EO-WASSIM

WAter and Salinity Stress IMpact on crop yield due to unconventional water use for irrigation employing satellite data and agro-hydrological modelling

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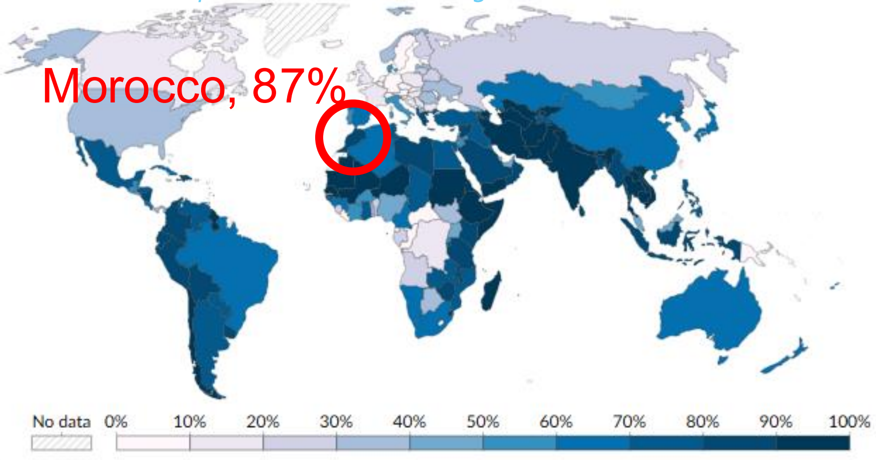
Context

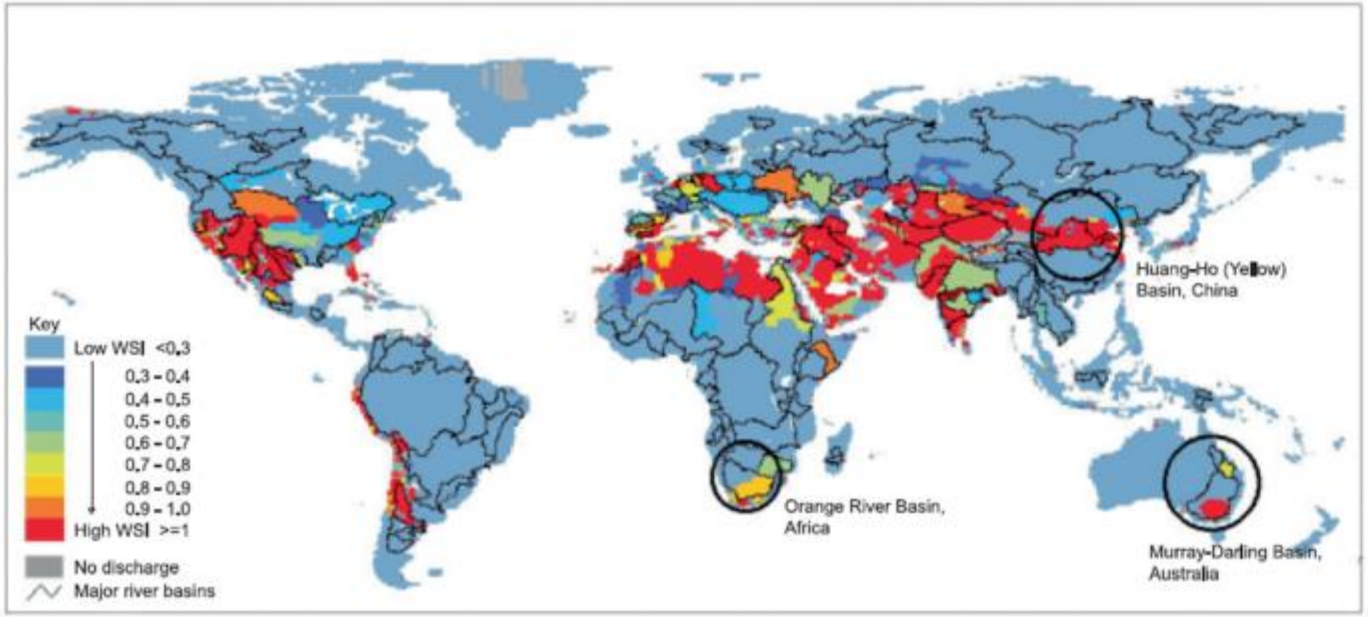
- Global population growth and changing climate are increasing the stress on water resources, especially in densely populated and arid areas
- On average in the world, freshwater withdrawals from agriculture are roughly 70% of the total available resource, but can increase in high water-risk areas
- Unconventional water sources (from desalination plants and/or reused water from urban settlements) can be a valuable help



Agricultural water as a share of total withdrawals as of 2021 (World Bank, https://data.worldbank.org/indicator/ER.H2O.FWAG.ZS)

- The combination of different data from remote sensing can be extensively used to power and validate models to help with agricultural management. Their extensive areal coverage allows to analyze large areas and implement consortium-wide water and agricultural management measures

- Policymakers, water managers and users can greatly benefit from more capillary, comprehensive monitoring of irrigation water use and its effects



Water Stress Indicator map (Smakhtin et al., 2024, IWMI)

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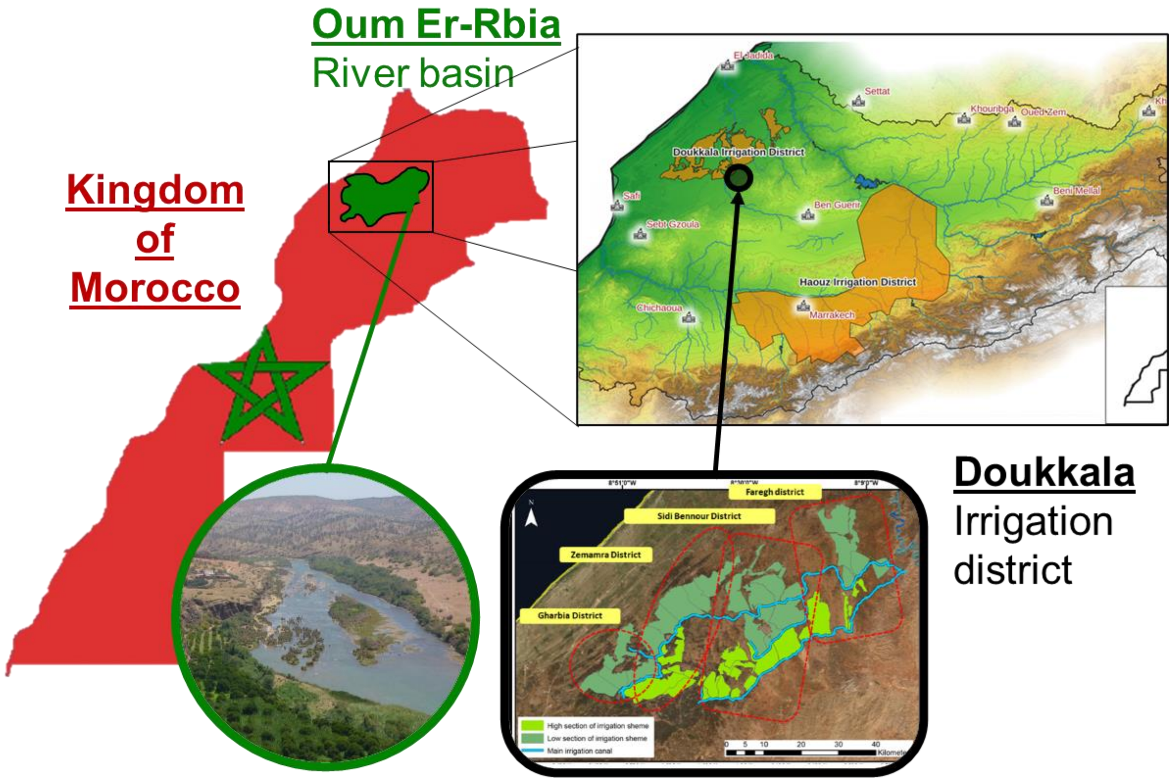
Moroccan case study & context

Water availability in **Morocco** is predicted to drop to 500 m³/capita/year by 2030, while water demand is projected to grow from 14.3 billion cubic meters (BCM) in 2010 to 23.6 BCM in 2030. With an average yearly rainfall of 140 BCM, comparable to the estimated Evapotranspiration (118 BCM/yr), the country has a mainly arid/semi-arid climate.

