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Integrating remote sensing data with SWAT ecohydrological model in a typical Greek complex landscape

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The project “SUSTAIN-R”

A few words about the project…

- Research project focused on nutrient recovery and aquatic ecosystem restoration
- **Funding: Water4All Partnership - 2023** Joint Transnational Call, co-funded by the **European Union** and **national funding organisations**

- **Consortium:** multidisciplinary European partnership with expertise in nutrient recovery, water treatment, monitoring, modelling and ecosystem restoration

- **Main objective:** to develop and demonstrate innovative tools, methodologies and technologies for aquatic ecosystem restoration

- **Greek case study:** Pinios River Basin, Thessaly, an intensively cultivated basin where water quantity and quality are strongly affected by agricultural activity

- **Aim of this work:** The present work contributes by developing a remote sensing supported SWAT modelling framework, providing the hydrological basis for future nutrient and water quality simulations

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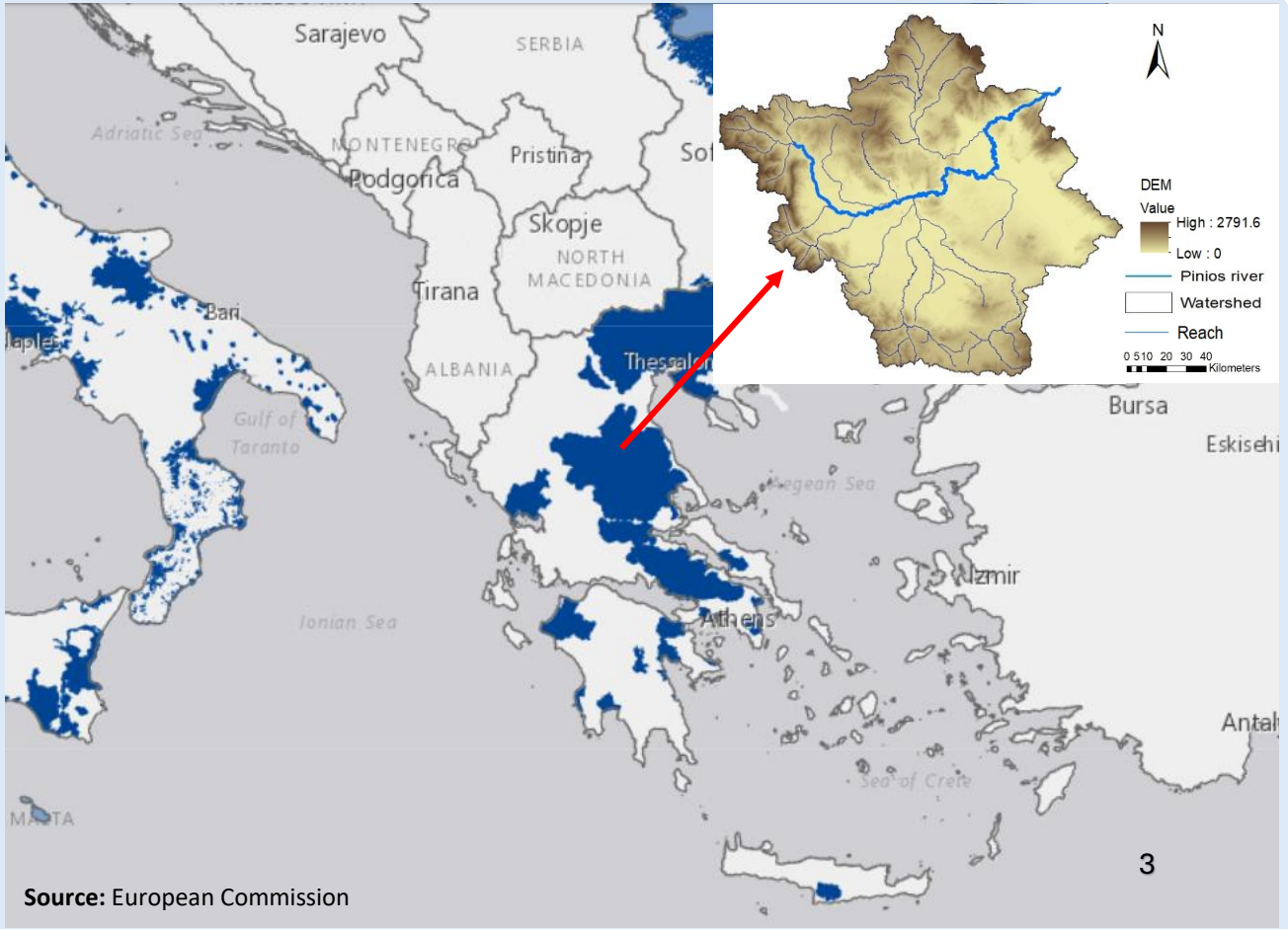
Pinios River Basin

