# EO for Africa Symposium 2024

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# Multi-scale and multi-model approaches to water management with satellite data: the experience of the AFRI-SMART project in Morocco


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# AFRI-SMART context and objective

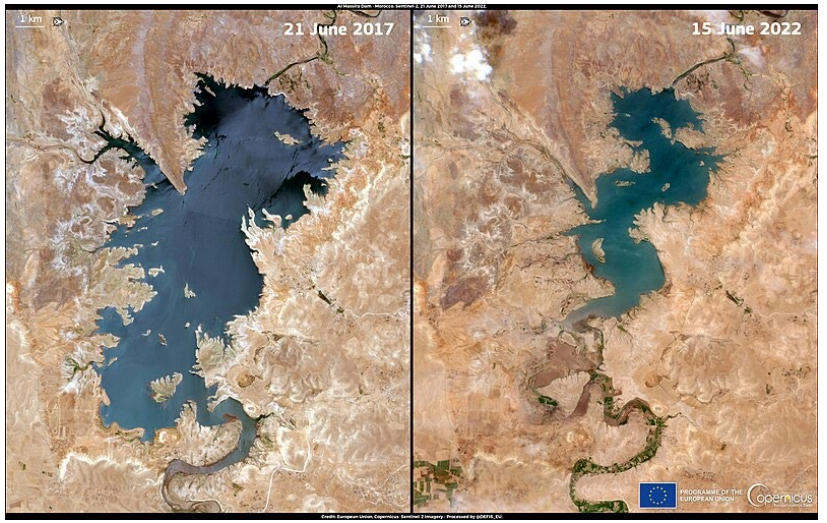
National Incubators
facilitating adoption of EO
with national R&D partners

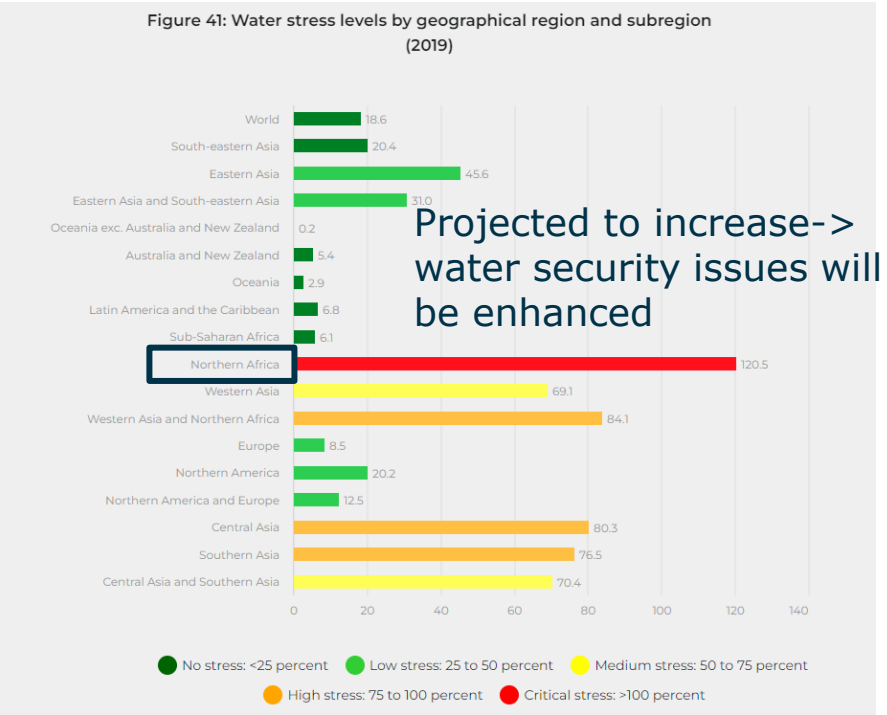
EO AFRICA

Develop and validate **EO-based solutions addressing sustainable agriculture and drought monitoring,** by **co-developing** together with African experts and end-users increasing their knowledge and capacity, developing an operative platform and database for results visualization and sharing with end-users


The AFRI-SMART project will tackle this challenge in the Morocco country

The website link is: https://www.afrismart.polimi.it



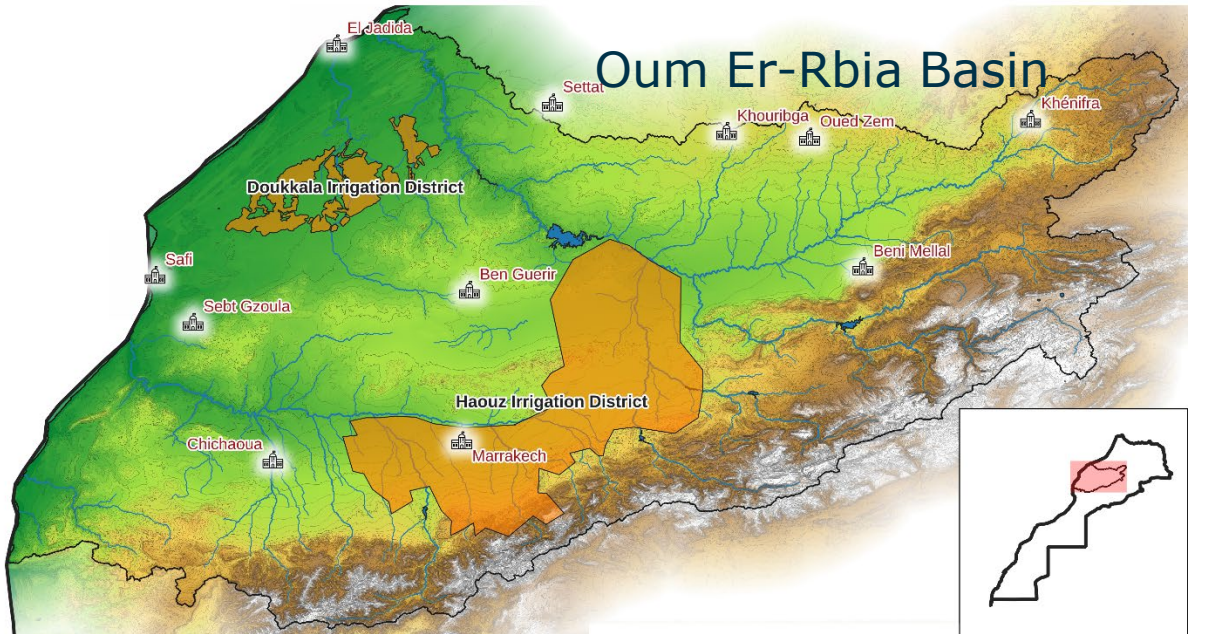




Projected to increase-> water security issues will be enhanced

FAO. 2022. Indicators. In: *Sustainable Development Goals*. June 2022. www.fao.org/sustainable-development

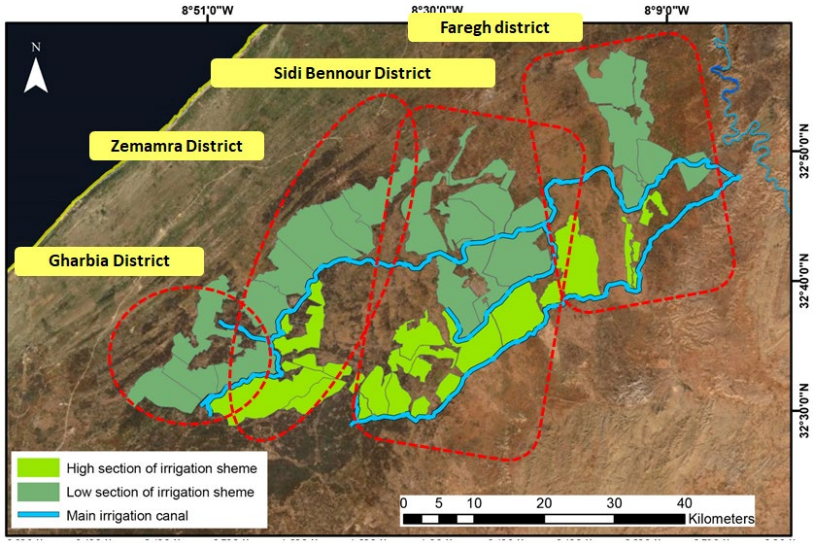
# AFRI-SMART case study

- **Decreased water availability**, due to increased drought periods, inaccurate management and water infrastructures
- **Increased water demand** (extention of irrigated areas, urban development and industrial)




ORMVAD office stopped supplying water to farmers by mid-2020

Doukkala area (96,000 ha)



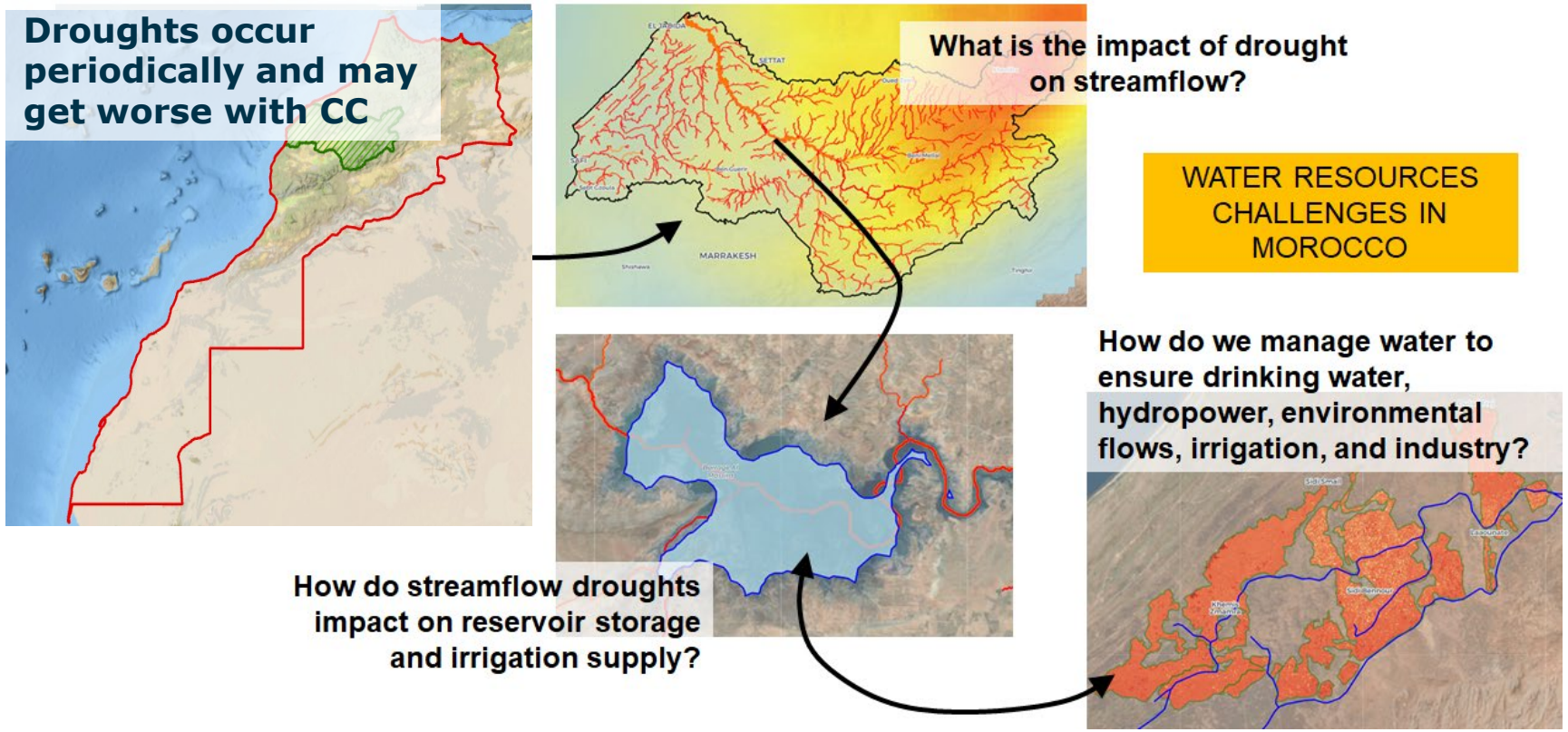




Sugar beet, spring wheat, alfalfa (perennial crop) and summer maize

# The problem we are trying to address

- **Estimate and forecast of water availability and needs under a changing climate, at multiple spatial scales**
- **Improvement of water management at national scale during droughts conditions, mitigating water use conflicts**

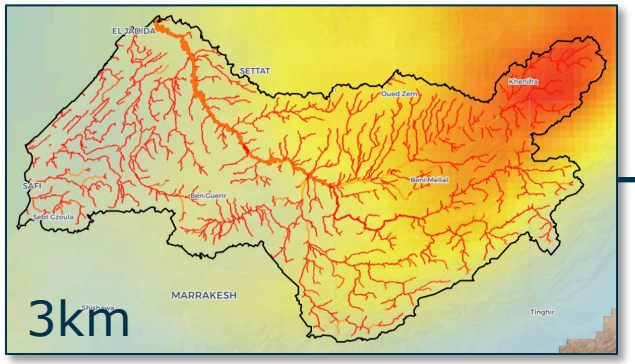



Thus, more accurate information on water availability distribution in space and time is needed to address sustainable agriculture and to guarantee food security, through an adequate irrigation supply and basin integrated water management.

