and analyze differences in water demands in several ID located in the Ebro basin during five consecutive growing seasons (2017-2021) as well as to obtain projections of water demands until 2100 using six global climate models (GCM) in two contrasting RCP scenarios. IDs are characterized by having different water allocations and regulations in water management, irrigation systems and crops.

Materials and Methods

The studied area is located in the irrigated area of Lleida (Catalonia, Spain), in the North East of the Iberian Peninsula and inside the Ebro basin. Irrigation water management is organized by the following eight irrigation districts (ID): Canal d'Urgell (CU), Aragón y Cataluña (CAYC), Canal de Pinyana (CP), Segarra-Garrigues (SG), Algerri-Balaguer (AB), Segrià Sud (SS), Carrassumada (C) and Garrigues Sud (GS). The study area has a typical semi-arid Mediterranean climate with mild, wet winters and very hot and dry summers, and with an average annual rainfall and reference evapotranspiration (ET_0) of 300 mm and 1100 m, respectively.

In order to compute crop water demand for each ID during the years 2017 to 2022, the actual crop evapotranspiration (ETa) was estimated through the two-source energy balance (TSEB) modelling scheme and with Copernicus based inputs. The TSEB is a model formulated originally by Norman et al. (1995). The Copernicus-based inputs used in the TSEB modelling approach are described in Guzinski et al. (2020). Briefly, biophysical variables were estimated from the biophysical processor of Sentinel-2. Meteorological inputs obtained from the ECMWF ERA5 reanalysis dataset. Land Surface Temperature (LST) was derived from Sentinel-3 at 1 km resolution, but disaggregated until 20 m using the Data Mining Sharpening (DMS) approach. Further information on the pyTSEB model scheme (https://github.com/hectornieto/pyTSEB) and of the pyDMS module (https://github.com/radosuav/pyDMS). Gap filling due to cloudy dates was retrieved from a crop stress coefficient (K_{cs}) obtained from adjacent dates and applied to the reference ET (Jofre-Čekalović et al. 2022).

In order to generate projections of water demand in the study area, the PIRAGUA_atmos_climate dataset (https://digital.csic.es/handle/10261/271116) was used (Quintana-Seguí y Le Cointe, 2022). An analogue resampling technique was used in order to reconstruct the new dataset of climate data, a daily basis for the period 2006-2100. This dataset was run on a subset of six CMIP5 global climate models (GCM) and in two contrasting scenarios: the RCP4.5 and the RCP8.5. The six CMIP5 global models were the following: MRI-CGCM3, MIROC-ESM, CNRM-CM5, MPI-ESM-MR, INMCM4 and BCC-CSM1-1. Then, FAO-56 Penman-Monteith reference evapotranspiration (ET_0) was obtained for each model and the two contrasting scenarios. ET_0 at 2.5 km were resampled at 20 m using the cubic spline method. On the other hand, crop coefficients (Kc) maps were obtained for each date of the 2017-2021 growing period as the ratio of potential evapotranspiration (ETp), calculated from Penman-Monteith and ET_0. Daily averaged Kc for the five years were then used to obtain a new ETp for each date until 2100, for each of the assessed models and scenarios.

Results and Discussion

Cumulative actual evapotranspiration (ETa) was significant between irrigation districts, among years and between irrigated and rainfed fields. The interaction between ID and year was not significant. On average, cumulative ETa was significantly higher for 2017, which accounted for 838 mm. Rainfall of 2017 was the lowest. On the other hand, 2019 and 2021 showed the lowest ET_a values, with 714 and 710 mm, respectively. The irrigation districts with the highest ET_a rates for irrigated fields were AB, CAYC and CU, followed by C and CP. The lowest ETa values were observed in GS and SS. Average accumulated ETa was 811 and 680 mm for irrigated and rainfed fields, respectively. Yearly differences of cumulative ETa between ID can be spatially observed in Figure 1. Despite of the significant differences in ETa between years, the spatial pattern was maintained constant throughout all years.

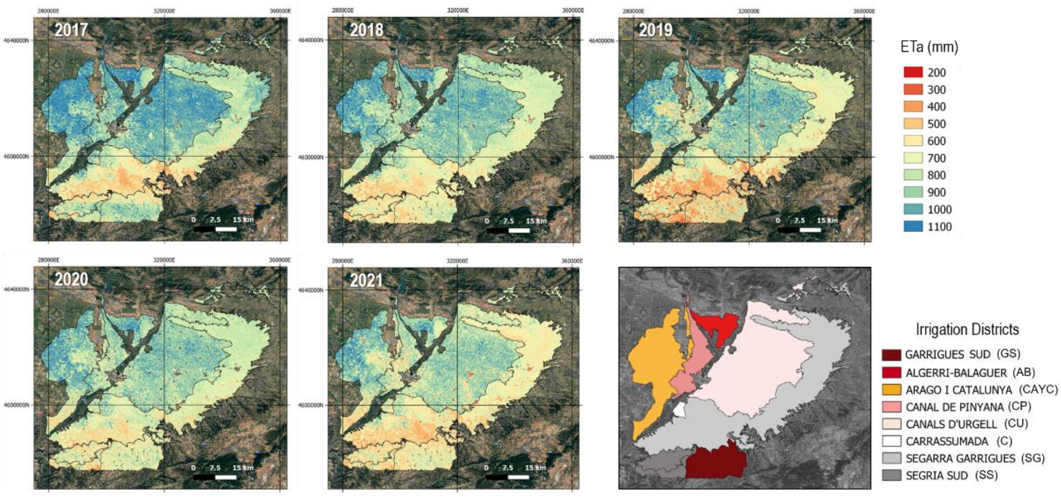

Figure 1. Maps of cumulative actual crop evapotranspiration (ETa) for the period 2017-2021