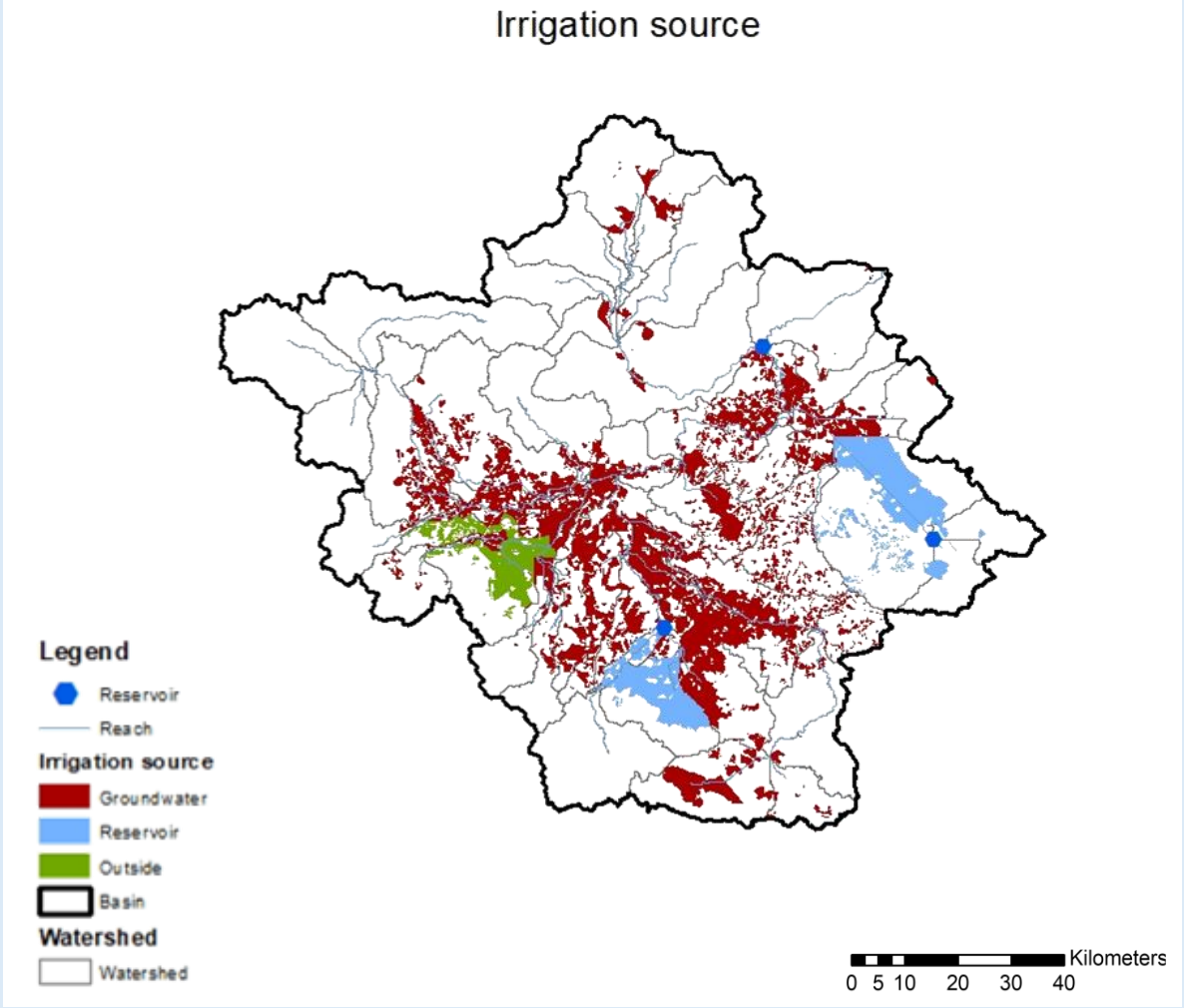
- The most important agricultural producer in Greece
- Total water consumption→ 94% Irrigation
- Water scarcity
- Nitrate vulnerable zone
- Water quantity and water quality tightly connected through agricultural runoff, nutrient transport and reservoir dynamics



Source: European Commission

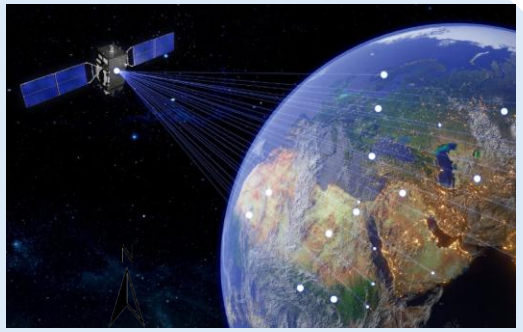
Hydrological challenges

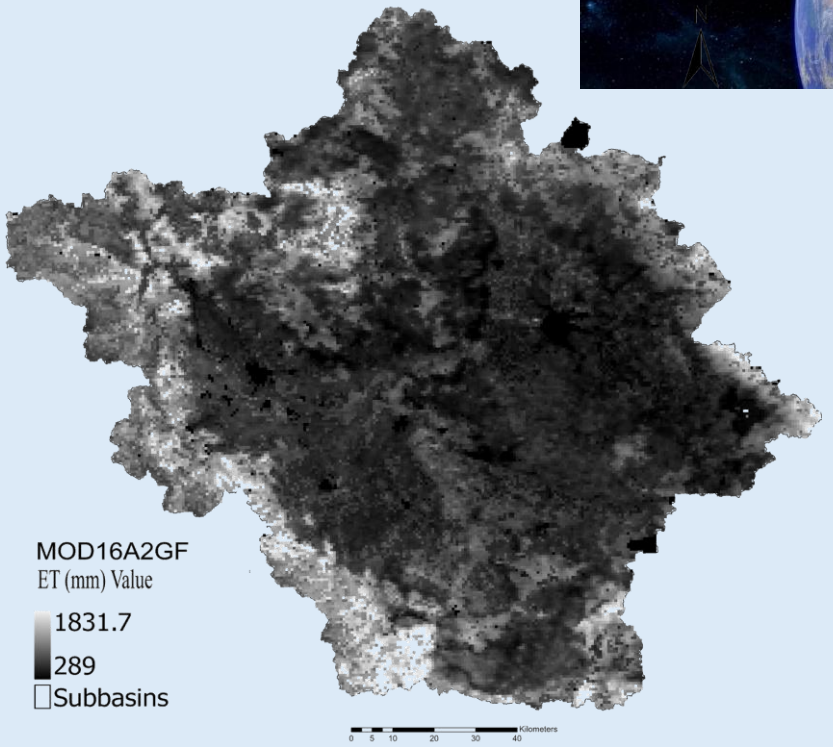
- Strong **spatial variability in mean annual precipitation** across the basin
- Ranges from ~**400 mm/yr** in Thessaly plain to more than **1850 mm/yr** in the western mountainous areas
- High **seasonal irrigation demand**, especially during the crop growing period
- Groundwater overexploitation and water-quality deterioration have been reported
- Need to represent internal water-balance processes: ET, runoff, percolation etc



Why remote sensing?

- SWAT requires spatially explicit information on soils, land use, terrain and vegetation dynamics
- In large agricultural basins, field observations are often sparse and unevenly distributed
- RS products provide spatially distributed and temporally consistent information on land surface conditions
- Satellite and global geospatial datasets support model setup, evaluation and calibration
- However, preprocessing is required to ensure consistency in resolution, projection, classification and temporal scale





ET (mm)- Annual 2018

RS datasets used in this study (1)

All datasets were converted to a common projection, clipped to the basin extent and prepared in SWATcompatible format.