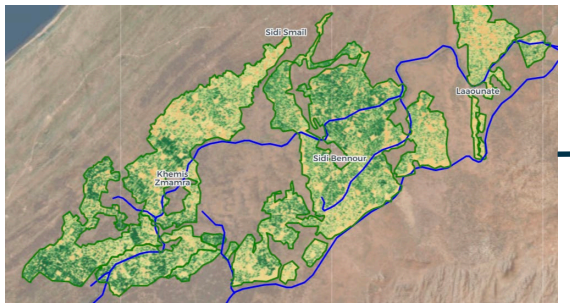
# How to address this problem…

## Monitoring
historic simulation for 1979-2022

Precip / SM / Streamflow

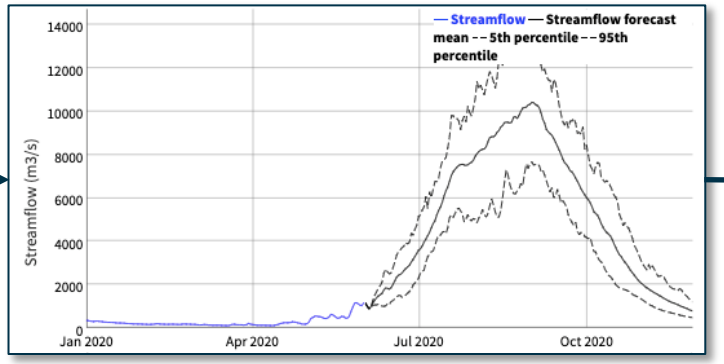



30m Crop water use

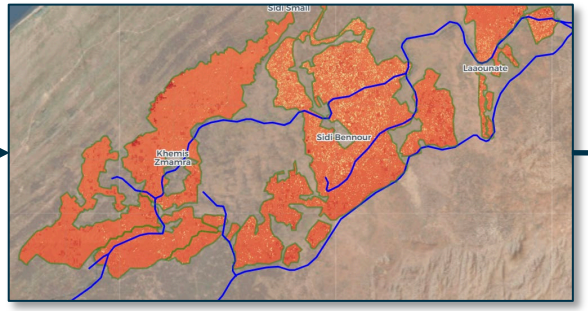



## Forecasting

Streamflow

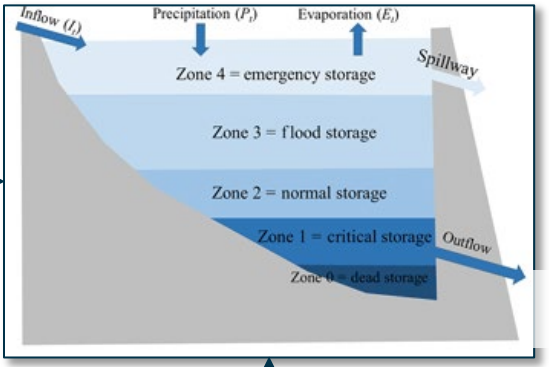



Crop water demand

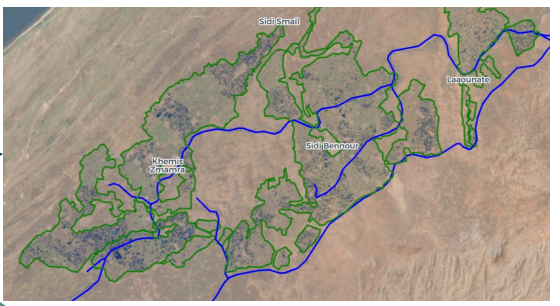



## Management?

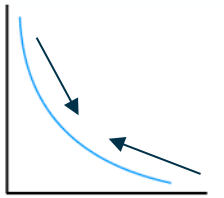
Reservoir operation




Irrigation application



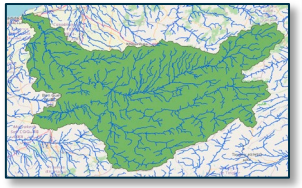

**Trade offs?**

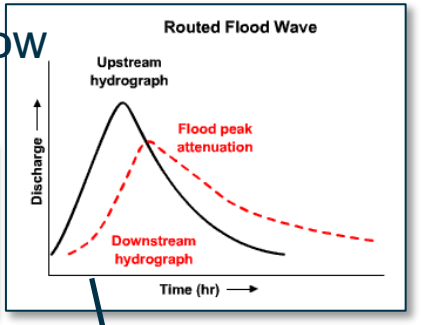


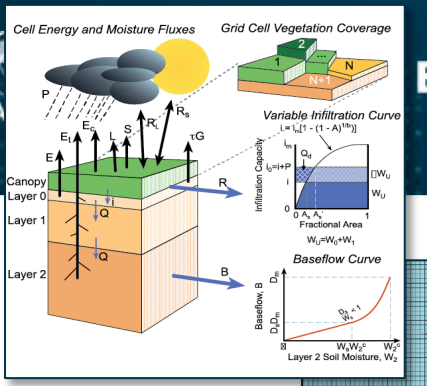
# The tools we are using

## END-USERS needs

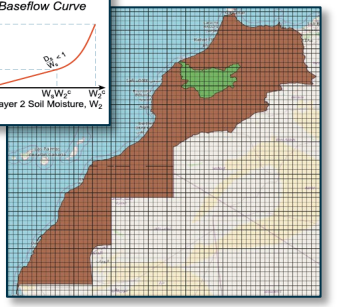
## RAPID Streamflow Routing Model



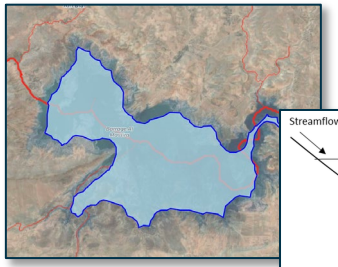


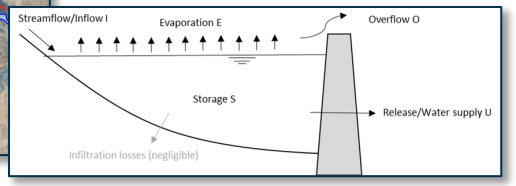




## Hydrological Model

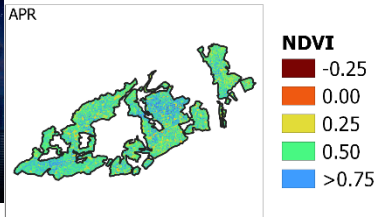


## Reservoir Routing Model

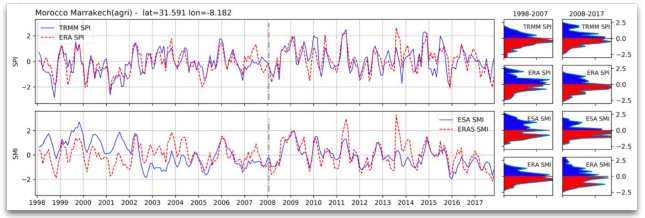





## Satellite data

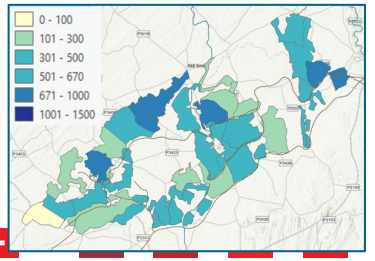



## Drought indicators




## Water availability

## FEST-EWB Agro-hydrological model




## Civil and industrial water uses

**Web-GIS platform**

# Cooperation with End-users

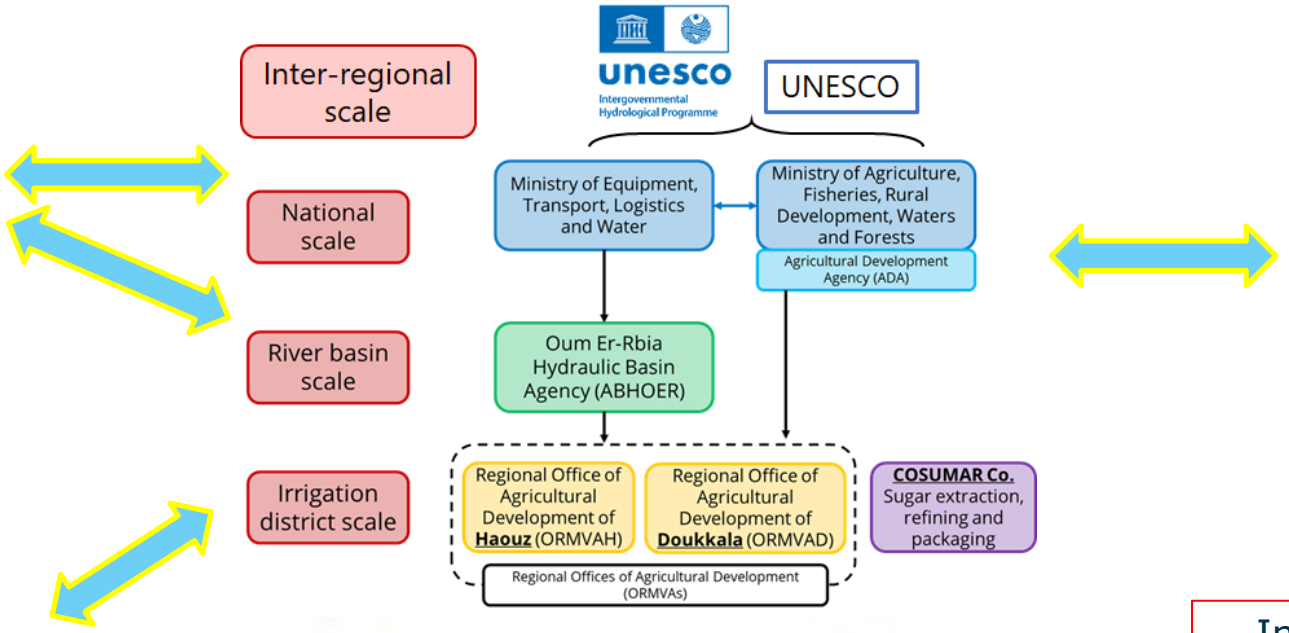
Involve relevant African end-user entities throughout the project with an agile approach to facilitate the integration of the developed solutions that are actually responsive to their necessities

## End-users expectations matching project outputs

From a survey and meetings

## Multi-scales approach

From numerical modeling to people



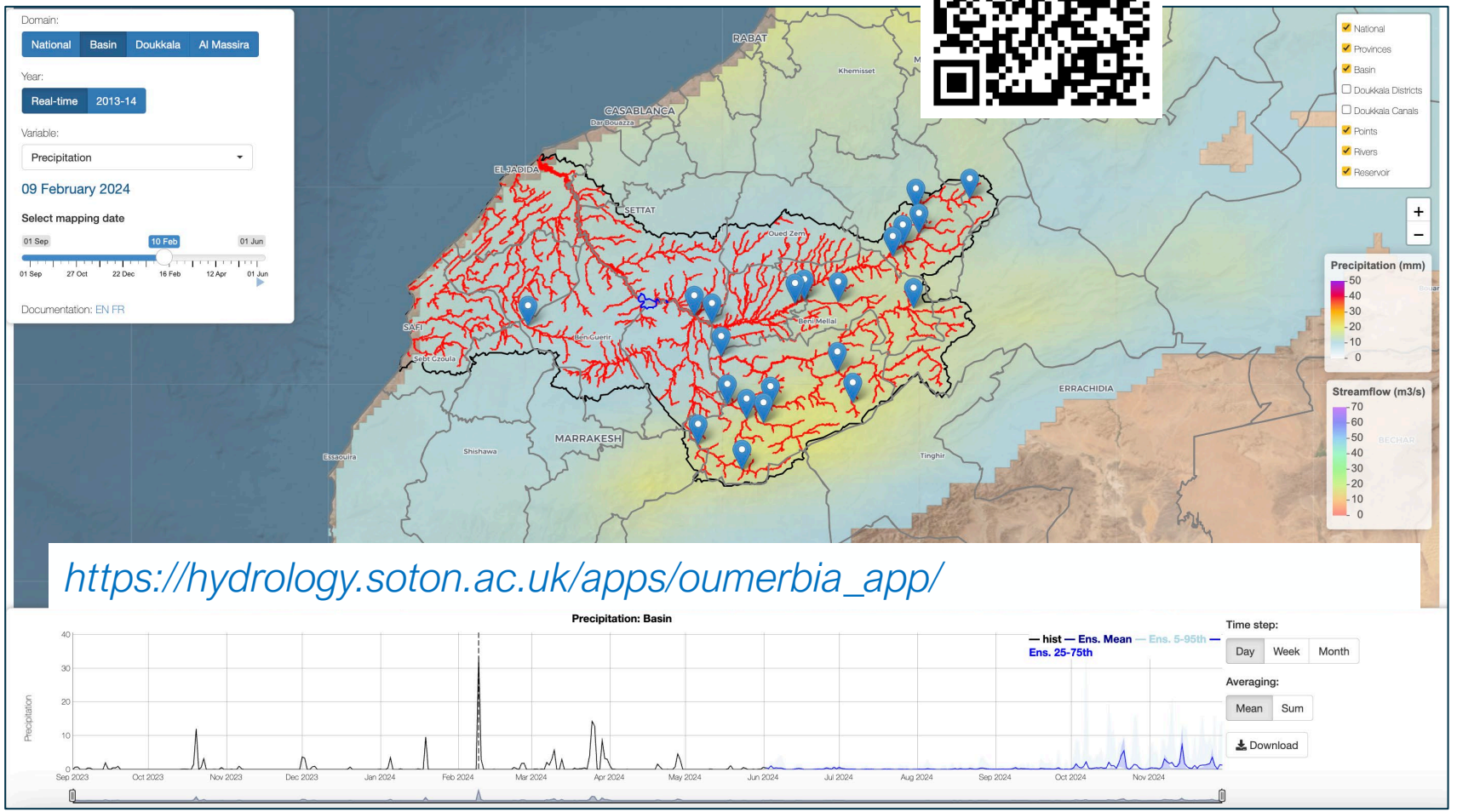

## Open source tools

## Final tools

1) the **data repository**, where all data and outputs will be directly accessible and downloadable
2) **a web-GIS platform** for outputs visualization and immediate information use