The **Oum er-Rbia river** is regulated through a network of basins which can store up to 2.8 BCM and provides water for nearby cities (Casablanca, Marrakech and others, 250+ MCM/yr), industrial activities (phosphate extraction industry, 80+ MCM/yr) and agriculture (190+ MCM/yr)



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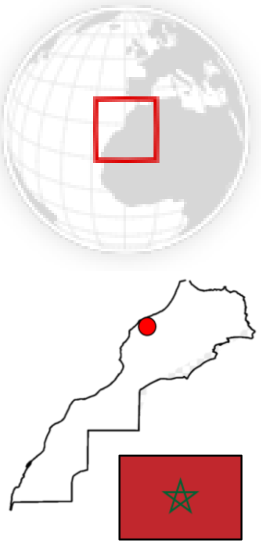
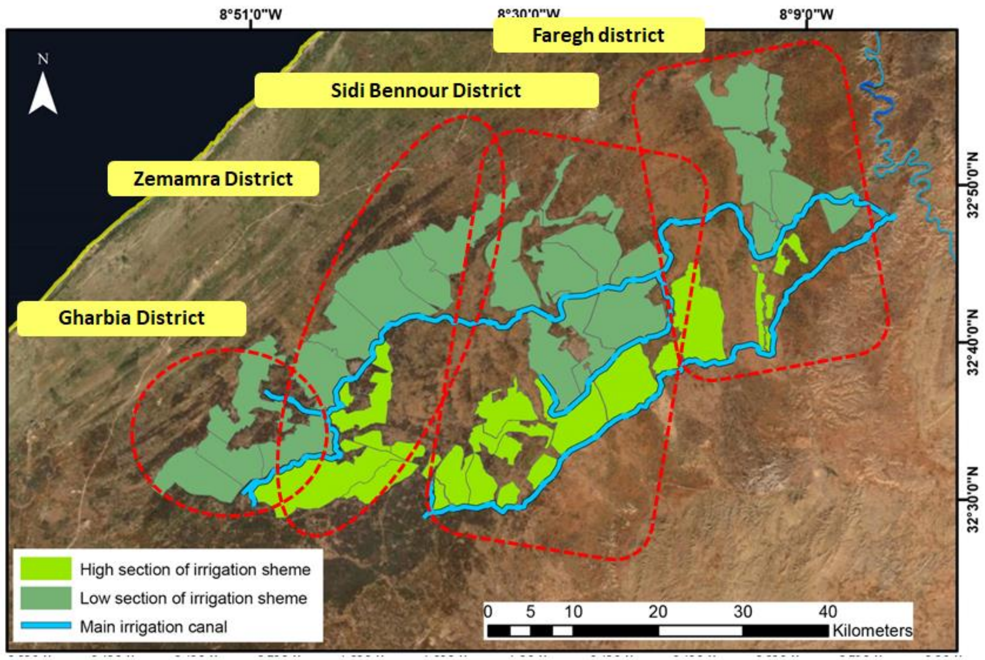
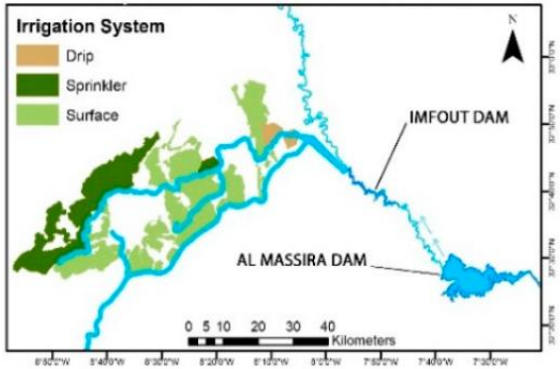
Doukkala Irrigation District case study





The **Doukkala Irrigation Consortium** in northern Morocco is heavily irrigation-dependent. It is the most important area in Morocco for sugarbeet (83% of national production via the local company COSUMAR) and receives water mainly from the Al Massira dam on the Oum Er-Rbia river.

Area	1,192 km^2
Crops	Sugarbeet, wheat, alfalfa
Irrigation	Surface + Sprinkler Distribution network + wells
Water volumes	Rainfall: 220 mm/yr Irrigation: 400 mm/yr



In the period 2020-2025, a prolonged drought has caused all water transfers from the local water managers (ORMVAD) to cease and farmers relied on private wells: local measurements have detected a decrease in groundwater level and an increase in its salinity.

The Moroccan government is increasing its desalination capacity to be prepared for water scarcity conditions in the future.

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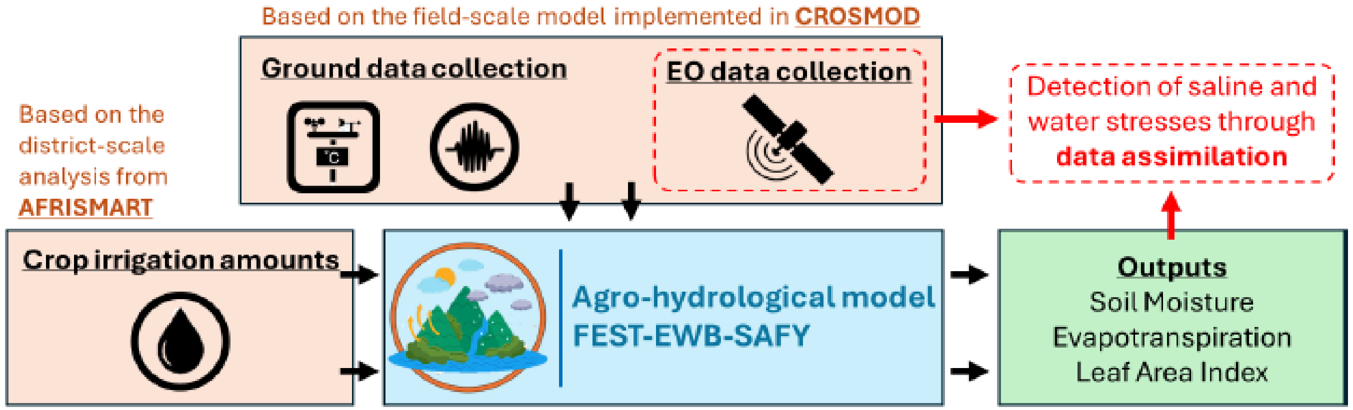
EO-WASSIM structure & objectives

- Combine ground and EO data to feed the FEST-EWB-SAFY agro-hydrological model, simulating energy and water fluxes and crop growth to estimate crop yield in a water-scarce, salinity affected area in Morocco
- Improve the representativity of agro-hydrological modelling with data from ground field campaigns describing field crop type and management