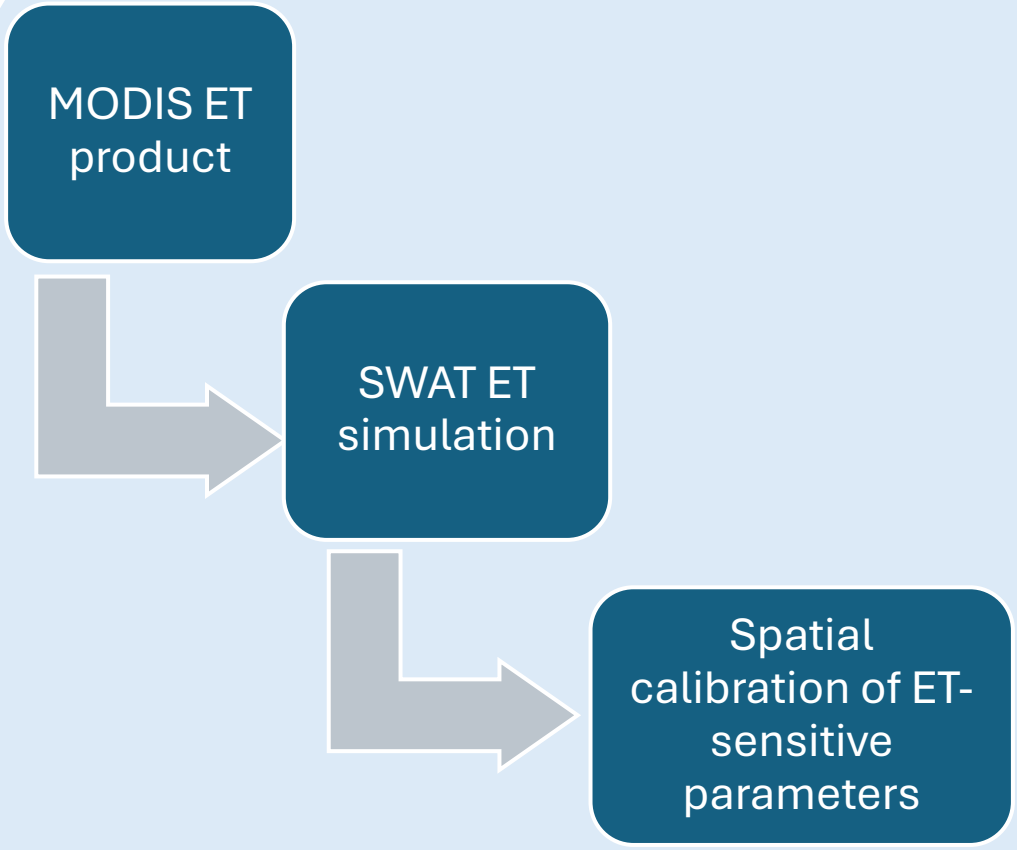
Dataset / Source	Main Purpose	Spatial resolution	Temporal Coverage	Role in SWAT framework
SoilGrids v2 / ISRIC	Soil physical and chemical properties	250 m	Static	Soil attributes for the SWAT soil database (soil texture, bulk density, organic carbon etc.)
HiHydroSoil v2 / FutureWater / ETH Zürich	Hydraulic soil properties	250 m	Static	Hydraulic parameters (saturated hydraulic conductivity, available water capacity etc.)
USDA Classification Framework / USDA NRCS	Soil texture and hydrologic classification	—	Static	Conversion of soil properties into SWAT-required texture classes and hydrologic soil groups
MOD16A2GF v6.1 ET/PET / MODIS/Terra	Actual and potential evapotranspiration	500 m	2018-2025 8-day, 3-monthly, annual	PET comparison, ET evaluation and spatial ET calibration

RS datasets used in this study (2)

All datasets were converted to a common projection, clipped to the basin extent and prepared in SWATcompatible format.

Dataset / Source	Main Purpose	Spatial resolution	Temporal Coverage	Role in SWAT framework
CORINE Land Cover (CLC)-2018 / Copernicus	Land cover characterization	100 m	Static	Baseline land use layer for non-agricultural and general land cover classes
Copernicus Cropland Layers (2018-2023) / Copernicus	Agricultural and land monitoring products	10 m	2018-2023 annual	Refinement of agricultural land use classes, identification of dominant crop types, crop rotation patterns for improved agricultural definition
Copernicus DEM GLO-30 / Copernicus	Topographic characterization	~30 m	Static	Watershed delineation, stream network extraction, slope classification and subbasin parameterization