In the context of national and international water-related policies

# Web- GIS platform




- Provides easy access to the data through a web-GIS platform
- An online platform for monitoring water resources, floods and droughts, close to **real-time** for all of Morocco
- **Multi-scale:** from national, to river basin, reservoir and irrigation district

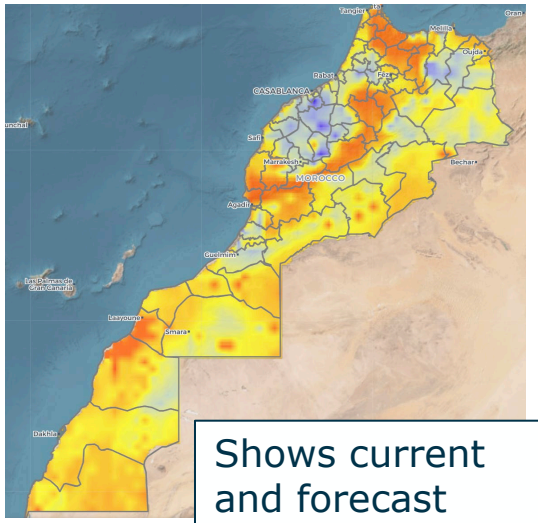
- Data are available for historic, near real-time and forecast periods
- Historic data can be used to compare with current conditions
- Real-time data can be used for monitoring of evolving drought conditions
- Forecasts data can inform decision making on water resources management

**The tool will be not a substitution of water operator decision,** but it will provide an objective, scientifically based, consistent, and easy-to-use high-level information**,** for improving water management. → **complement the diversity of existing systems and databases for the range of end-users**

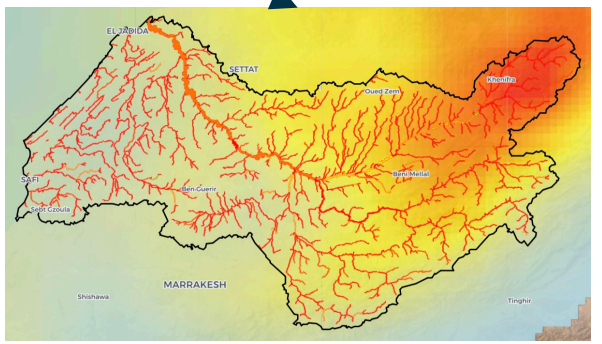
# The Web Platform – Multi-Scale Domains

Domain:

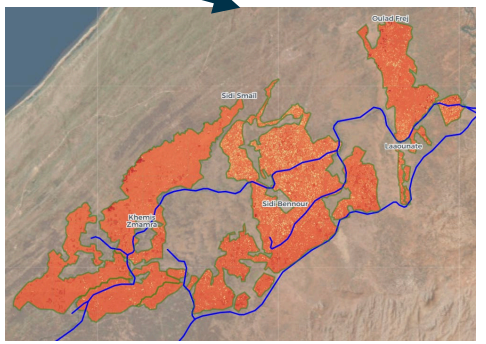
National | Basin | Doukkala | Al Massira



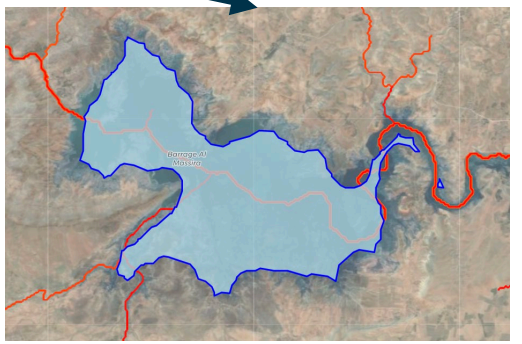
Shows current and forecast climate and hydrological conditions nationally



Shows current and forecast climate and hydrological conditions for the Oum Er-Rbia basin



Shows current and forecast crop and irrigation conditions for the Doukkala irrigation district



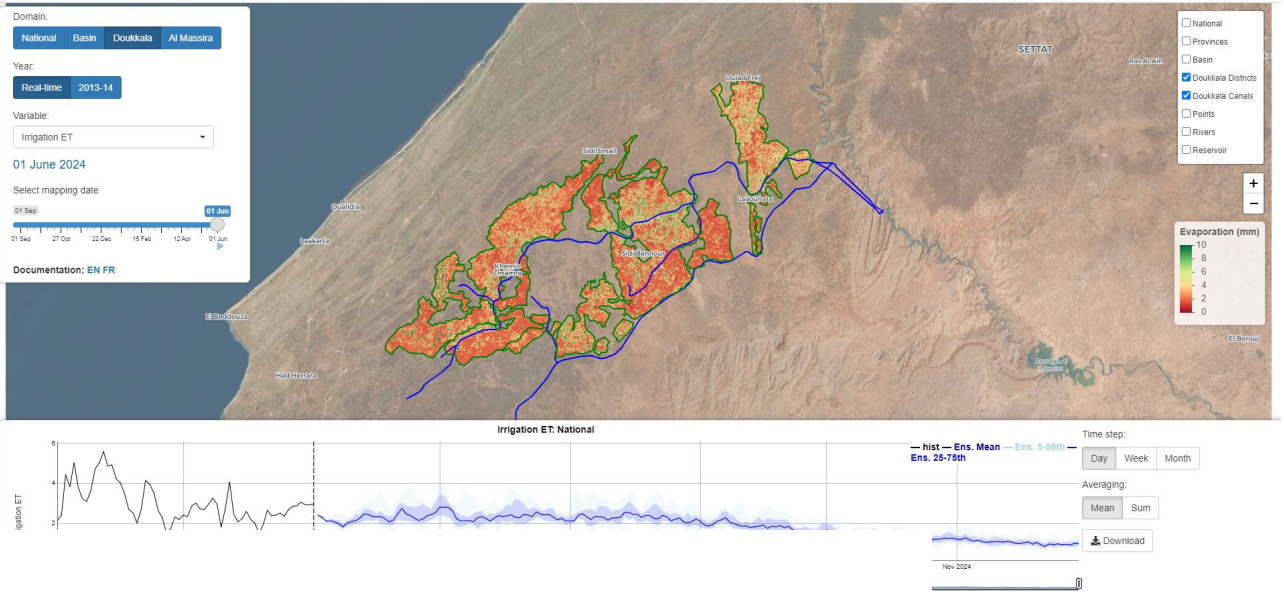
Shows current and forecast reservoir volume and releases conditions for the Al Massira dam

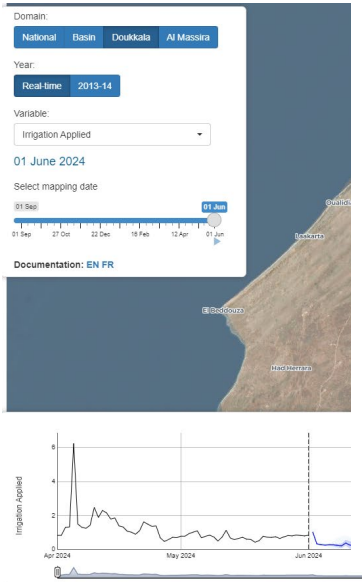
https://hydrology.soton.ac.uk/apps/oumerbia_app/

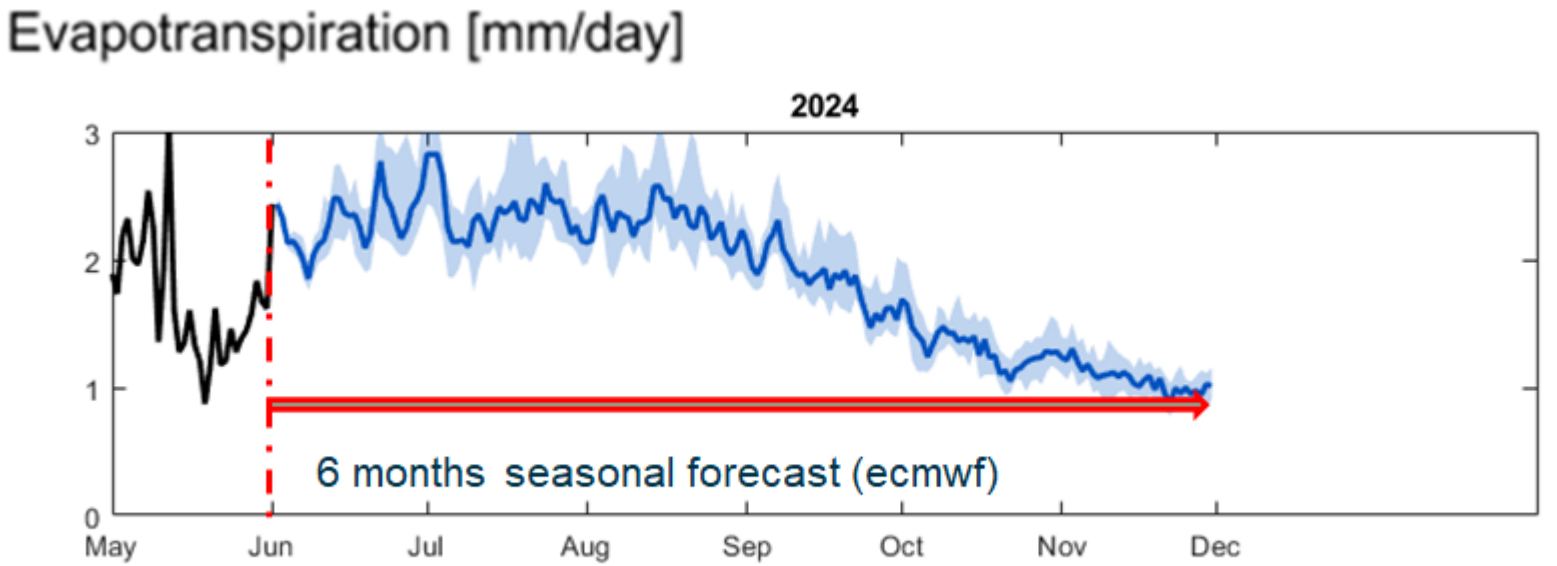
# The Web Platform – agricultural district of Doukkala

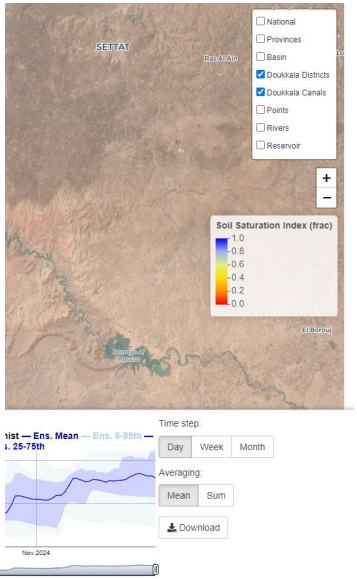
**Daily Monitor and seasonal forecast**

- Crop water demand at pixel scale (30 x 30 m)
- Irrigation water volumes
- Soil water saturation index