- Evaluate scenarios of deficit irrigation management or unconventional water use and their impact on crop yield
- Create a versatile, open-source tool to run the model in the different water management conditions

Working packages	2025		2026					
	Sep Oct	Nov Dec	Jan Feb	Mar Apr	May Jun	Jul Aug	Sep Oct	Nov
WP1. Case study analysis and data collection								
WP2. EO data retrieval and analysis								
WP3. Agro-hydrological model calibration								
WP4. Analysis of unconventional water use effects								
WP5. Findings diffusion								

Group meeting in Morocco, January 2026

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Part 1

2025-26 CRTS-UCD field campaigns

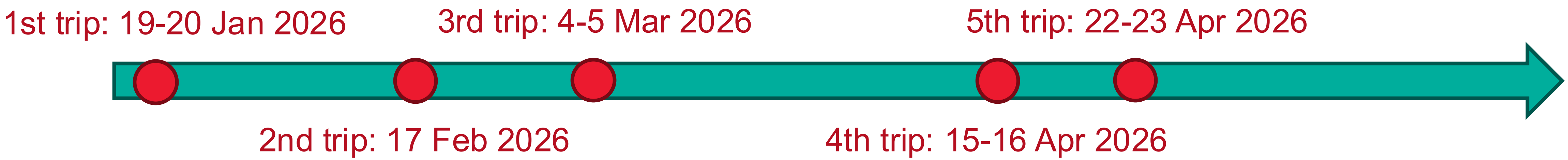
Overview of field campaigns

The CRTS team run a series of field campaigns in the Doukkala Irrigation district for the 2025-26 agricultural season, to improve the knowledge of field reality and strengthen the reliability of satellite observations and modelling results. The objectives of these field campaigns were:

- Characterize the soil and crop variability of the study area
- Monitor crop development throughout the agricultural season
- Identify crop management heteorogeneities in the area (e.g., sowing date, irrigation type)
- Observe irrigation practices and local hydrological conditions
- Confirm results of crop classification maps with ground truths
- Physico-chemical properties of the soils (salinity distribution, soil moisture, soil temperature)

Some numbers:

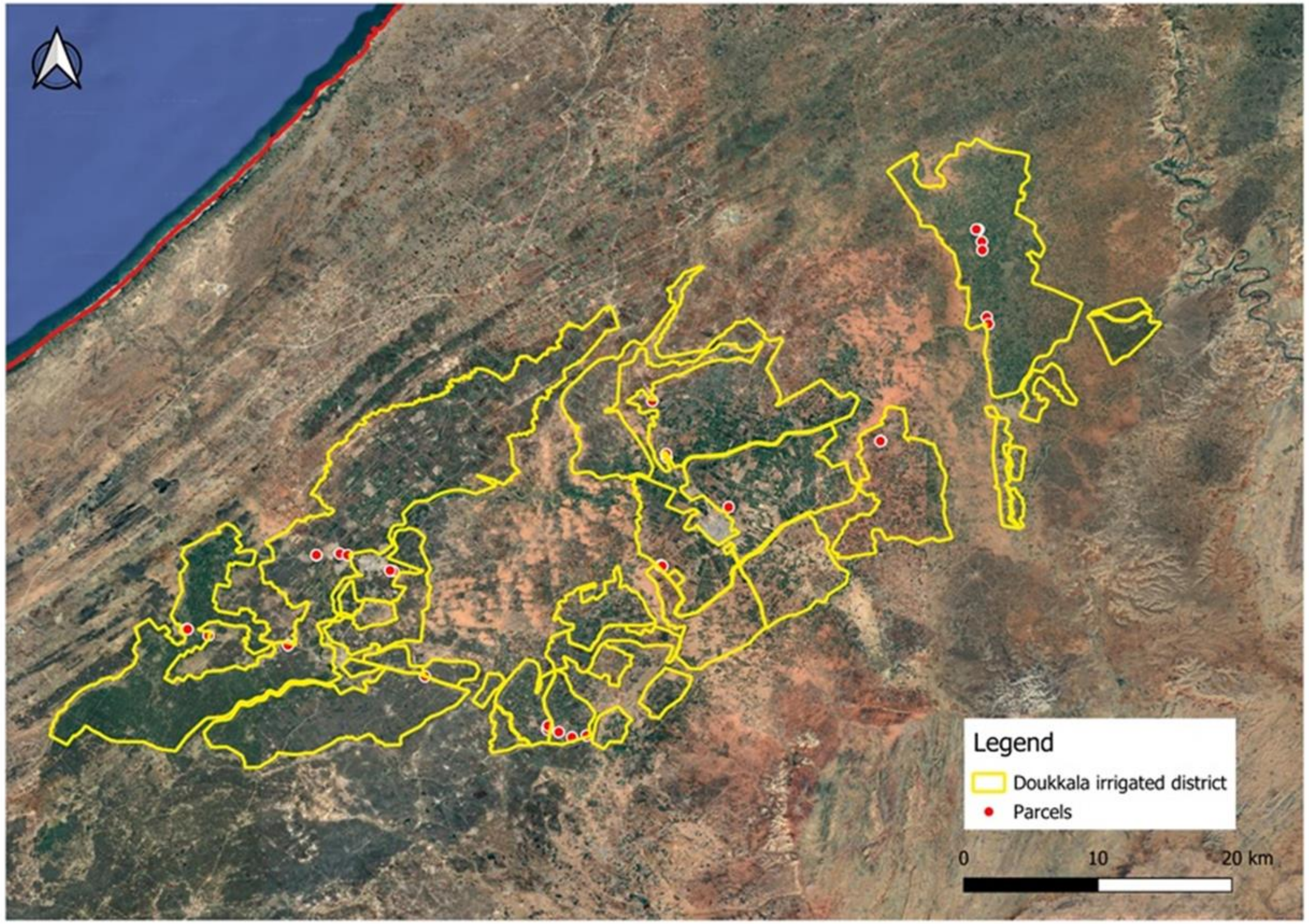
- Field outings: 5 (as of April 2026)
- Monitored fields: 32



Distribution of the Selected Plots within the Doukkala Irrigated Perimeter

The selection of plots was carried out according to several criteria:

- Representativeness of crops;
- Apparent homogeneity of the plots;
- Accessibility of the sites;
- Diversity of irrigation practices.



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Crop situation in the Doukkala irrigated perimeter

- Dominance of cereal crops (wheat, barley, oats) and sugarbeet over fodder crops (alfalfa);
- Favorable hydrological conditions due to the persistence of rainfall in 2026 after the 2020-2025 drought
- A reduced reliance on irrigation in most of the plots in this stage.
- Predominance of sprinkler irrigation, with notable presence of drip irrigation systems