MODIS ET for spatial evaluation and calibration of SWAT

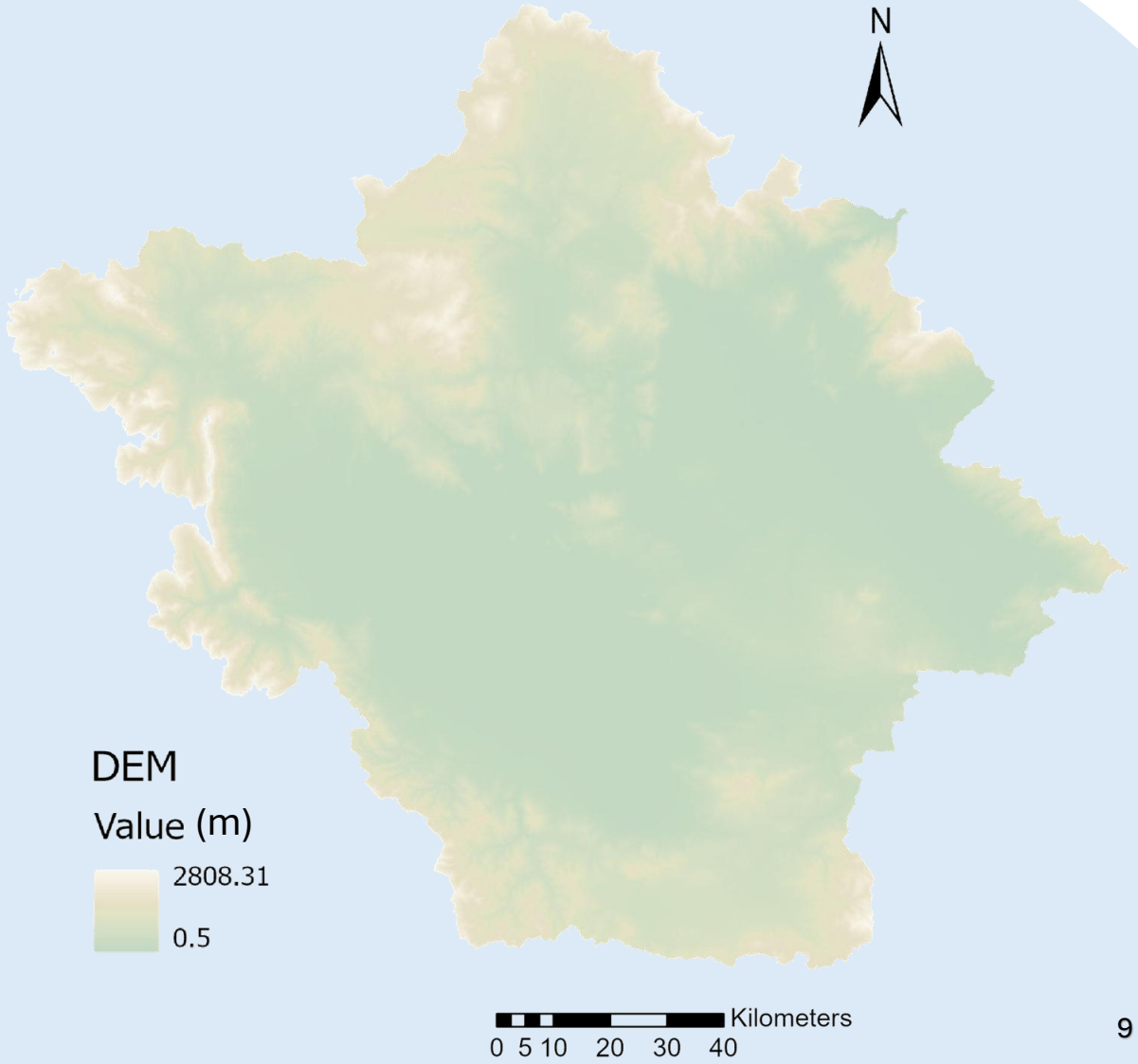


- Satellite based ET has been widely used to evaluate and calibrate SWAT model in data scarce basins
- The comparison between SWAT and MODIS ET can change with the spatial aggregation level
- MODIS ET has supported SWAT calibration in data scarce basins at the catchment and subbasin level
- ET adds spatial information on the internal water balance, beyond outlet discharge
- In this study, MODIS PET was used to support PET-method selection, while MODIS ET was used to evaluate and calibrate SWAT simulated ET across the Pinios River Basin

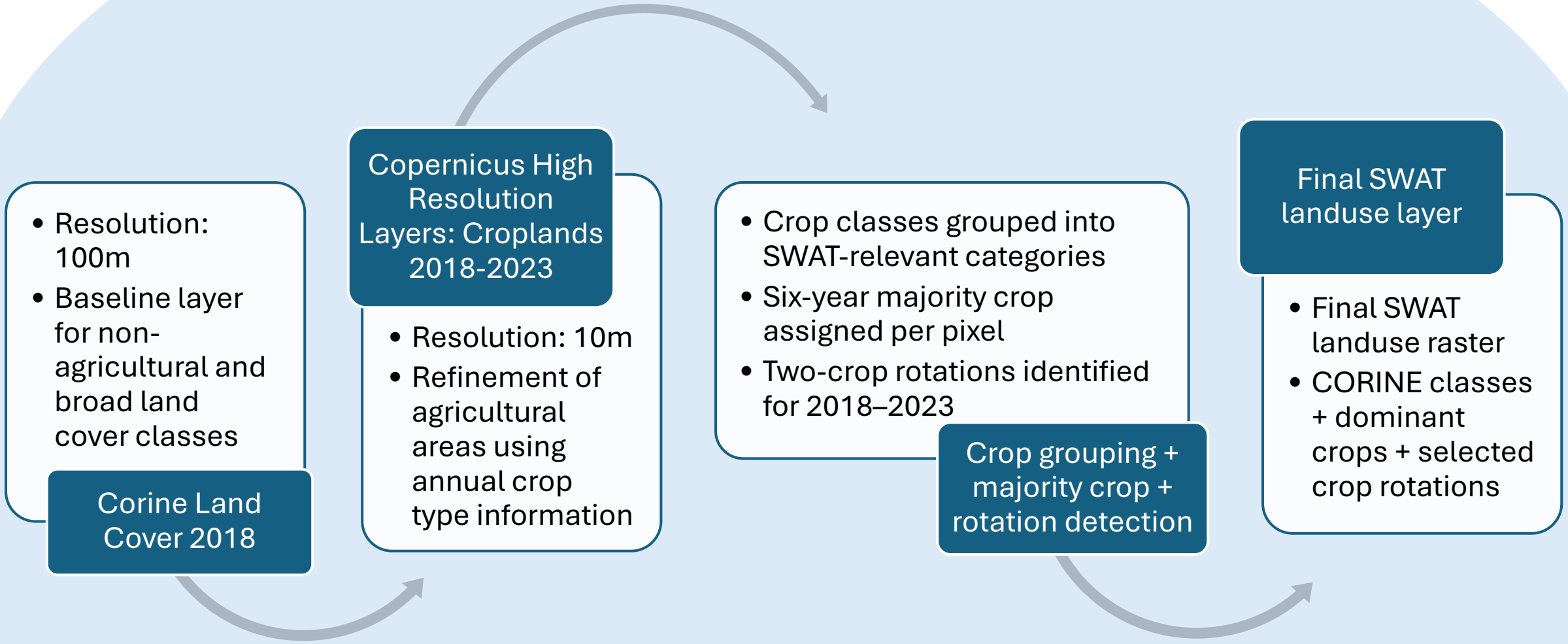
Abiodun et al., 2018; Odusanya et al., 2019; Sun et al., 2021; Bennour et al., 2022; Risal et al., 2025.

DEM

- Copernicus DEM GLO-30 was used for terrain representation
- Resolution: 30x30 m
- Range: 0.5-2,808 m
- The DEM supported watershed delineation, stream network extraction and slope classification