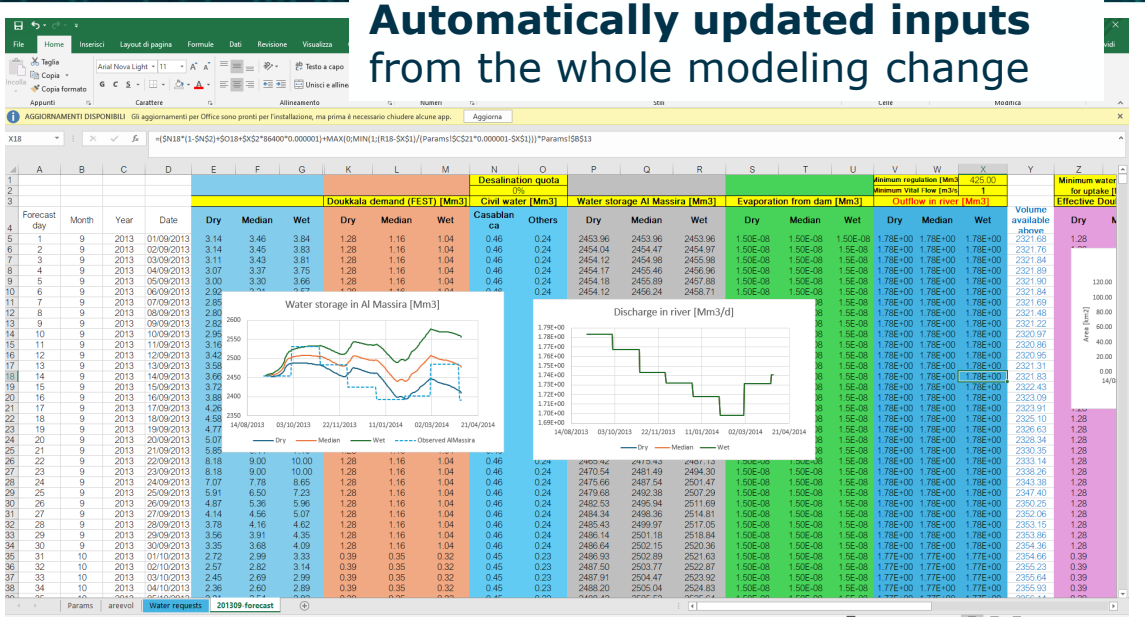



# Scenarios of sustainable water management

The platform will allow to simulate **different scenarios of water demand and availability**

1. Water level in the Al Massira dam
2. Water availability upstream (considering civil use, vital minimum flow) (additional water availability considering new desalinization plans)
3. Request for irrigation water demand from Doukkala

**Automatically updated inputs** from the whole modeling change




## Options – to be modified by end-user

- Percentage % desalinization water for Casablanca (or other)
- Minimum regulation volume [Mm3] or level [m] in Al Massira
- Minimum water storage Al Massira lake for Doukkala uptake [Mm3]
- Minimum Vital Flow [m3/s] downstream Al Massira dam

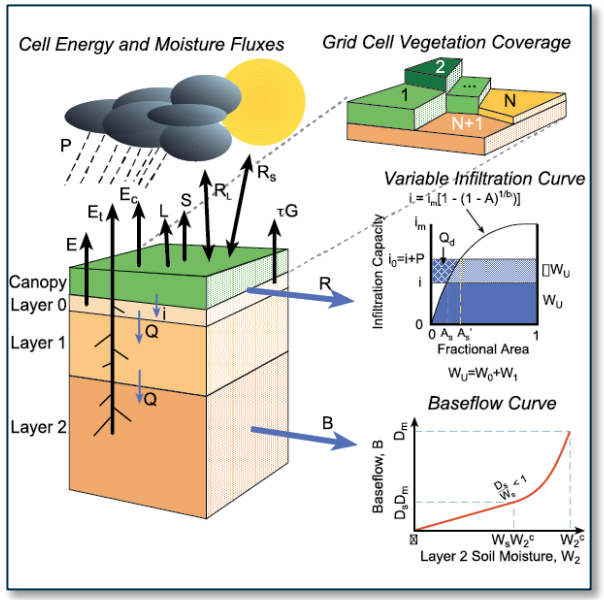
## Outputs

**Area of Doukkala which could be really irrigated**: (100 % and km2)

**Effective water available for Doukkala:** amount of water available for irrigation

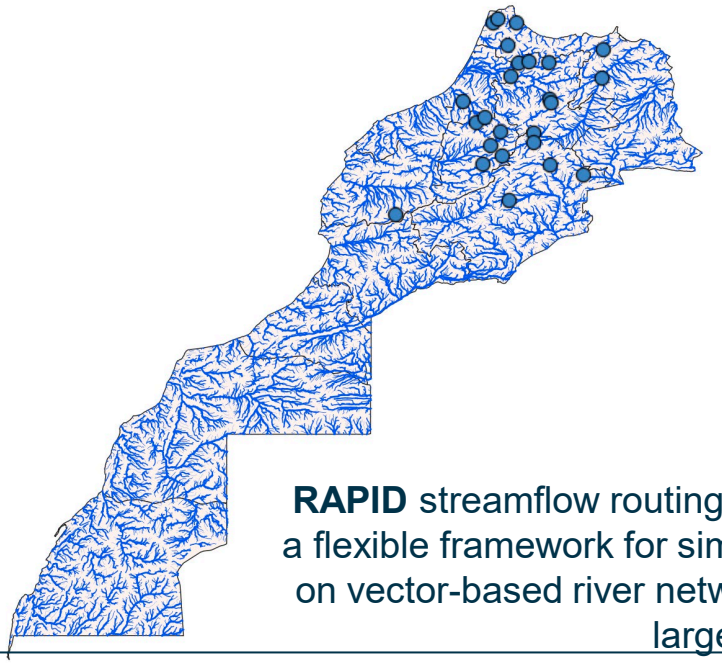
# Using Modeling to Estimate the Water Balance at National / Basin Scale

Modeling provides a consistent and continuous estimate of the water balance across scales, albeit with uncertainty




The **VIC** hydrological land surface model – a comprehensive land surface model with an extensive history of development and application that can be applied at high resolution for multiple ensemble forecasts

VIC predicts runoff on a 5km grid, which is then passed to RAPID to predict streamflow at 1000s of river reaches



**RAPID** streamflow routing model: a flexible framework for simulating on vector-based river networks at large-scale.

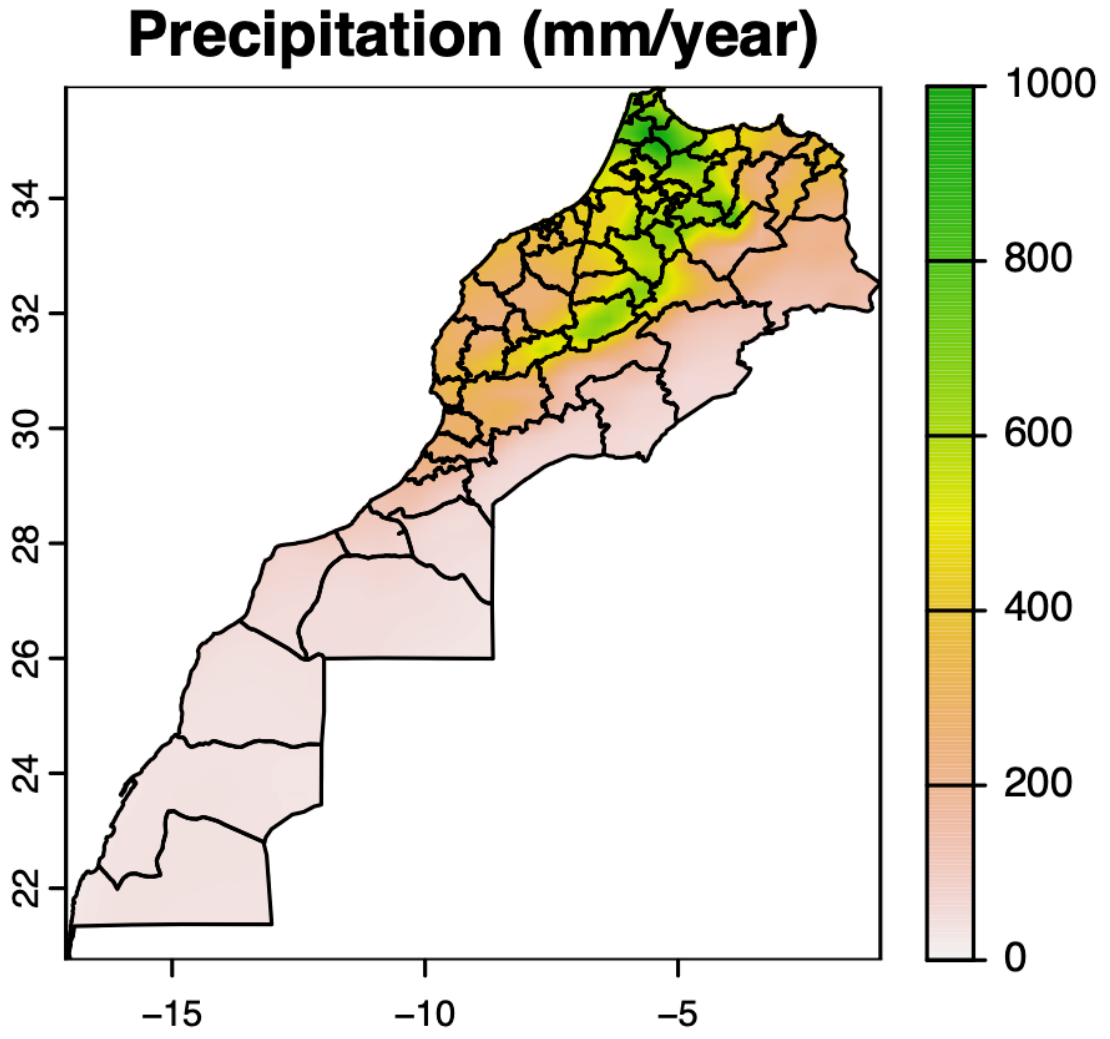
## Simulation

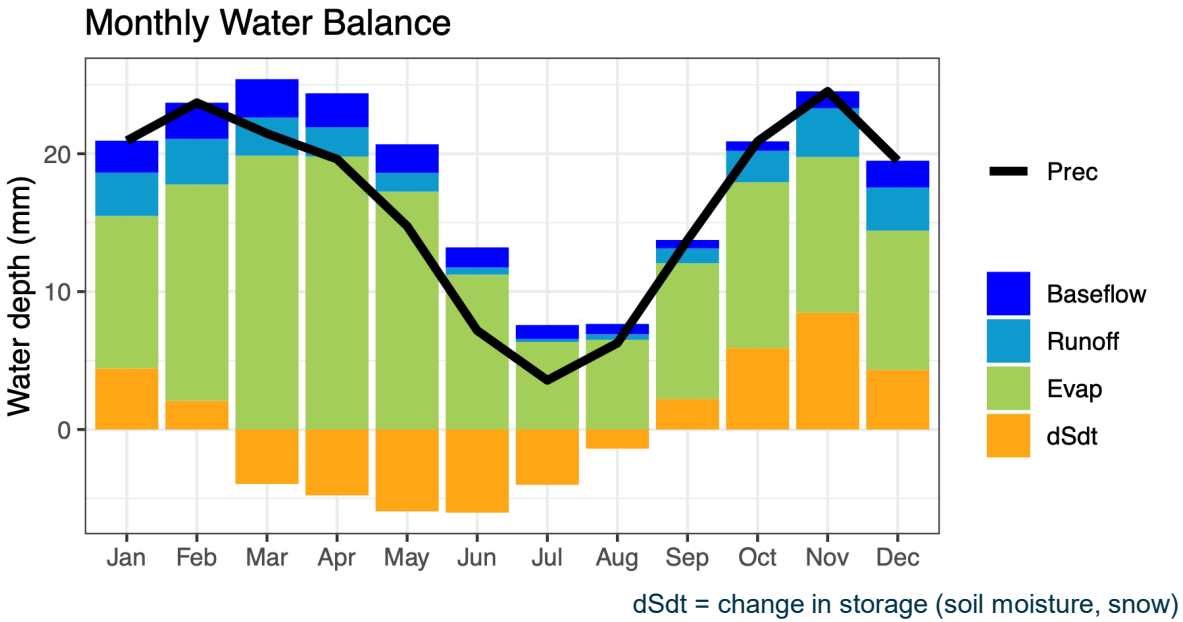
- VIC+RAPID historic simulation for 1979-present, daily
- Forced by ERA5 precipitation and other meteorology
- RAPID streamflow simulation run for 65,000 river reaches. Forced by VIC runoff.
- Quasi-calibrated parameters from global calibration

## Validation

- Forcings (precipitation, temperature) versus gauge data (GSOD, GHCN)
- Streamflow versus gauge data (GRDC)
- Evaporation and soil moisture versus satellite estimates
- Future validation for reservoirs (data from basin management authority)