Sugar beet fields

Wheat fields

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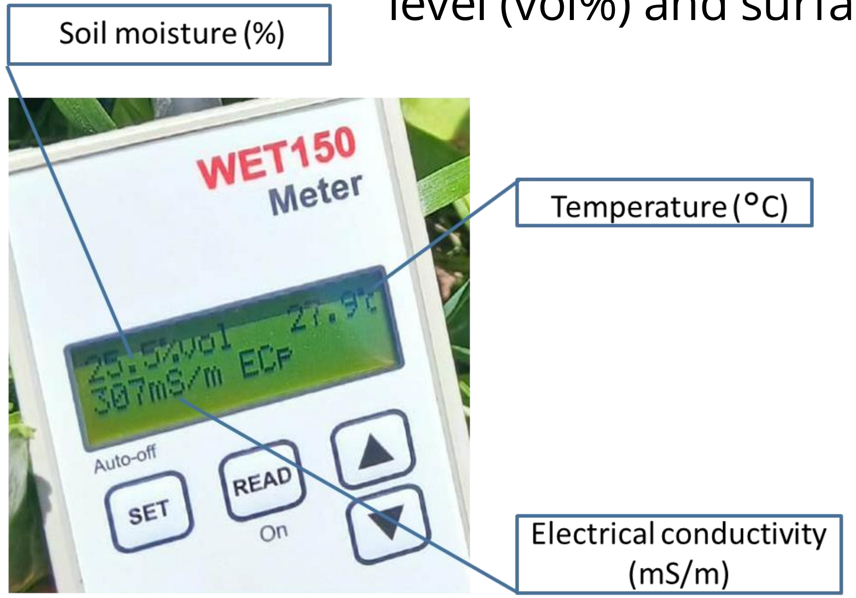
Field work

- For each plot, several measurements were taken at different points in order to account for spatial variability. The crop height value was generally derived as the average of the recorded measurements.
- The measurement was performed from the soil surface to the highest point of the plant, ensuring consistency across all observations and missions.
- Starting from the 4° field visit, after the purchase of a salinity monitoring instrument (within project framework), electrical conductivity (EC) measurements were taken, together with moisture level (vol%) and surface temperature (°C)



- During multiple field visits, it was possible to follow the development of the crops and distinguish between the cereals which share similar phenotypical characteristics in the early stages of their growth

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Various developmental stages of wheat

Heading–early flowering stage
The ears are fully formed and still green, indicating good vegetative vigor and a favorable yield potential.

Grain filling stage
The ears remain green but show early signs of maturation; some leaves begin to turn yellow, indicating the translocation of reserves toward the developing grains.

Various developmental stages of wheat

Physiological maturity stage
The ears are yellowing and the grains are fully filled, indicating that the crop is approaching harvest.

Full maturity / pre-harvest stage
The ears are completely yellow and dry, with a pronounced senescence of the leaves. The grains have reached their maximum size and weight, indicating that the crop is ready for harvest.

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Sugar beet plots under sprinkler irrigation

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Sugar beet fields irrigated by drip irrigation

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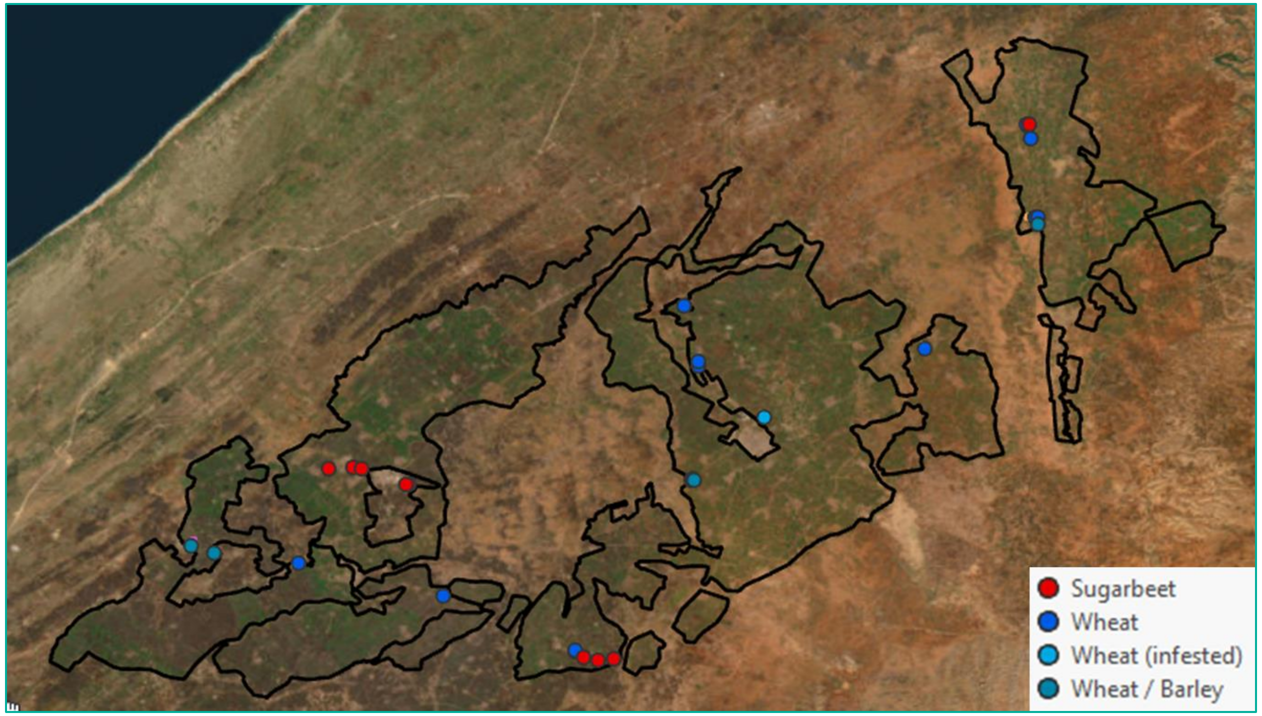
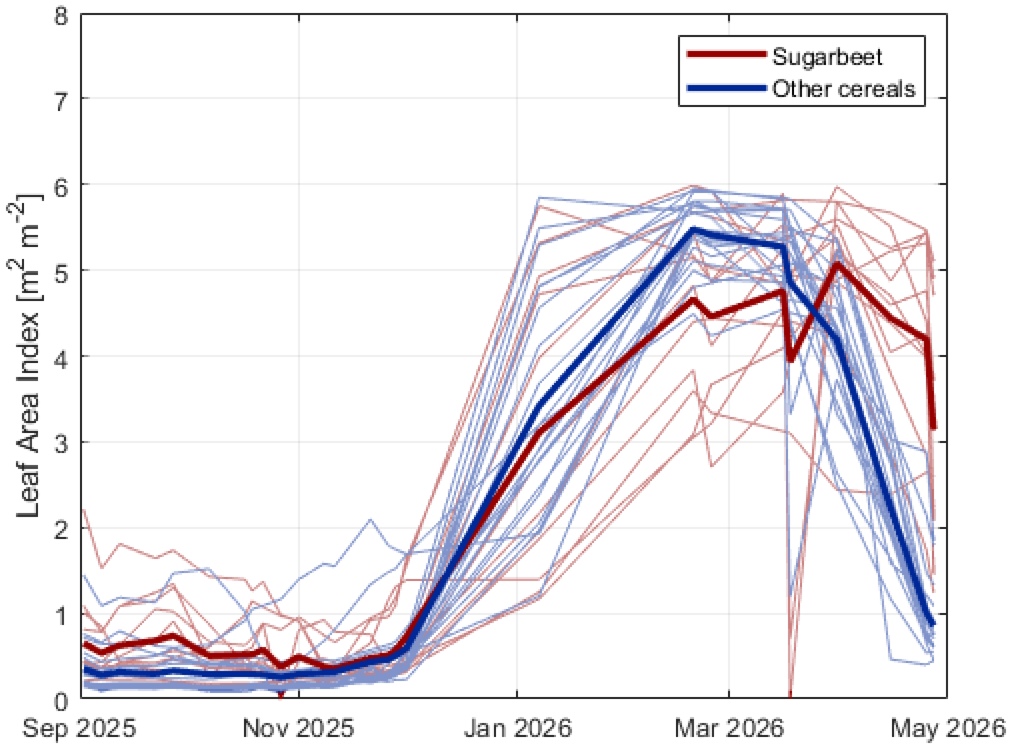
Field campaign results to validate crop classification

A crop classification algorithm was developed to distinguish sugarbeet from the cereal crops present in the area, mainly wheat and barley.