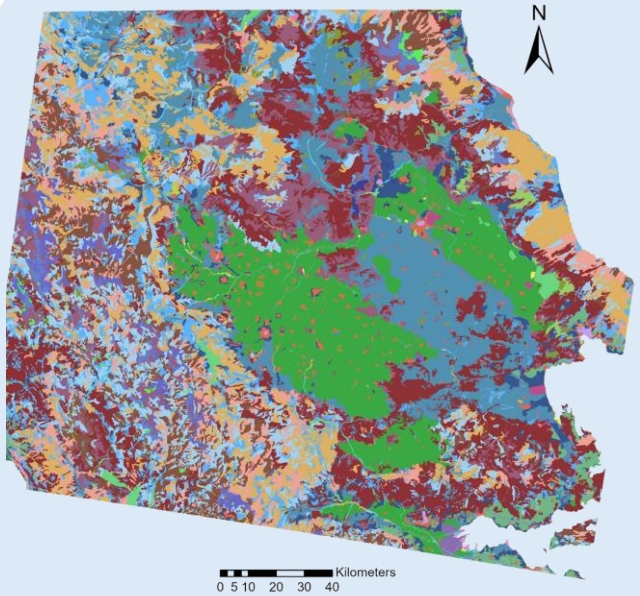
Landuse map development



Landuse map development

Copernicus HRL Croplands 2018-2023

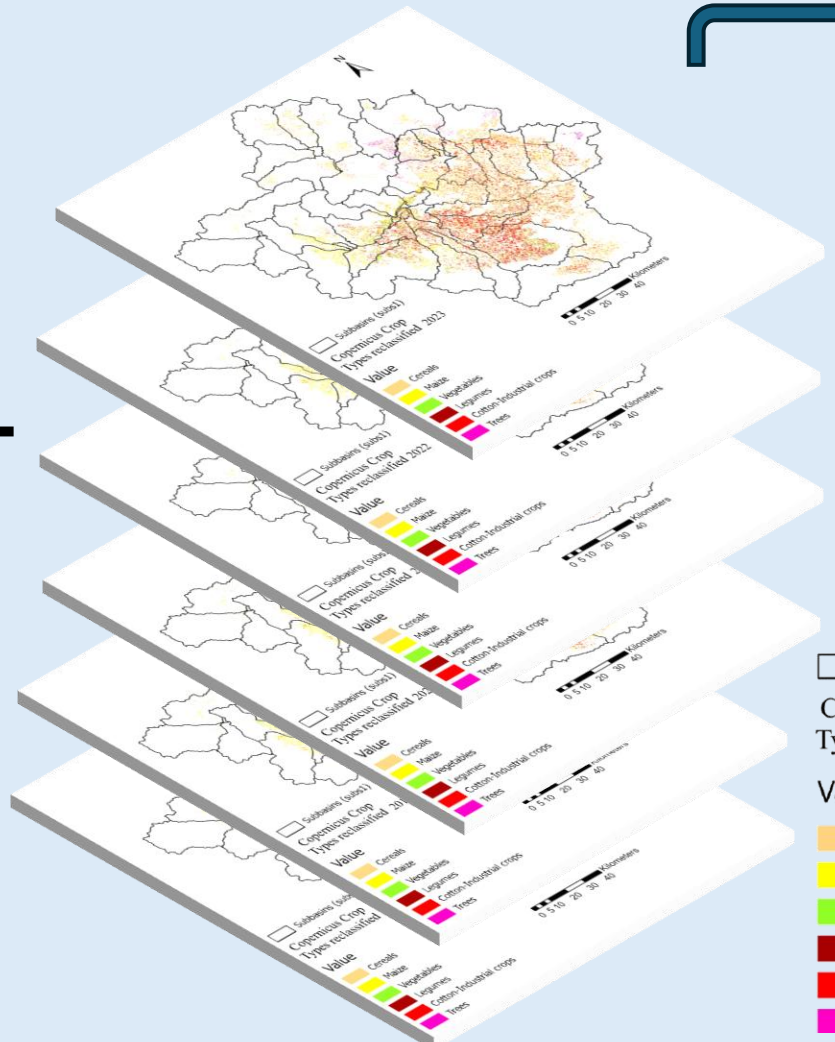
Corine 2018

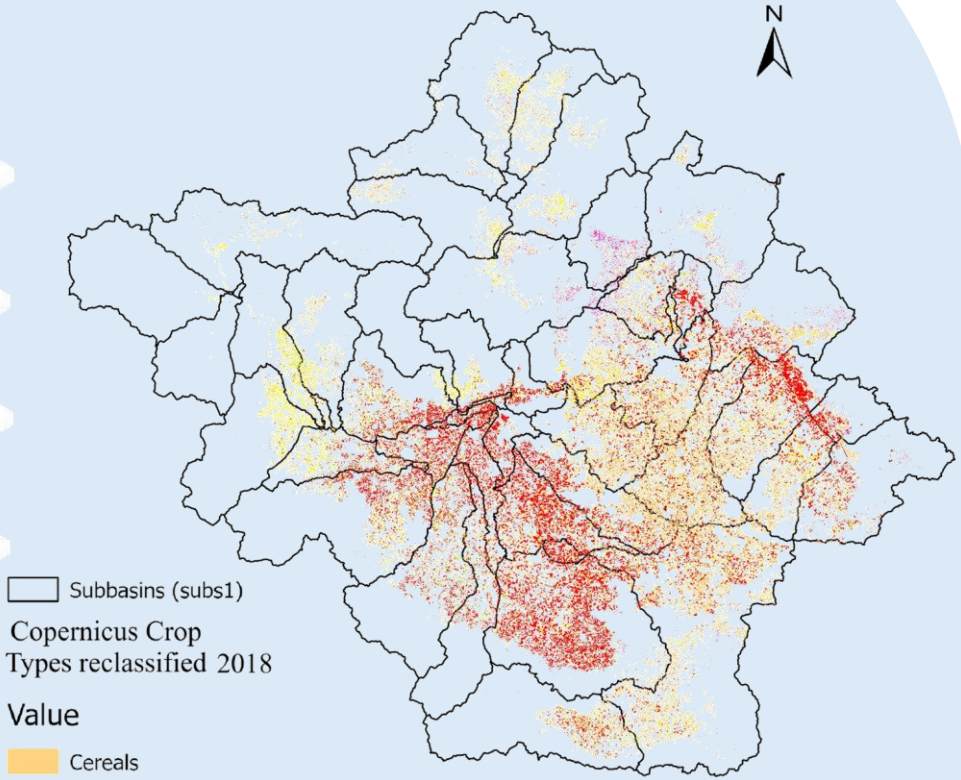


corine18_clp
CLC_legend.csv.LABEL3

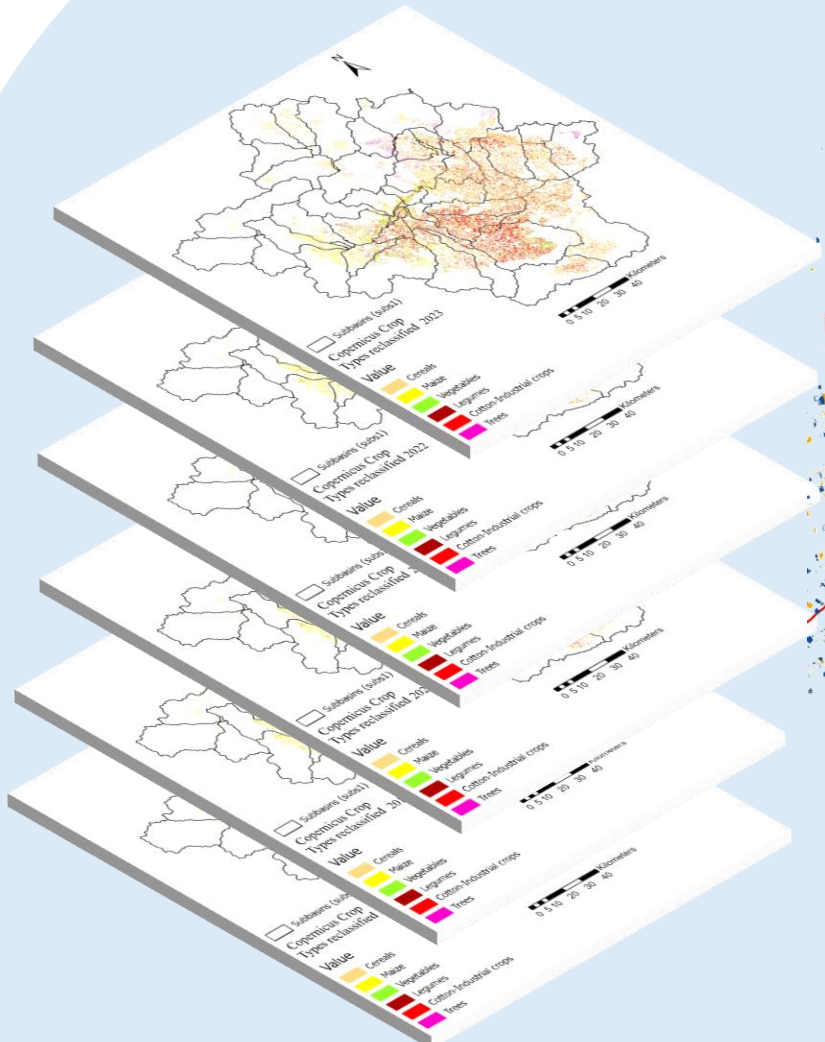
- Airports
- Bare rocks
- Beaches, dunes, sands
- Broad-leaved forest
- Burnt areas
- Coastal lagoons
- Complex cultivation patterns
- Coniferous forest
- Construction sites
- Continuous urban fabric
- Discontinuous urban fabric
- Dump sites
- Estuaries
- Fruit trees and berry plantations
- Green urban areas
- Industrial or commercial units
- Inland marshes
- Land principally occupied by agriculture, with significant areas of natural vegetation
- Mineral extraction sites
- Mixed forest
- Moors and heathland
- Natural grasslands
- Non-irrigated arable land
- Olive groves
- Pastures
- Permanently irrigated land
- Port areas
- Rice fields
- Road and rail networks and associated land
- Salines
- Salt marshes
- Sclerophyllous vegetation
- Sea and ocean
- Sparsely vegetated areas
- Sport and leisure facilities
- Transitional woodland-shrub
- Vineyards
- Water bodies
- Water courses