# Annual Water Balance

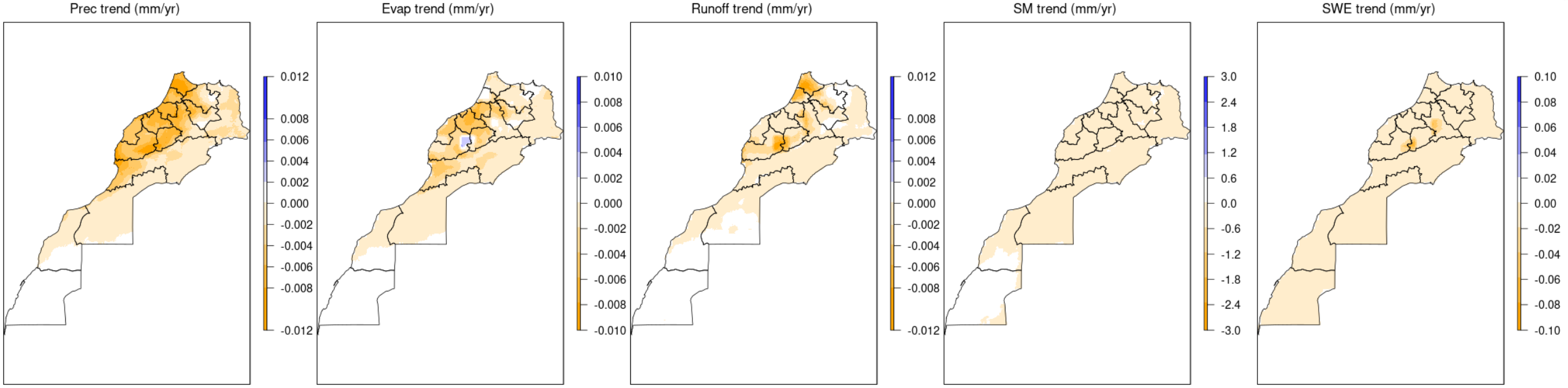


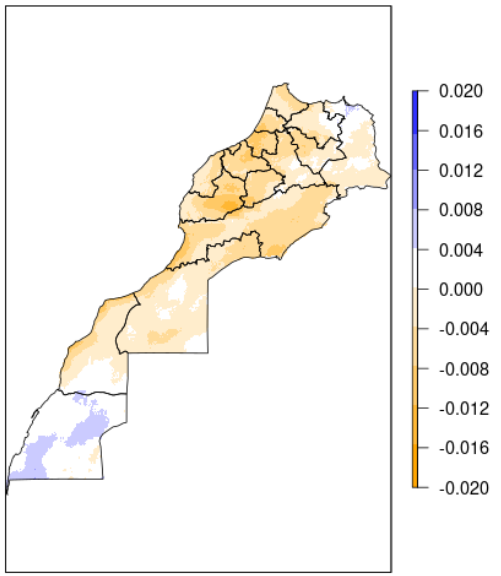




dSdt = change in storage (soil moisture, snow)

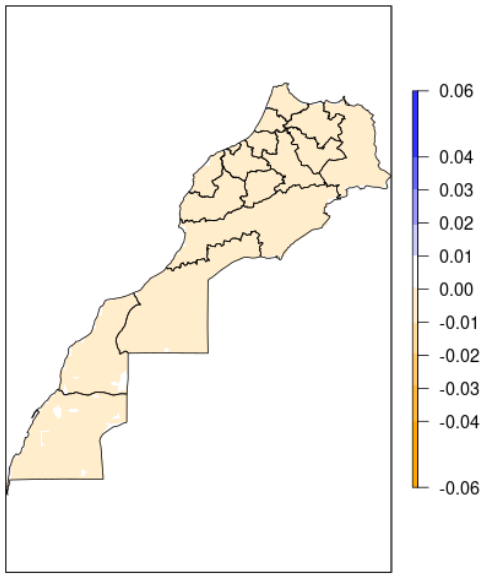
- Strong dry-wet gradient across the country
- Water balance driven by pattern of precipitation
- Evapotranspiration is about 75-80% of precipitation
- Runoff ratio is about 20-25%
- Baseflow is indicative of potential recharge
- Strong seasonal cycle from wet winter to dry summer
- Strong depletion of soil moisture and snow

# Annual Trend in the Water Balance 1979-2023

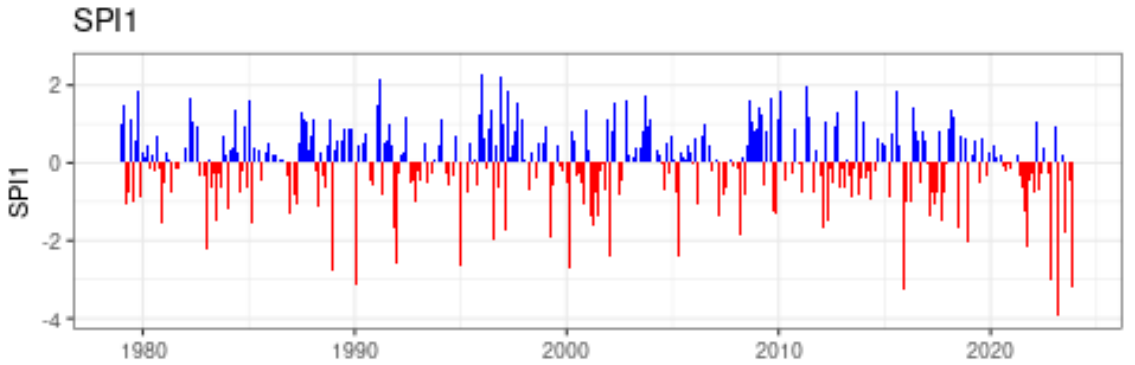


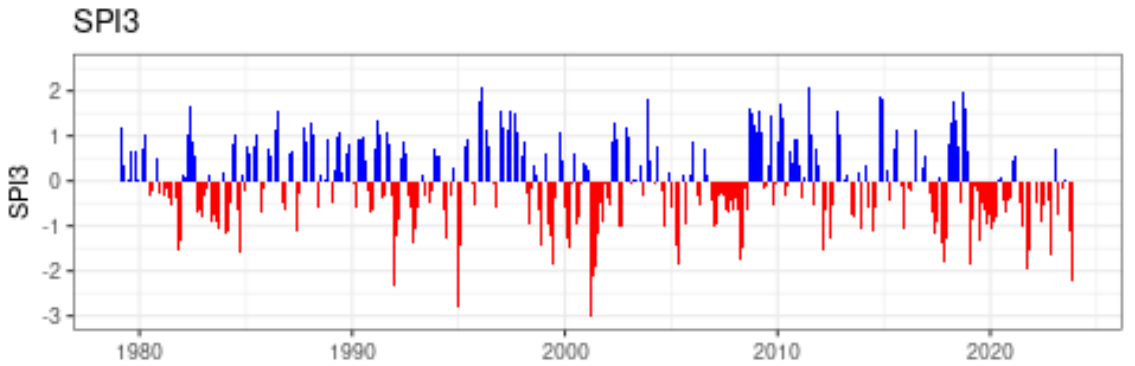



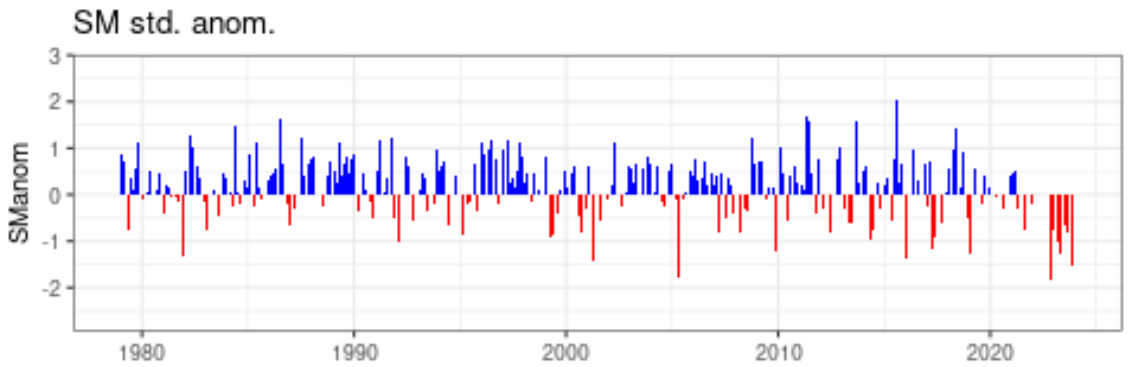

- **Overall drying driven by precipitation, but magnitudes are small**
- Snow (SWE) declines influenced by temperature warming also
- Soil moisture shows little change – slight drying



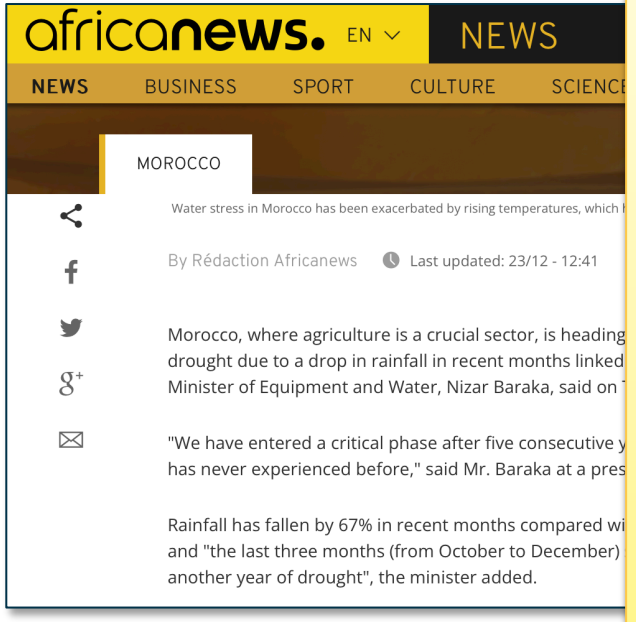
# Oum er Rbia Basin: Drought Indices




- Precipitation-based indices (SPI) show little change – but with recent drying which is consistent with reported impacts
- SPI1 reflects short-term (monthly) changes. SPI3 reflects seasonal changes – correlated with soil moisture
- Soil moisture index (top 30cm layer) shows drying since about 2020
- Potential over-estimation of drying because of operational data

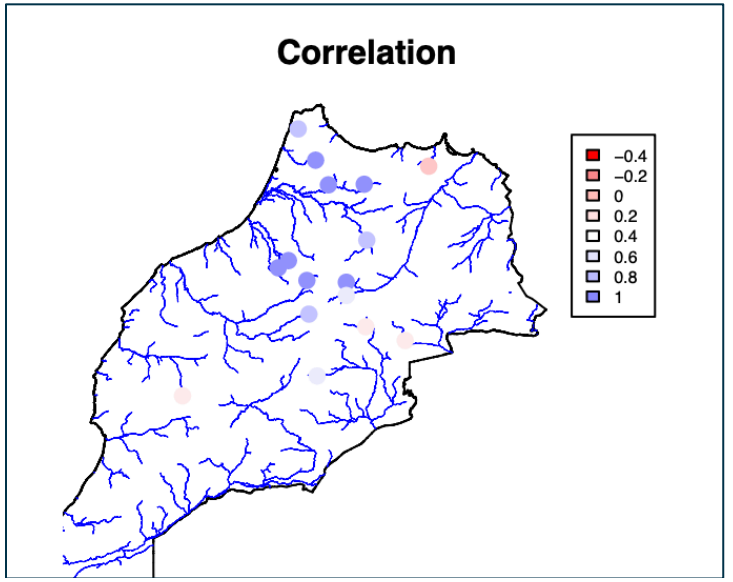



**Morocco droughts**
(ref: Bijader et al 2018, Worldbank report Dorte Verner et al., MENA dev Report Verner et al 2012 , Mohamed Bazza et al. FAO 2018 )