Observing the temporal evolution of the leaf area index from Sentinel-2, it is possible to see how the sugarbeet pixels have lower peaks and longer seasonal durations, consistent with the field observations.

The validation of this algorithm over the 32 monitored fields allows to prepare district-wide maps of crop parameters for the SAFY crop model.

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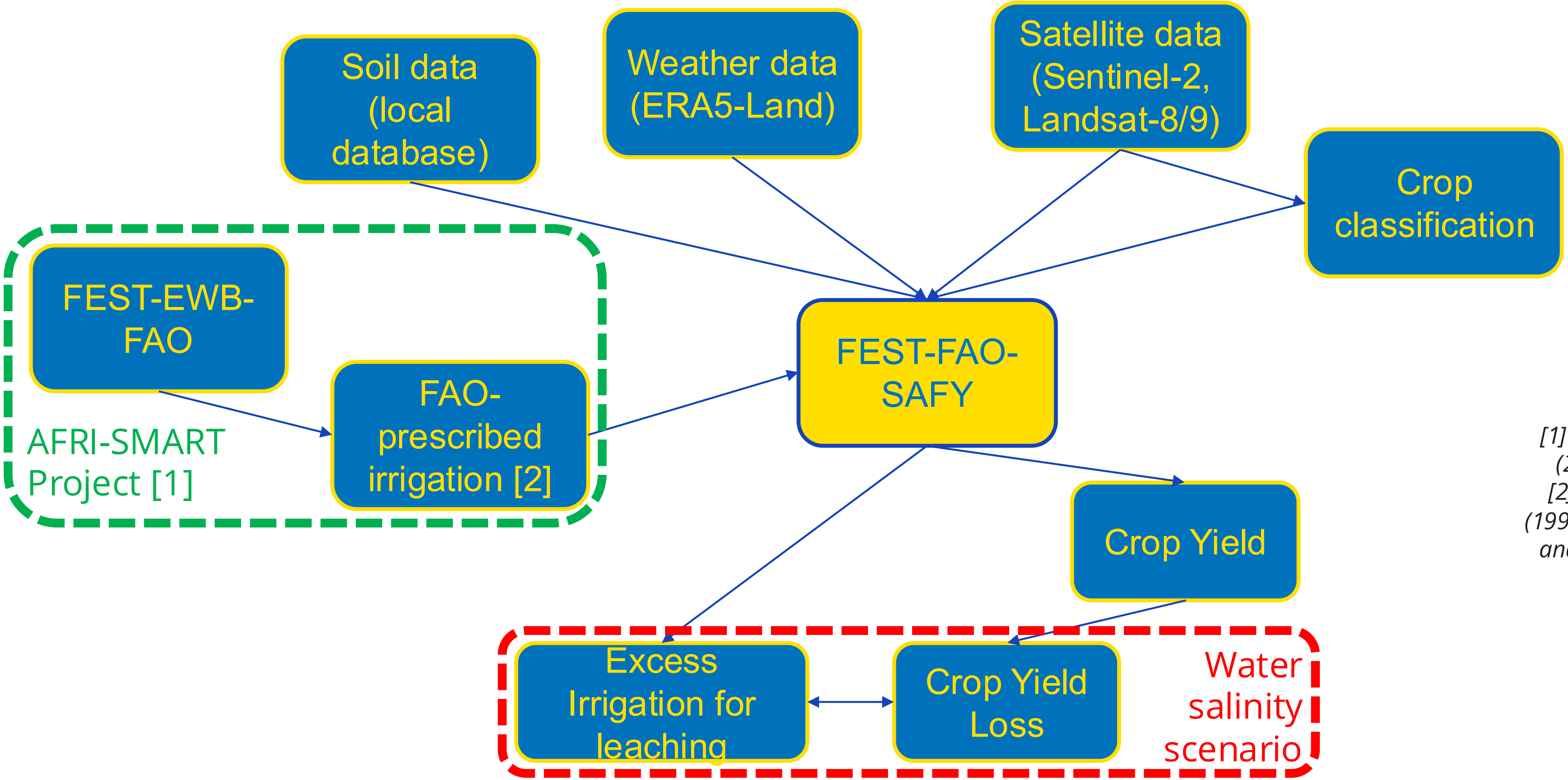
Part 2

Model simulations

Workflow



[1] Corbari, C., et al. (2025). WRR, 61(7)
[2] Allen, R.G., et al. (1998). FAO Irrigation and drainage paper No. 56.

Agro-Hydrological modelling

The **FEST-EWB** (Corbari et al., 2011) model is a distributed hydrological model that closes, for every step, both the energy and soil water balances of a pixel, computing internally the **Representative Equilibrium Temperature** (**RET**).
Whenever satellite observations of LST are available, these can be compared with the RET to calibrate the model.

$$Rn(\boldsymbol{RET}) - G(\boldsymbol{RET}) = L(\boldsymbol{RET}) + H(\boldsymbol{RET})$$

Surface energy water balance

$$\frac{\partial SM_{(1)}}{\partial t} \cdot \Delta z_1 = P + I + C_1 - Pe_1 - \beta \cdot ET$$

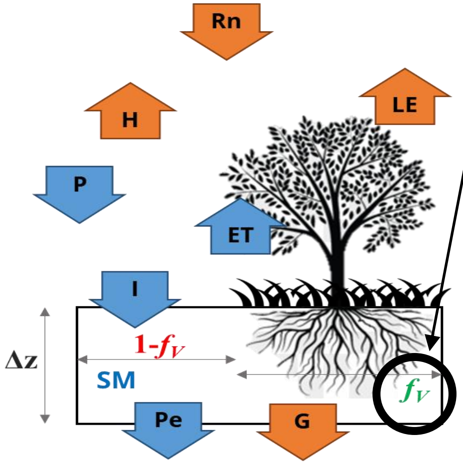
$$\frac{\partial SM_{(2)}}{\partial t} \cdot \Delta z_2 = Pe_1 + C_2 - C_1 - Pe_2 - \delta \cdot ET$$

Water mass balance (two layers)

$$\Delta DAM = APAR \cdot P_{LUE} \cdot f(Ta) \cdot K_{wat} \cdot K_{sal}$$

Biomass evolution

From Remote Sensing (Sentinel-2)



The **SAFY** (Duchemin et al., 2008) model simulates plant development employing a simplified parameter set. It can include external impact on crop development via a series of stress functions, for instance the salinity stress coefficient K_{sal}, linked to the crop sensitivity to salinity expressed in the b, K_y and EC_{LOW} parameters.