+

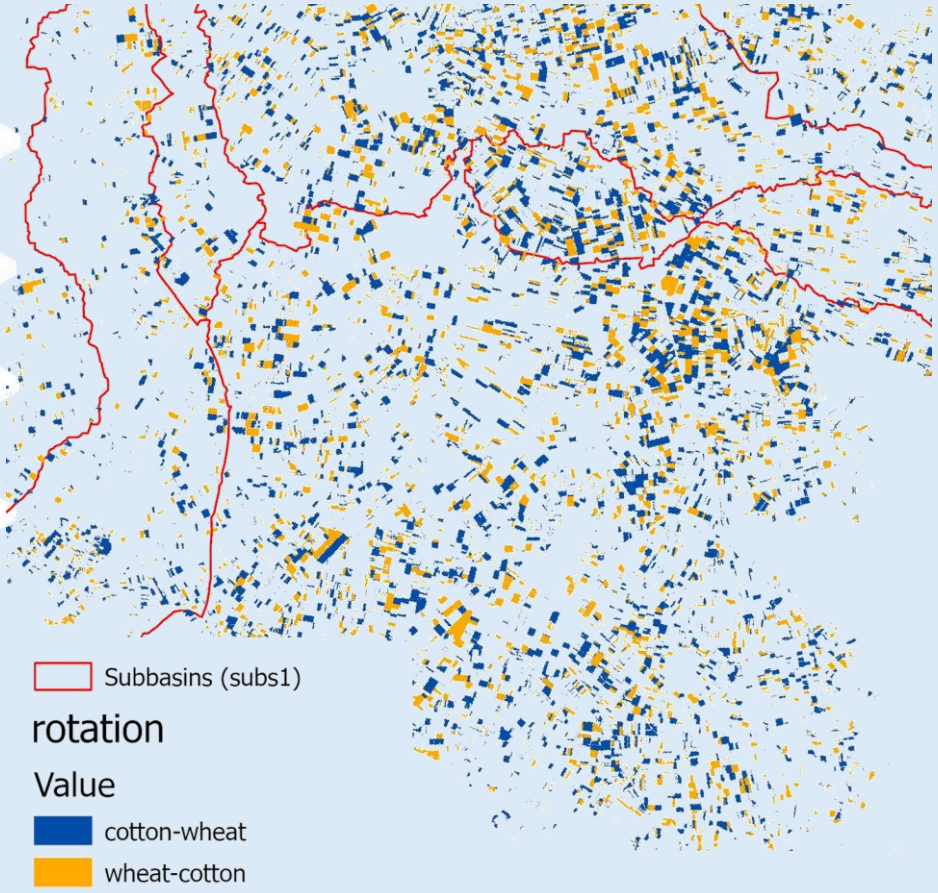




Landuse map development



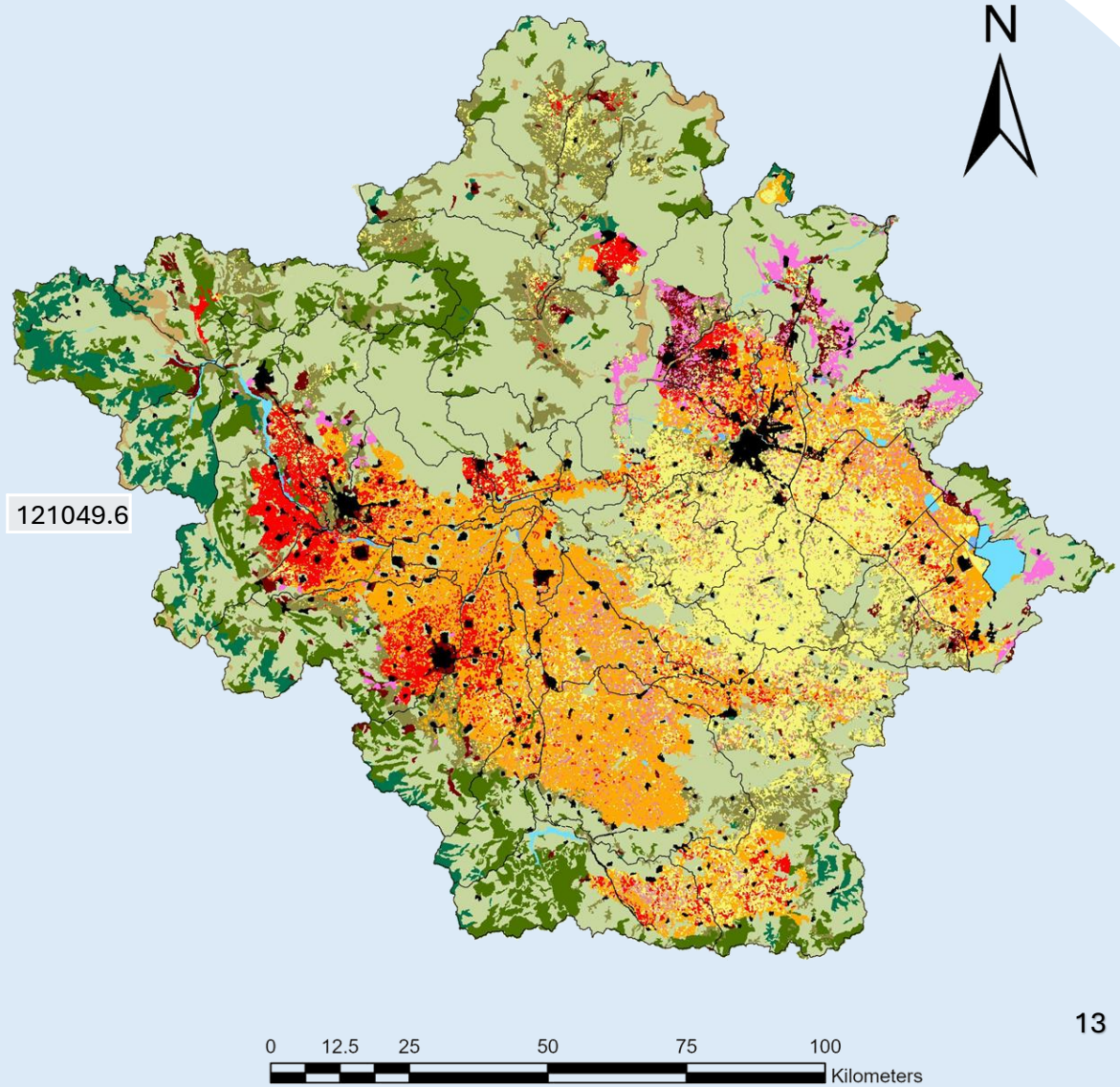
Copernicus HRL Croplands-Rotation



- Six annual crop-type layers 2018-2023 were analysed for repeated two-crop sequences
- Two SWAT rotation classes were created: cotton-wheat and wheat-cotton.
- This distinction preserves the basin's irrigated / non-irrigated agricultural balance while representing crop rotation
- Rotation pixels were retained only when both crops appeared repeatedly during 2018-2023

Landuse map development

- Area: 1,064,758.41 ha
- Cropland: 484,268.8 ha (45%)
- Pasture: 409,152.5 ha (38%)
- Forest: 121,049.6 ha (11%)
- Irrigated land: 222,770 ha
- Main crops:
  Cotton: 28%
  Wheat: 30%
  Corn: 10%
  Rotation cotton-wheat: 6%
  Other (Alfalfa, Orchard, fallow land): 25%



Soil map development

Input data

SoilGrids250m v2.0
texture, bulk density, organic carbon, pH, coarse fragments, water retention