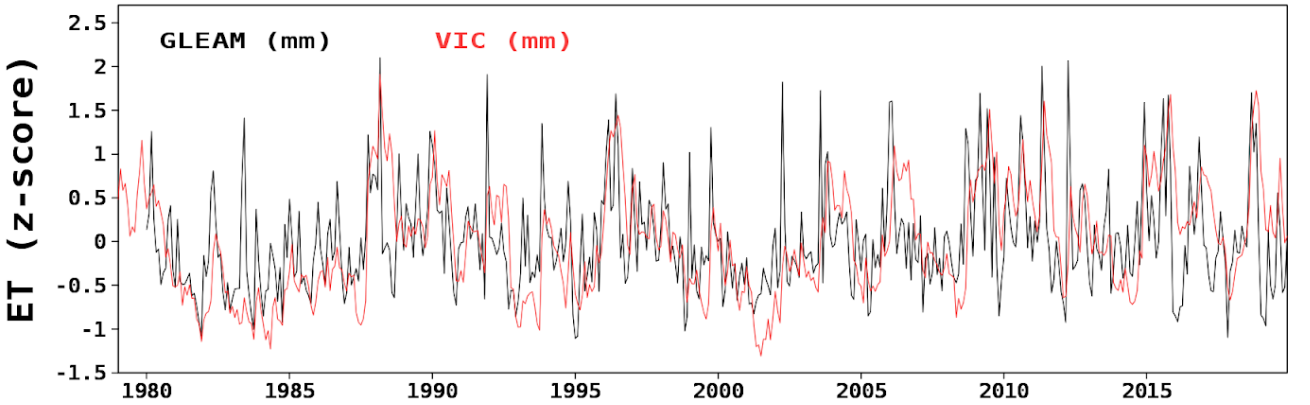
2004-2005
2006-2007 (extreme)
2007-2008
2011-2012
2015-2016 (march)
2018 (extreme)
2022 (extreme)
2023

# Validation of the Hydrological Models

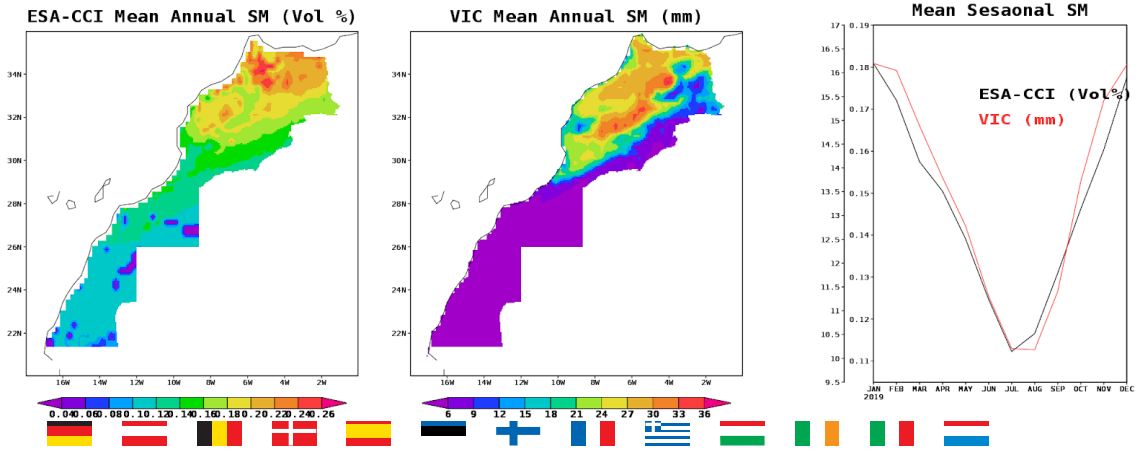
## Comparison of model (uncalibrated) with daily observed streamflow

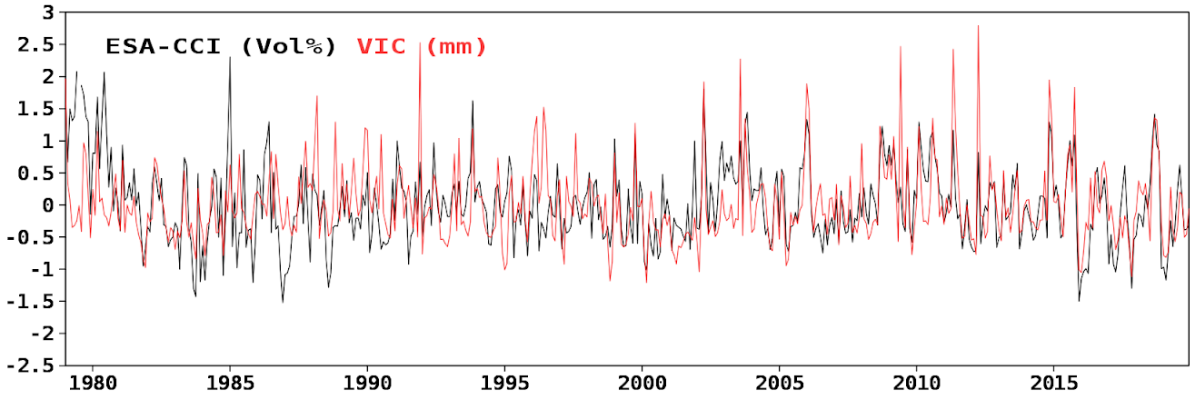



## Model evaporation compared to GLEAM satellite-based product




## Model top 10cm soil layer compared to ESA-CCI merged dataset (top 1-3cm)

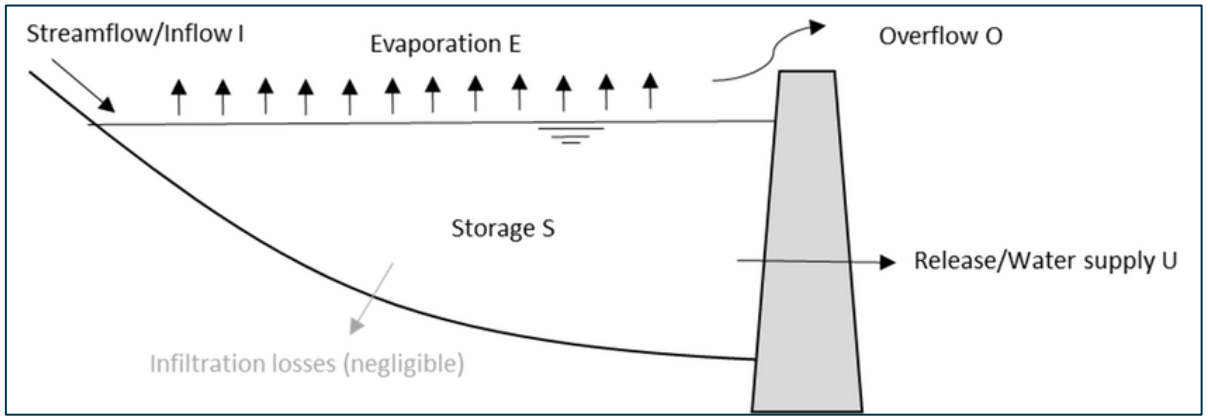





ENCY

# Reservoir Modeling – Al Massira dam



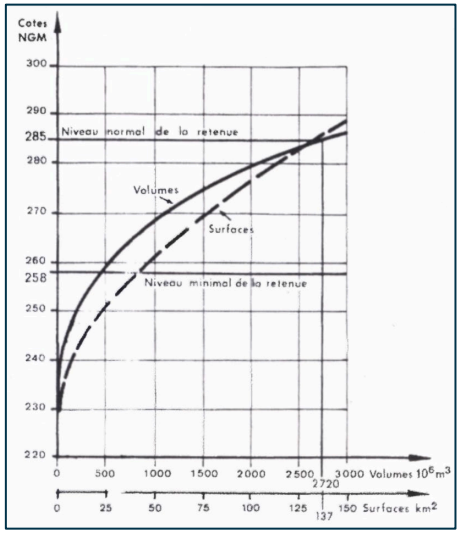

Release R

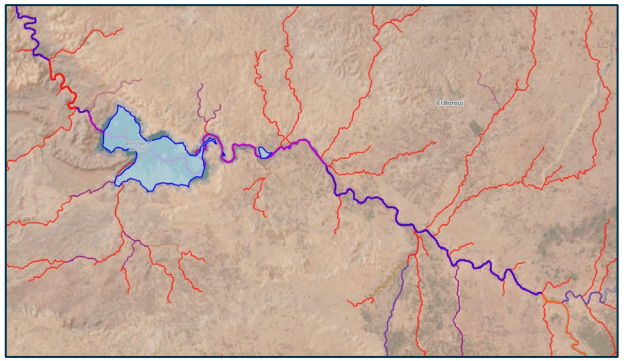
Irrigation supply, D

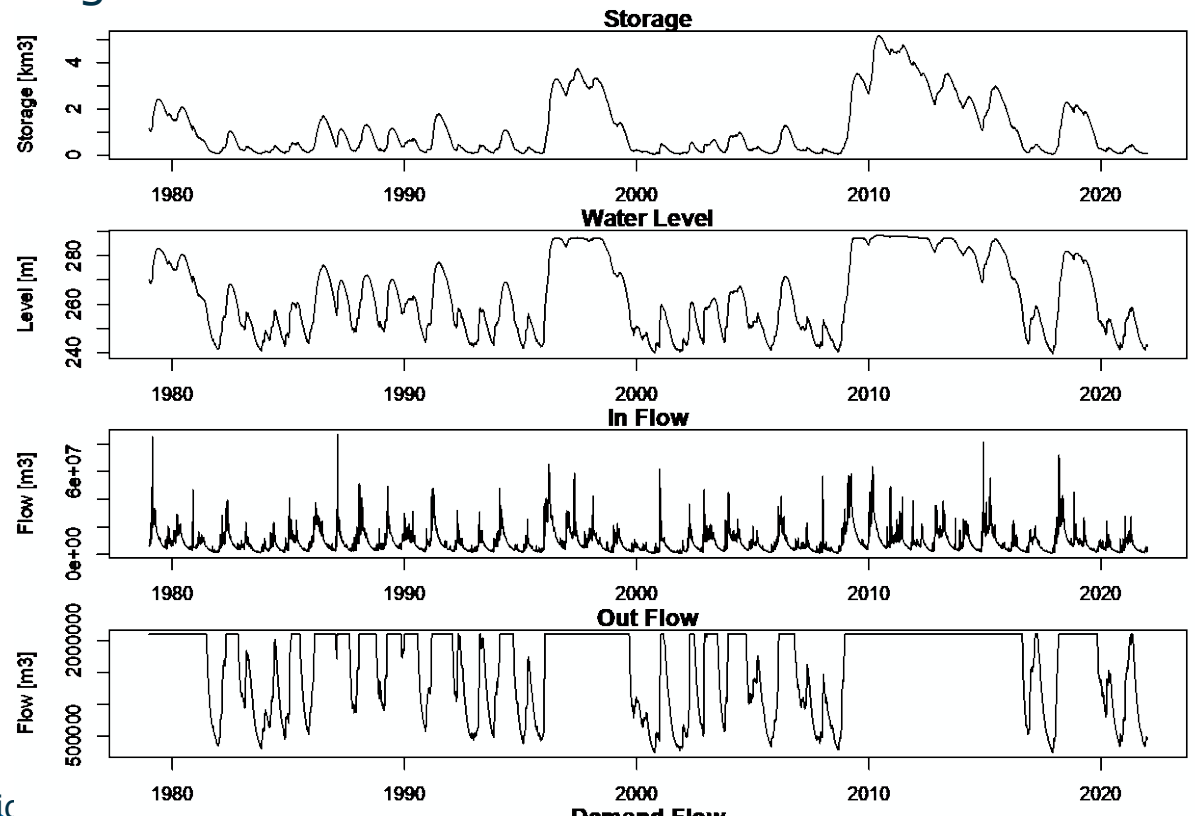
Hydropower generation H

Assumptions
- Irrigation supply (D) = min(demand, f(S))
- Hydropower (H) = f(S)
- Release (R) = f(S, Q50)

Height-Volume-Area Relationship






Hydroécol. Appl. (2000) Tome 12 Vol. 1-2, pp. 183-206 Étude du régime thermic

# Irrigation management

## FEST-EWB-SAFY

*FEST-EWB: Flash – flood Event – based Spatially – distributed rainfall – runoff Transformation – including Energy - Water Balance*

*SAFY : (Simple Algorithm For Yield Estimate)*

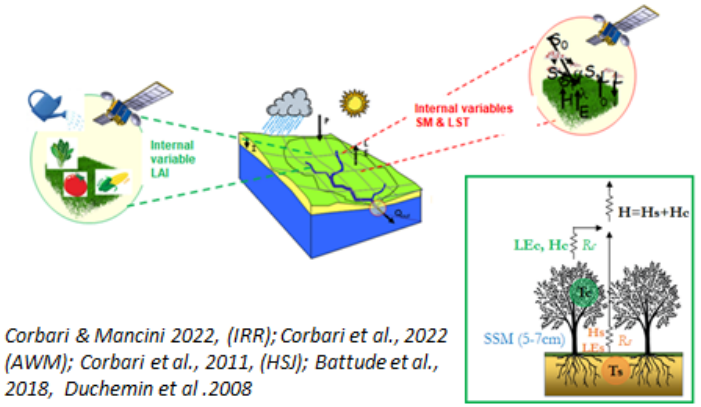
**Soil water balance** $P_{tot}=R+ET_{eff}+D+(\theta_{t+1}-\theta_t)*Z$