Corbari et al. (2011) Model. Earth Syst. Environ. 10, 1–17
Duchemin et al. (2008) Env. Modell. Softw. 23(7), 876-892

$$K_{sal} = 1 - \frac{b}{K_y \, 100}(EC - EC_{LOW})$$

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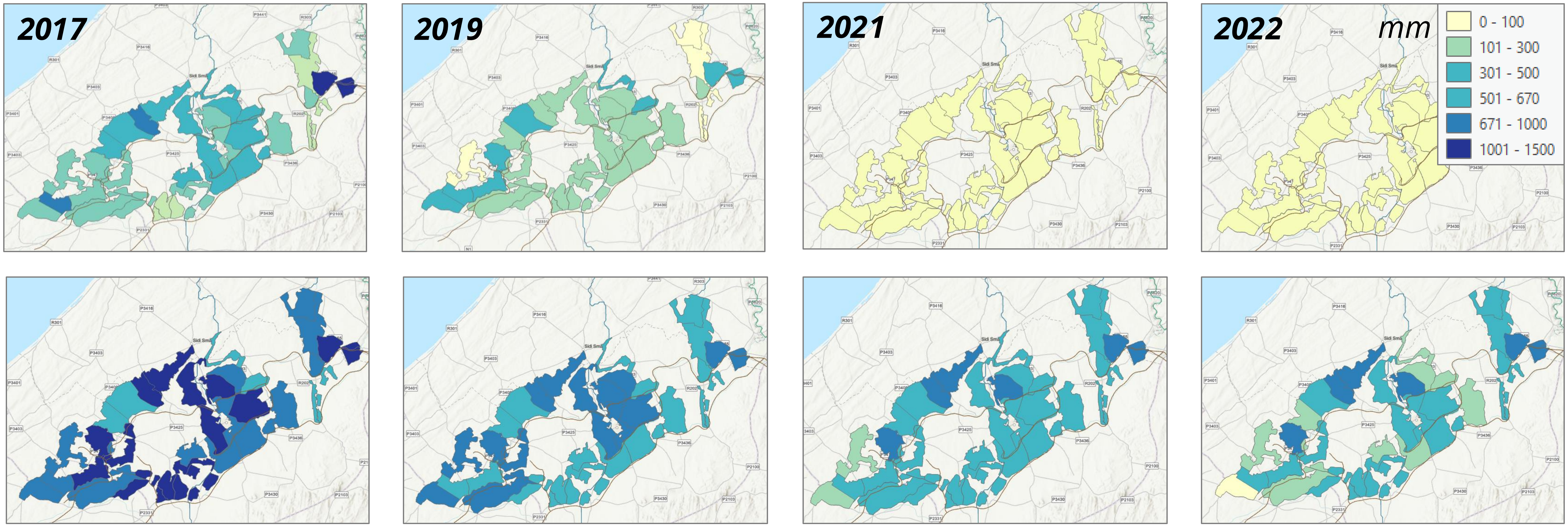
Irrigation strategy results

During these years, water pumping occurred in the area to integrate (or substitute) the surface water use

First row: observed irrigation as officially recorded by ORMVAD
Second row: simulated irrigation from FEST-EWB



Work performed within the ESA project EO Africa – National Incubators EXPRO+
More on the estimation of irrigation water volumes in Doukkala in Corbari, et al. (2025) WRR, 61

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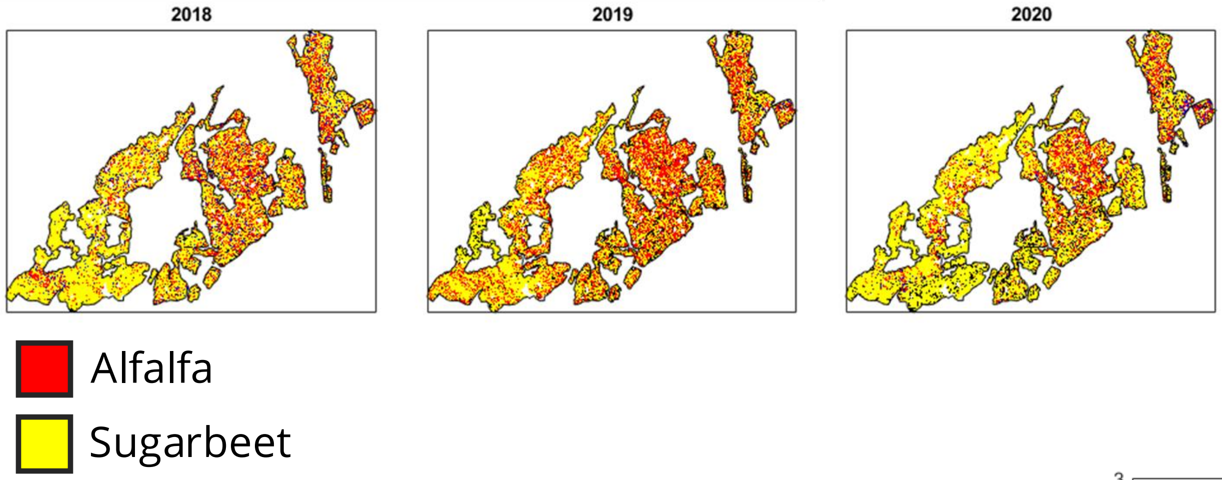
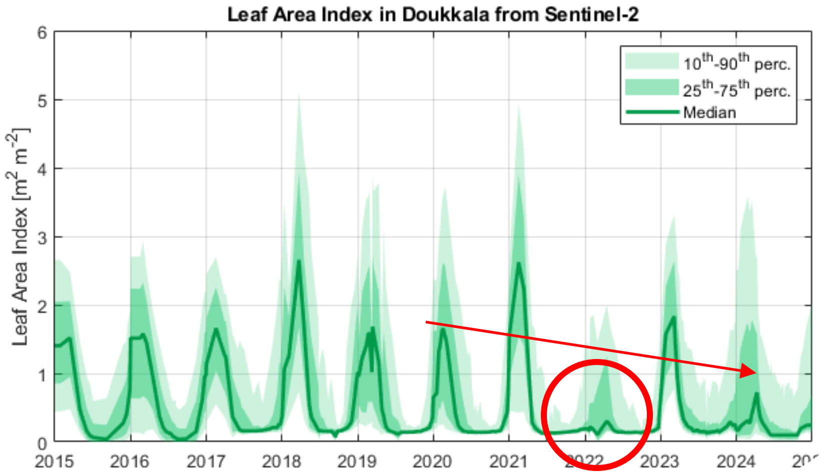
Crop Model results (1)

Analysing satellite data, it was possible to observe the impact of the drought on local agronomical patterns. Observing the yearly cycles of the different pixels, it was possible to classify the main local crops:

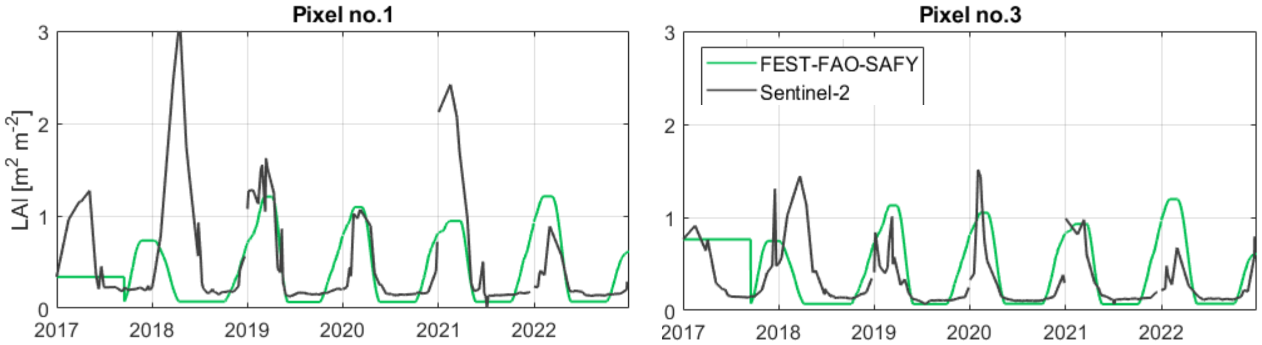
- Alfalfa is an all-year crop with multiple harvest/regrowth cycles
- Sugarbeet grows between Nov and Jun