Figure 2 shows cumulative ETa for each irrigation district during years 2017-2021. Cumulative ETa was always higher for CU due to its larger area, crop types and irrigation system used. Total cumulative ETa in CU varied between 514 to 576 hm^3, depending on the year. It is important to highlight that 50.6% of fields in CU were flood irrigated, causing then a higher soil evaporation. CAYC was the second ID in extension and this was also reflected by its high crop water demands. Total cumulative ETa in CAYC varied between 283 to 254 hm^3, depending on the year. SG, CP and AB accounted for similar values, being cumulative ETa of 102±5.6 hm^3, 77±4.0 hm^3 and 57±1.7 hm^3, respectively for each ID. Finally, C, SS and GS showed the lowest ETa rates, either because they are smaller or have lower water allocations and consequently, other major crops or irrigation practices. C has the lowest irrigated area with a total of 1346 fields under irrigation. Total ETa of C accounted for less than 1% of total water demand in the area. Similarly, SS and GS accounted each for 2% of total water demand.

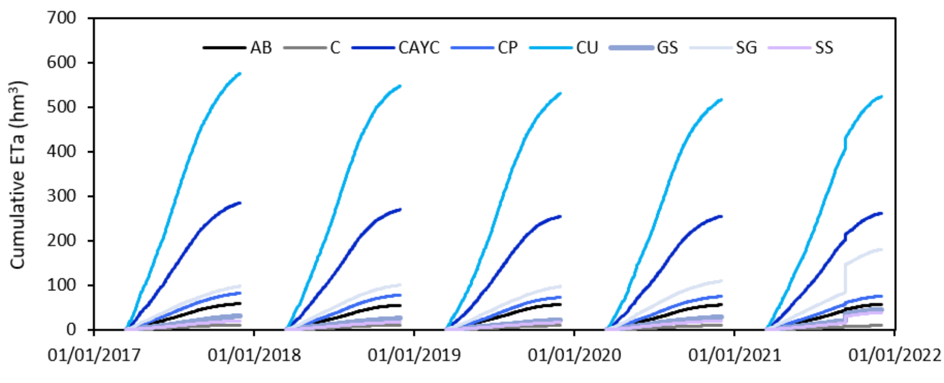

Figure 2. Comparison of cumulative actual crop evapotranspiration (ETa) for each irrigation district during growing seasons 2017 to 2021.

Projections of crop potential evapotranspiration until 2100 for two different RCP scenarios are shown in Figure 3. It can be observed, how ETp in the optimistic scenario (RCP4.5) is lower in comparison to the worst scenario in terms of CO_2 emissions. In both cases, ETp tends to increase, but the slope was higher in the latter. Results indicates that by 2050 crop water demand will increase, on average, 11%

and 16% respectively for RCP4.5 and RCP8.5. In addition, this increase will respectively reach up to 20% and 35% by 2100.

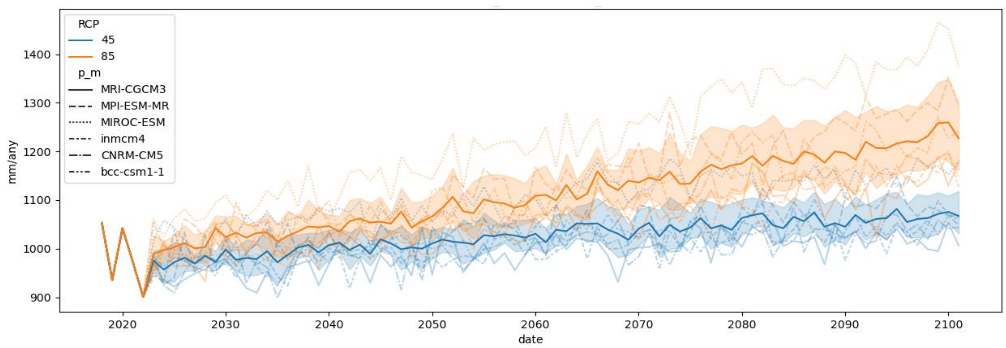

Figure 3. Projections of crop potential evapotranspiration (ETpot) in the area of study under two RCP scenarios

Conclusion

This study has shown the potentiality of using high-resolution remotely sensed ETa time-series for assessing crop water demands of various irrigation districts with different water allocations. This type of information is relevant for irrigation district managers in order to improve the water supply-demand balance. Projections of potential water demands indicated an increase of 20 and 35% by 2100, respectively for an scenario RCP4.5 and 8.5.

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