**Energy balance** $Rn-G-H-LE=\frac{dS}{dt}$

$ETeff=\frac{LE}{\rho Cp}$

**Crop growth** $\Delta DAM = APAR \cdot Pgro\_Lue \cdot F_T(Ta)K_s$

LAI, SM




*Corbari & Mancini 2022, (IRR); Corbari et al., 2022 (AWM); Corbari et al., 2011, (HSJ); Battude et al., 2018, Duchemin et al .2008*

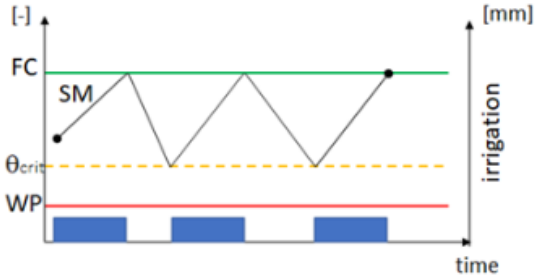
*Corbari et al (2011) HYP* *Corbari et al., 2015 (Jh)*
*Corbari & Mancini, 2014 (JHM)*
*Corbari et al., 2014 (HSJ)*

## The irrigation strategies

### 1 FAO approach

Optimal irrigation volume in between the two thresholds reducing the percolation flux

$$\Theta_{crit} = f(crop, cultivar, soil, climate)$$




### 2 Assimilation of SMAP/Sentinel1 downscaled Soil moisture

1km spatial resolution

The irrigation volume: additional water input that, considering the water losses for drainage plus soil water storage, allows

$SM_{FEST\text{-}EWB} = SM_{satellite} + e$

### 3 Assimilation of downscaled Sentinel3/2 Land surface temperature

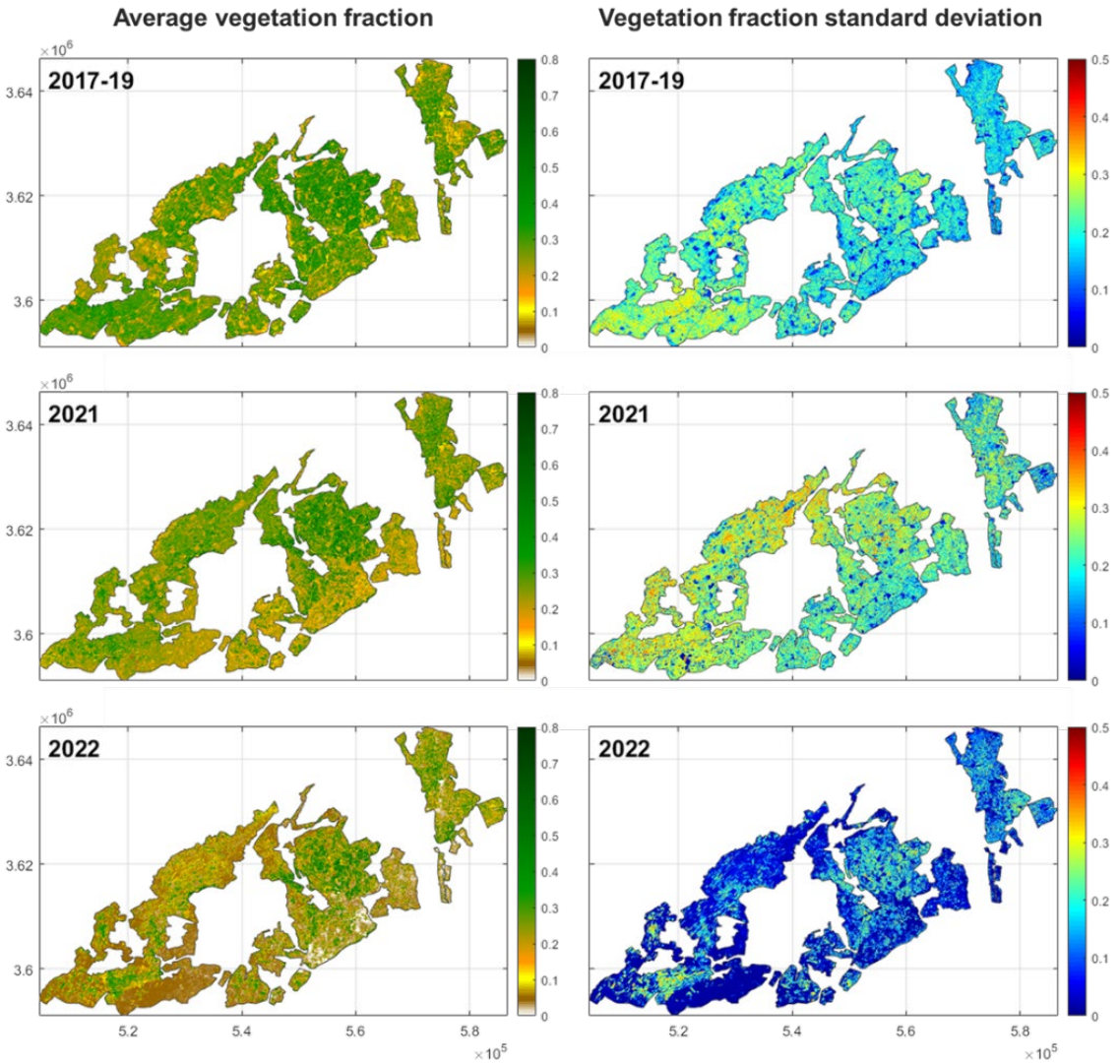
30 m spatial resolution

The irrigation volume: additional water input that, considering the water losses for drainage plus soil water storage, allows

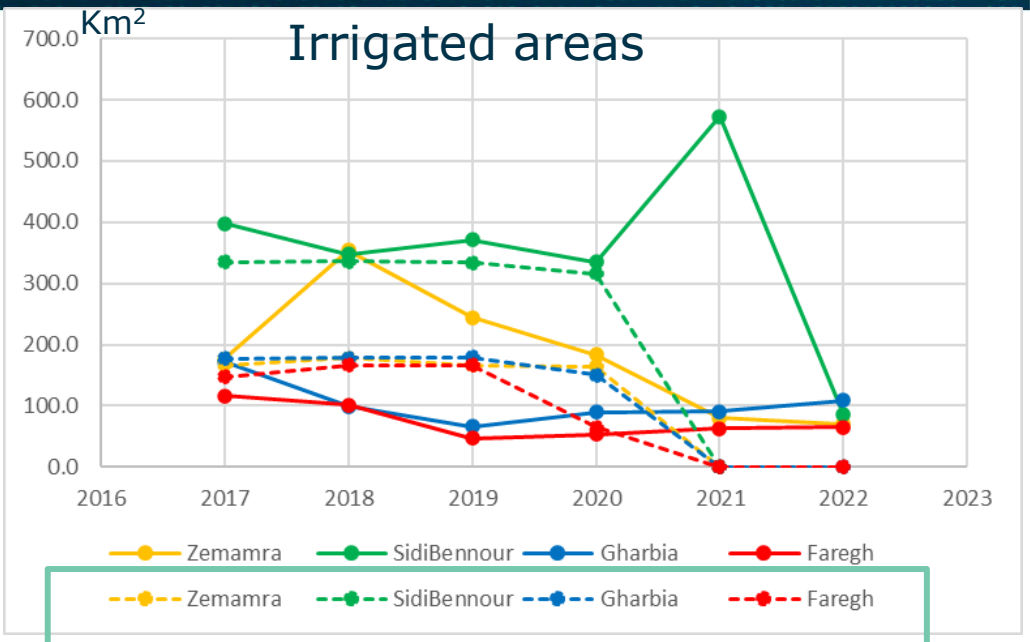
$LE_{FEST\text{-}EWB} = LE\ (LST)_{FESTresidual} + e$

# Cropped area reduction

## Sentinel2

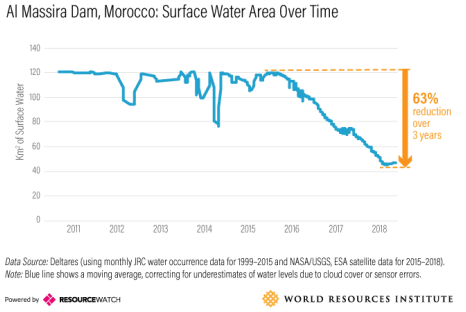


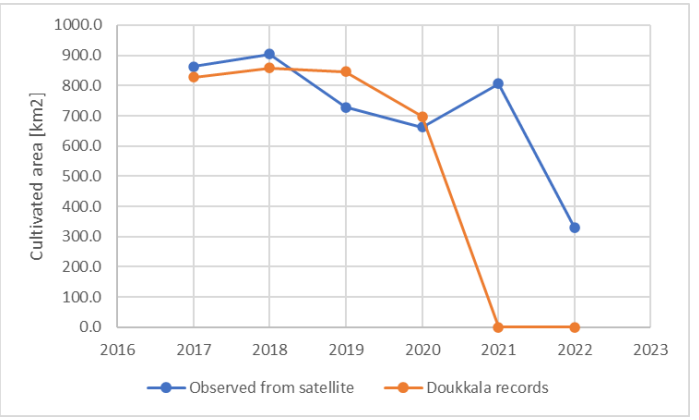

In the last three years there was a decrease in the cultivated areas; Especially during 2022




Official record from ORMVAD

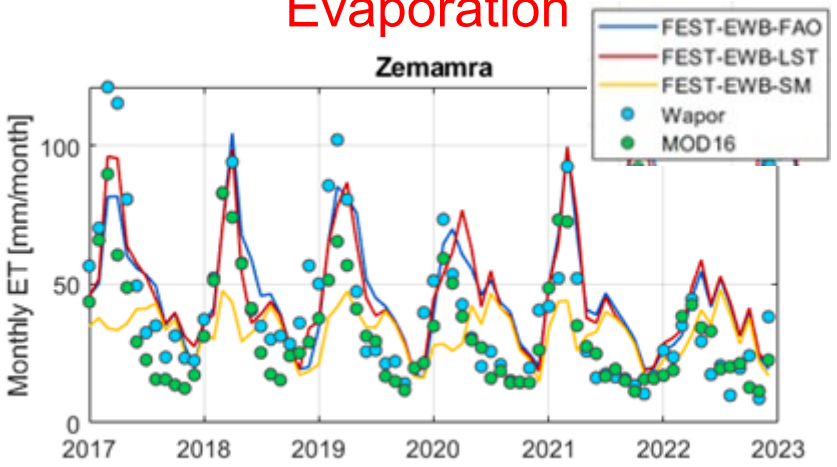
From mid-2020 ORMVAD stopped providing water for irrigation