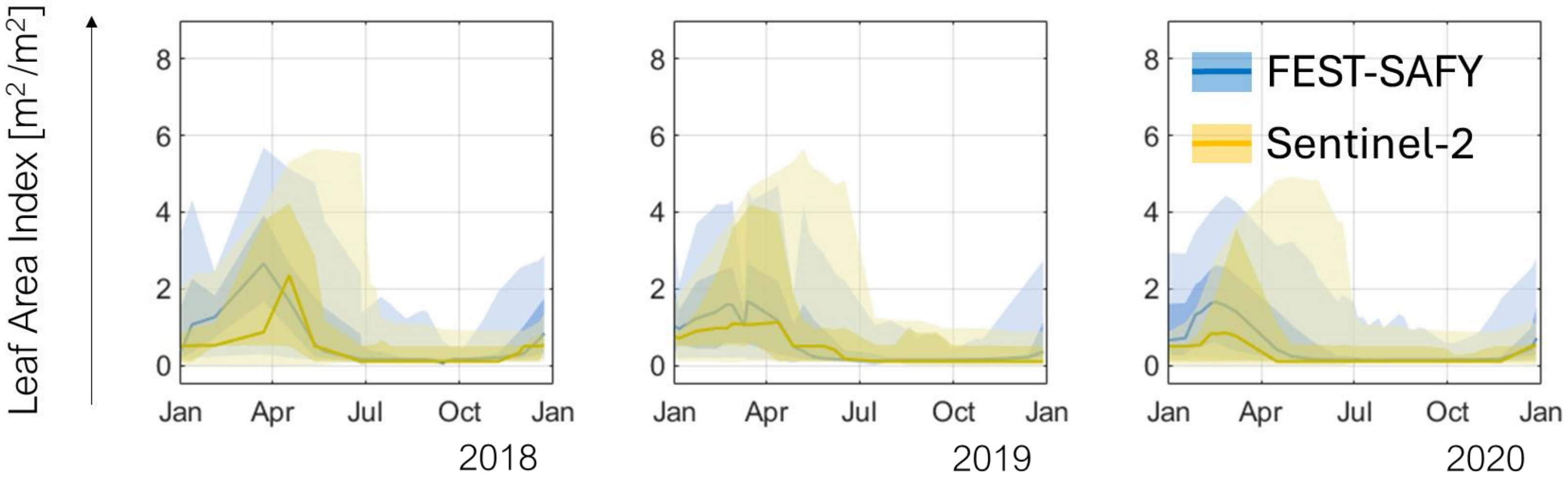


In 2022, after two seasons without water from the dams, the cultivated area was only 320 km² (34% of the average area cultivated in normal years)

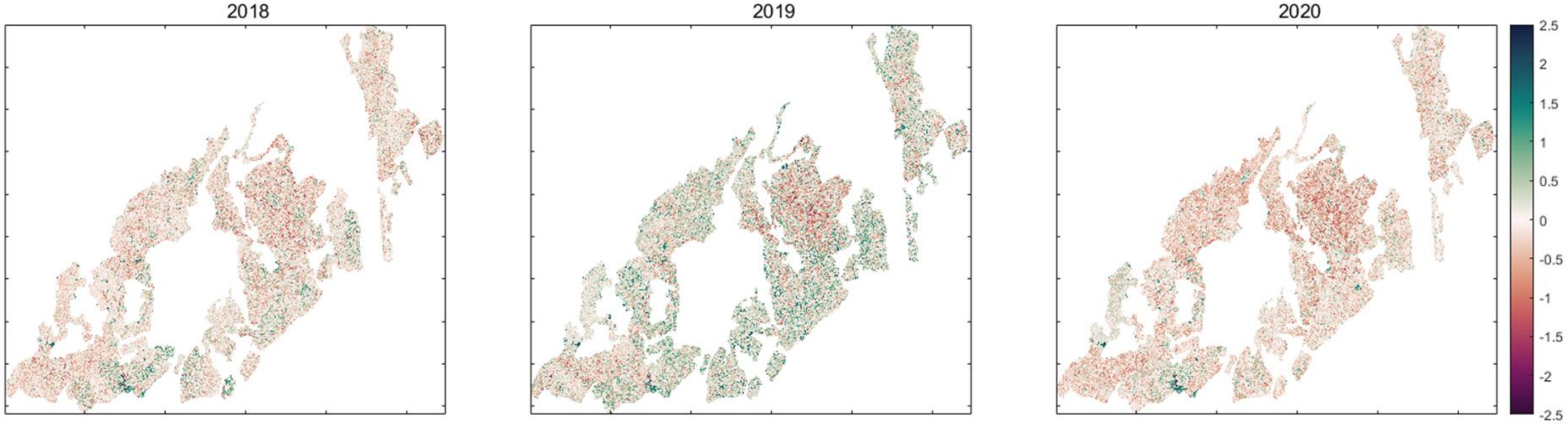
Once the crops are identified, the model is run with the proper parameters



Crop Model results (2)



The crop component of the model was calibrated by comparison with observed LAI data from Sentinel-2.



The identification of cultivated area was performed based on the analysis of year-cycle signatures of LAI. Crop growth start and end (harvest) were triggered based on crop-specific thresholds.

Mean yearly error of modelled LAI against observations from Sentinel-2 was 0.2 m^2 m^{-2}.

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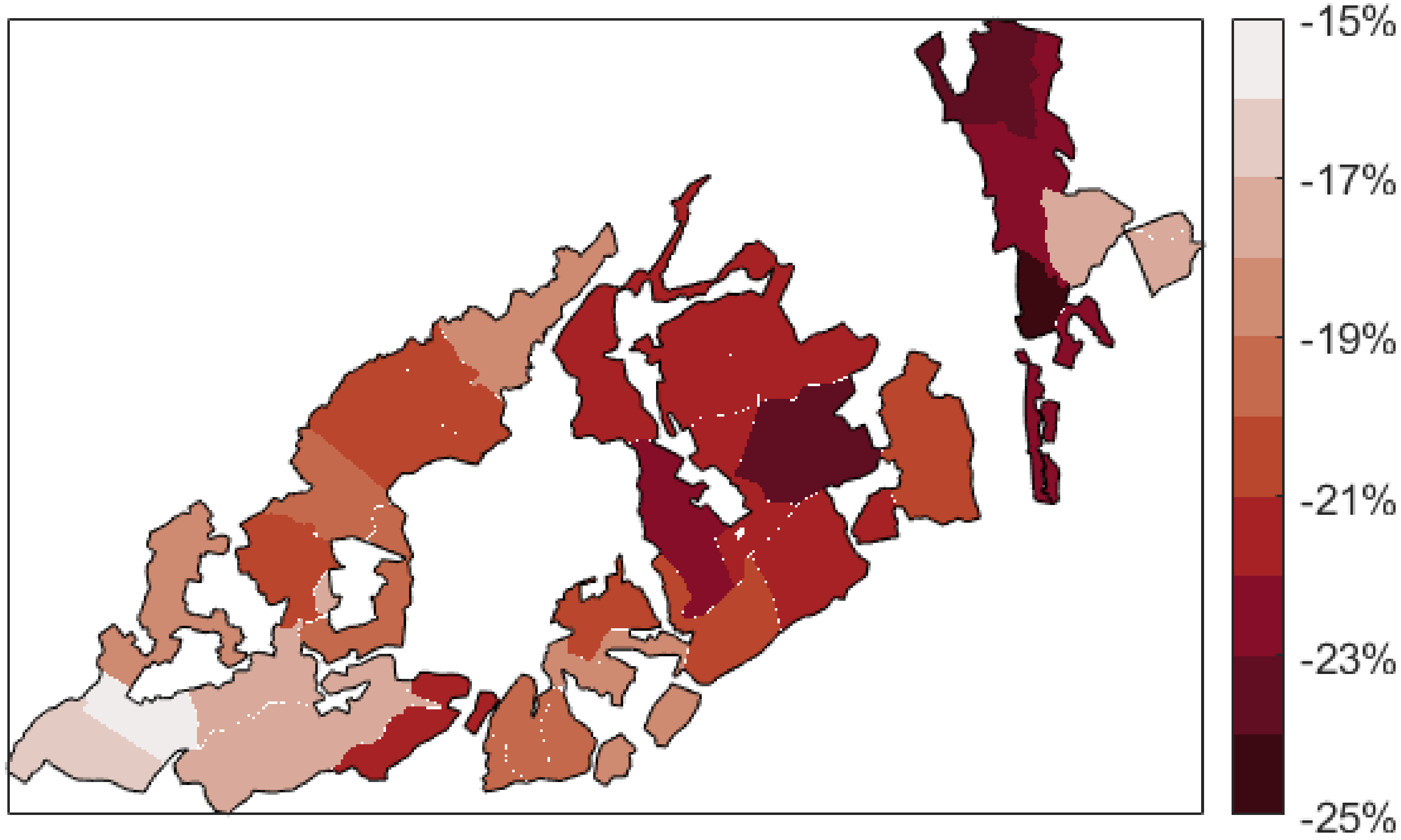
First results of Salinity impact (1)

Relative Yield Loss

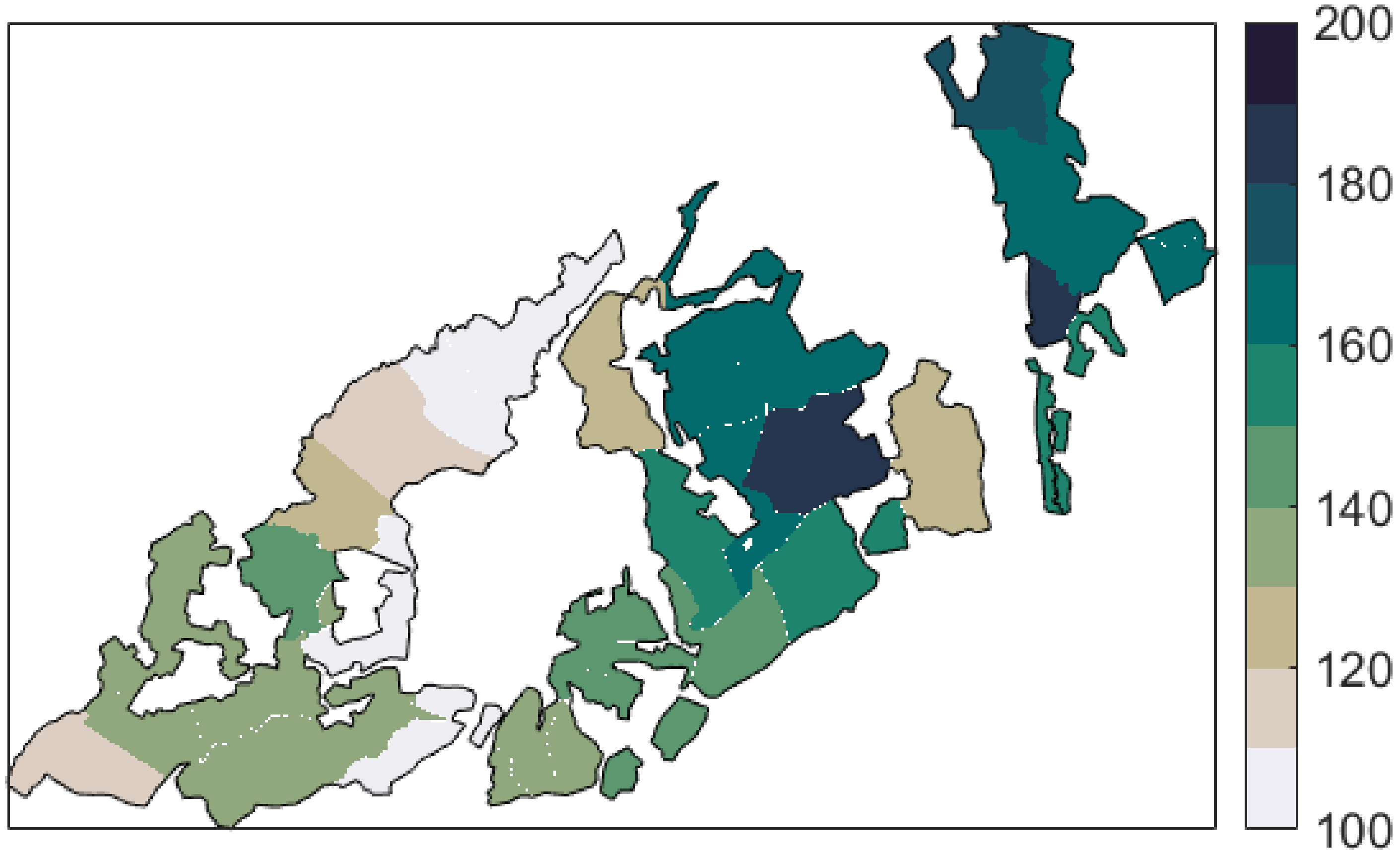


Jamaa, et al. (2024) Model. Earth Syst. Environ. 10, 1–17
Fadili et al. (2018), Hydrogeology Journal, 26:2459–2473

- According to some recent studies (*Jamaa et al., 2024; Fadili et al., 2018*), salinity in the Doukkala groundwater can be relatively high (with peaks above 9 dS/m of water electrical conductivity, EC)
- Using this water for irrigation can have an impact on crops like alfalfa (EC_{LOW} = 2 dS/m) but also sugarbeet (EC_{LOW} = 7 dS/m)
- A model simulation with a medium-high salinity water (EC = 8 dS/m) was performed to assess the effect on yield
- The production drop on average is -20%, and heavier in areas with large alfalfa production. Sub-sector-level average production drops reach a maximum of -24%, with pixel maxima as high as -53%.

First results of Salinity impact (2)

Extra irrigation volumes [mm]



- To avoid yield loss, and following FAO guidelines, salinity impact on crop can be countered by reducing the concentration of salts in the soil. This leaching can be done by adding a further irrigation amount to force water percolation and salt transport to the lower soil horizons, out of the reach of the plants.
- These leaching requirements (LR) depend on the salinity tolerance of the crops, and can be computed as:

$$LR_R = \frac{EC}{2 \cdot EC_{MAX}} \rightarrow IR_{NET}^{(upd)} = IR_{NET}^{(o)} \cdot (1 + LR_R)$$

- The extra irrigation required to counter the effect of salinity is heavier in areas with sandier soils and can reach up to 30% of the regular water use

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Next steps

- Continue field visits to follow the conclusion of the sugarbeet growth period and strengthen the collaboration with institutional and professional stakeholders (ORMVAD, COSUMAR) to facilitate access to key information like irrigation rates and seasonal yield

- Implement improved crop type masks from satellite data, validated against ground truths, within the agro-hydrological model for the simulation of crop development and water needs.

- Include field observations in the formulation of unconventional water use scenarios to assess the effect of less or lower-quality water (non-negligible salinity) on crop yield

- Implement the modelling working chain in an open-source Jupyter environment for easy and capillary distribution to the public

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