# Irrigation model validation

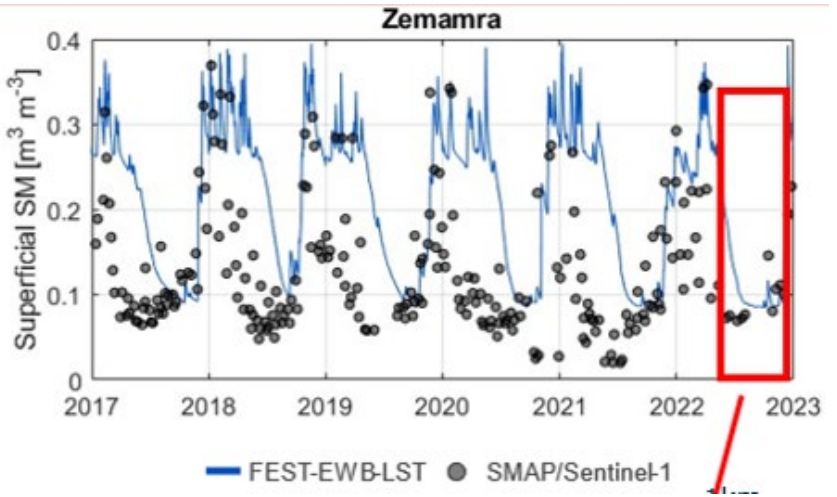
## Evaporation




**MOD16** - 500 m – average 8 days

**WaPOR** - 250 m – accumulated 10 days

## Soil moisture



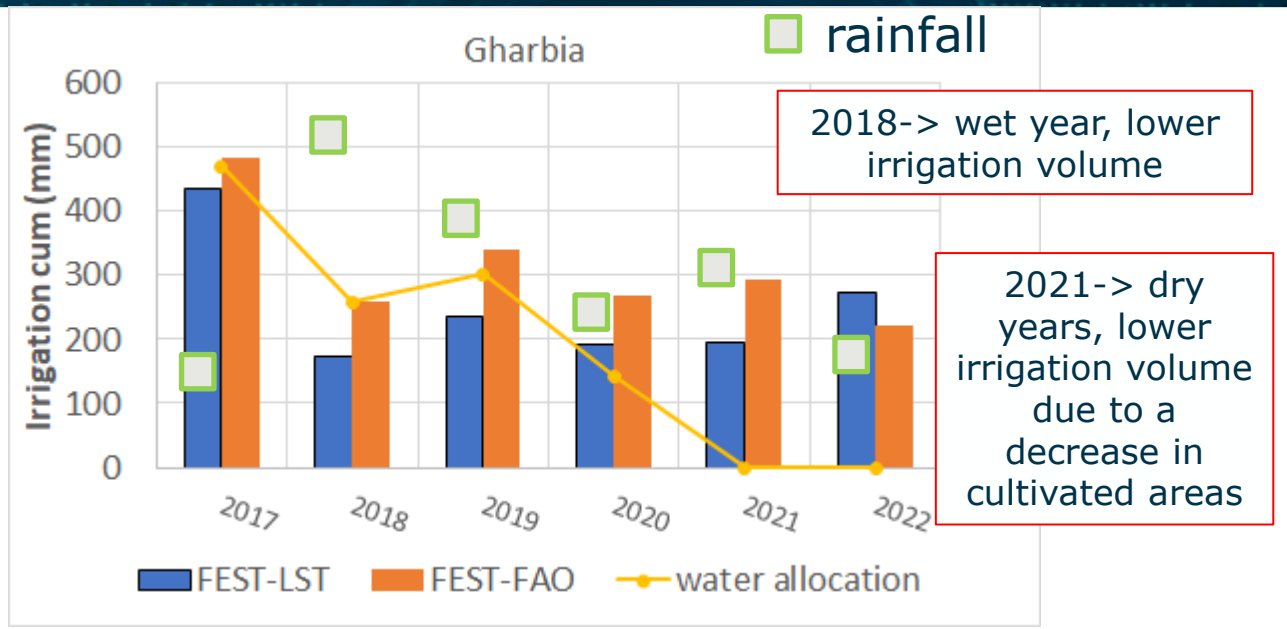

- generally good correlations between FEST-EWB-FAO and FEST-EWB-LST and the Wapor and lower with MODIS
- Low correlation maps between FEST-EWB-SM ET and the two ET products

| Error indicator | FEST-EWB | FEST-EWB-LST |
|---|---|---|
| Pearson correlation | 0.60 | 0.59 |
| RMSE | 0.063 $m^3/m^3$ | 0.064 $m^3/m^3$ |

| Error indicator | ET dataset | FEST-EWB | FEST-EWB-LST | FEST_EWB-SM |
|---|---|---|---|---|
| Pearson correlation | Wapor | 0.71 | 0.77 | 0.29 |
| | MOD16 | 0.74 | 0.73 | 0.31 |
| RMSE | Wapor | 16.3 mm/month | 14.9 mm/month | 22.5 mm/month |
| | MOD16 | 11.1 mm/month | 11.2 mm/month | 15.7 mm/month |

Uncercentainties due to the low spatial resolution of satellite (1km (original SMAP 25km) SM in respect to field dimensions, in this semi-arid context, and low temporal frequency

# Monitoring irrigation: simulated vs observed




2018-> wet year, lower irrigation volume

2021-> dry years, lower irrigation volume due to a decrease in cultivated areas

Sentinel-3-Landsat8-9

| Year | # final images |
|---|---|
| 2017 | 180 |
| 2018 | 150 |
| 2019 | 170 |
| 2020 | 126 |
| 2021 | 125 |
| 2022 | 135 |

## FEST-LST

-Few images per year over Morocco area

-using the LE (LST) based, the whole soil layer involved in the crop evapotranspiration process is considered

SMAP/Sentinel-1

| Year | # final images |
|---|---|
| 2017 | 69 |
| 2018 | 71 |
| 2019 | 53 |
| 2020 | 60 |
| 2021 | 59 |
| 2022 | 40 |

## FEST-Soil moisture

-Few images per year over Morocco area

-**small irrigated fields sourranded by dry areas**, SM spatial resolution is limiting the procedure

## FEST-FAO

-theoretical scheme, which could be a good approximation of local agriculture

**-calibrated method for the irrigation management**

# Monitoring irrigation: simulated vs observed

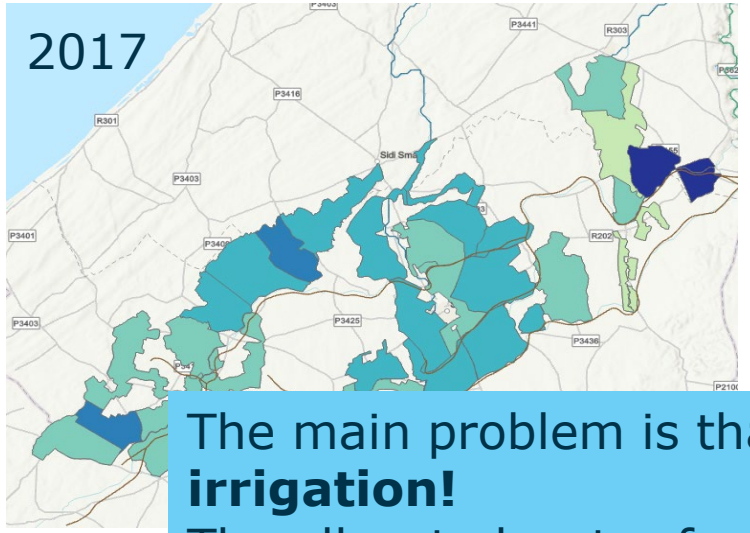
aggregated information over the water distribution distric

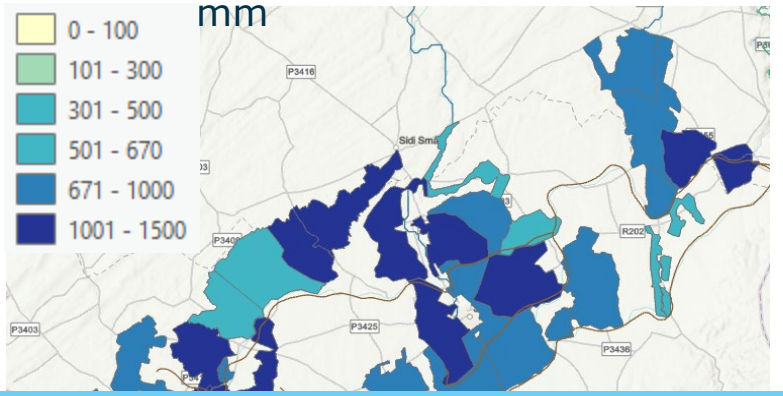
Volumes provided by ORMVAD

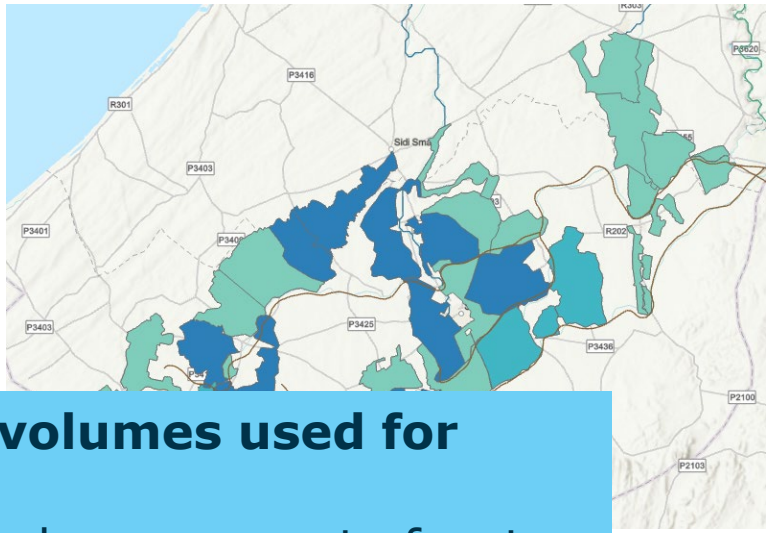
Actually used volumes FEST-EWB(FAO)

Actually used volumes FEST-EWB(LST)

2017

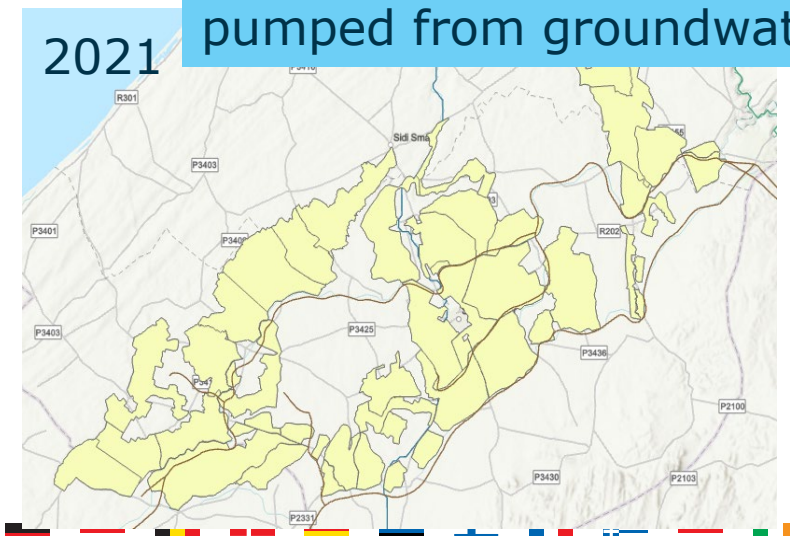


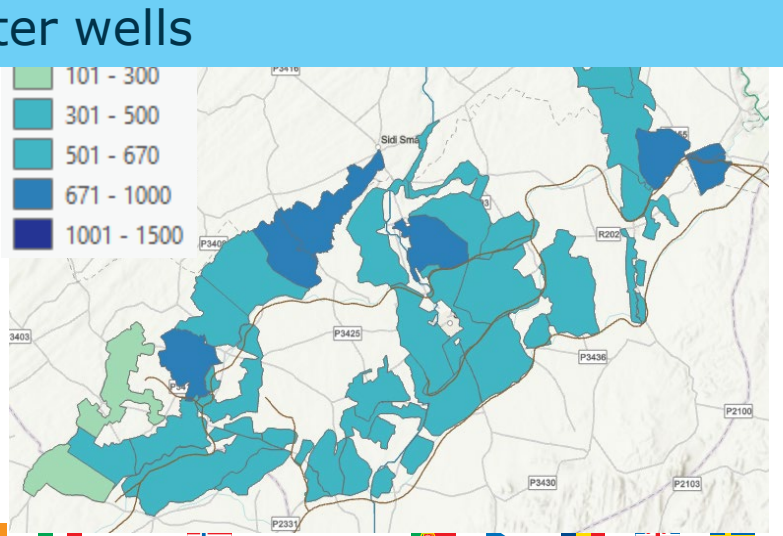


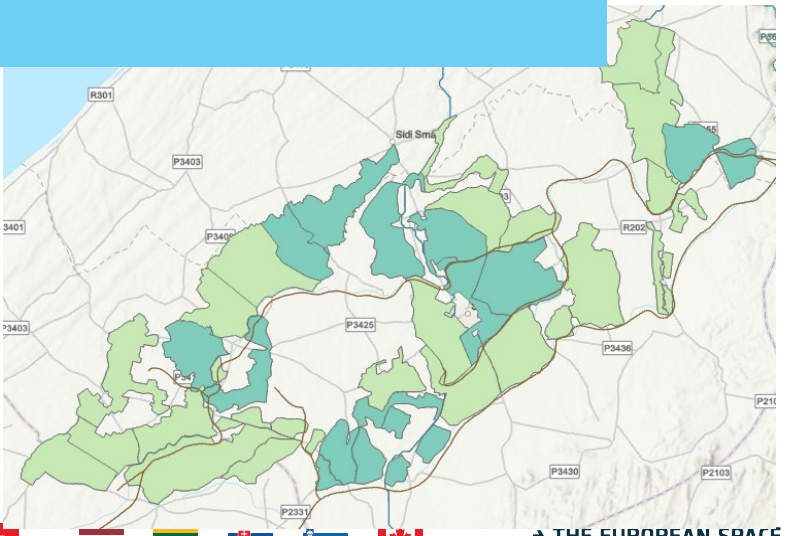



The main problem is that **these are not the real water volumes used for irrigation!**
The allocated water for irrigation must be increased by the huge amount of water pumped from groundwater wells

2021





# Conclusions

Important definition of the precise end-users needs as well as the continuous interaction with them for growing the trust in the solution

Necessary integration of different satellite data (from visible, to thermal and microwave) and modeling frameworks to provide a multi-scale monitoring, forecasting and managment of water resources at multiple levels, especially where ground measurements are scarce

Periodic droughts exacerbate the overall lack of water, which have persisted in the recent ~ 5 years.

Uncertainty in the estimates of crop irrigation water use/needs both provided by the Irrigation consortium and from groundwater wells

Integrated water management across sectors is needed to provide sustainable provision of water under increasing demand and climate change