HiHydroSoil v2.0
Ksat, hydrologic soil group

Processing

soil-profile grouping →

3-layer profile: 0–30, 30–60, 60–200 cm

depth-layer aggregation

gap filling

USDA texture classification

Derivation of SWAT variables

Output

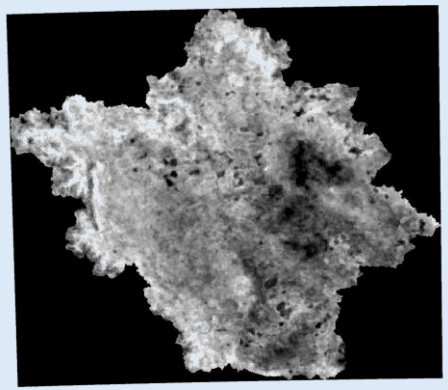
SWAT-compatible soil database

19 SWAT soil variables

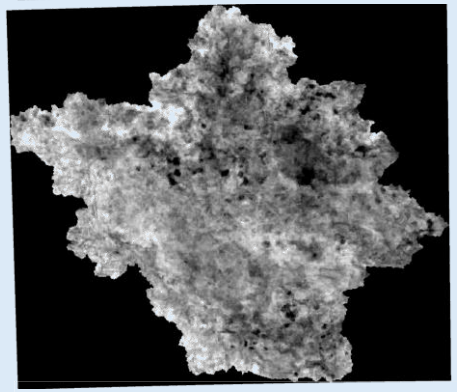
250 m resolution

soil map linked to soil profiles

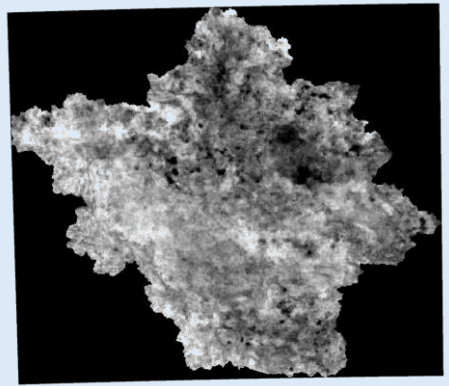
AWC



0-30cm



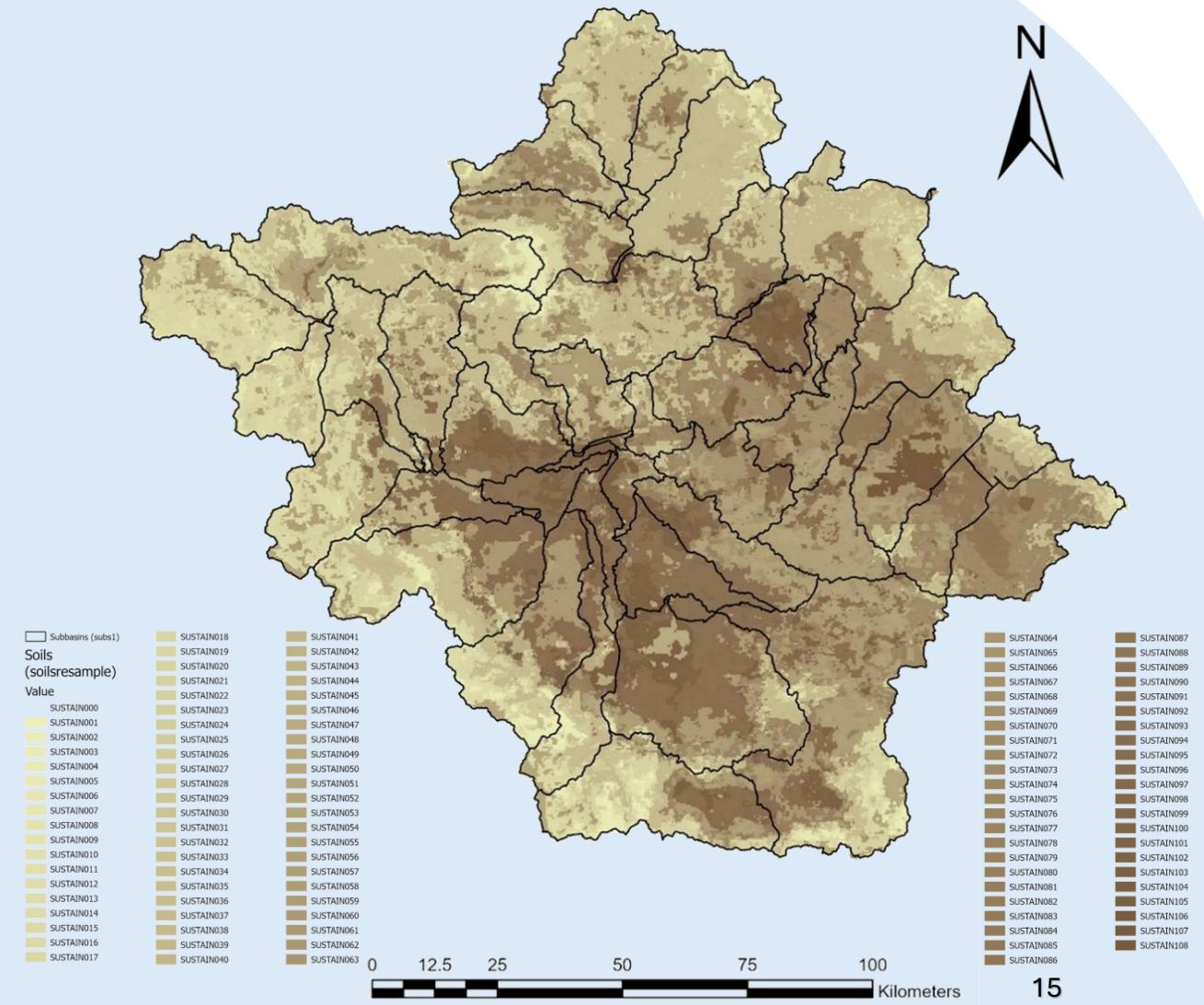
30-60cm



60-200cm

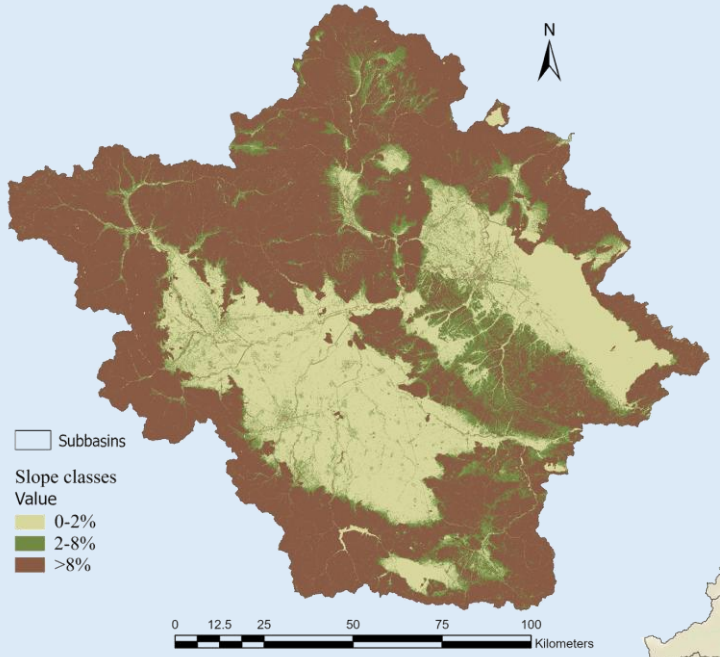
Soil map development

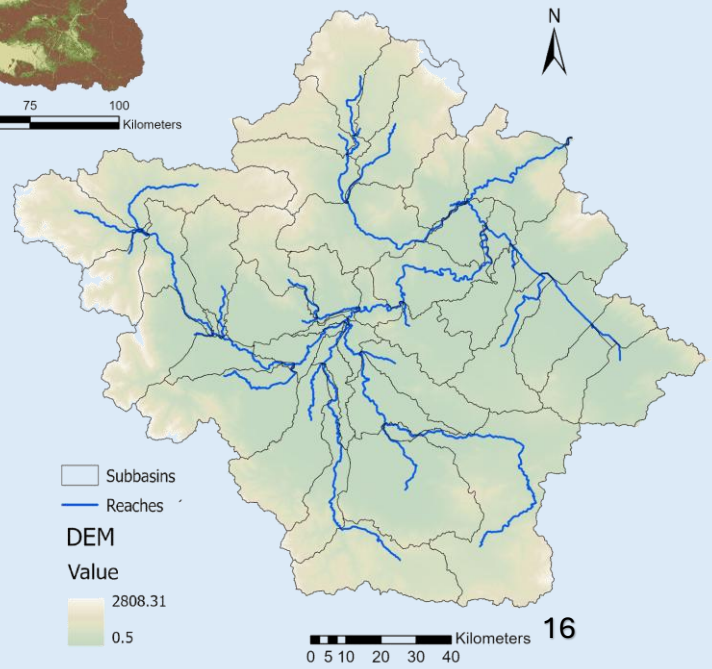
- Soil classes were based on **texture, bulk density, soil organic carbon and Ksat**
- Class limits were defined for each parameter and their intersection produced the initial soil classes
- This yielded **291 initial classes**
- Classes with <100 cells were merged with neighbouring soil classes, **reducing the total to 108 classes**
- For each soil class, SWAT parameter values were calculated as layer-wise averages of the cells belonging to that class



Simulation of Pinios river basin

- Based on DEM analysis, agricultural land was classified into three slope classes: 0–2% (50%), 2–8% (25%), and >8% (25%)
- A 5% threshold was applied for land use, soil type, and slope during HRU definition, due to the high spatial detail of the input maps
- This approach reduced the total number of HRUs and model complexity, while preserving the dominant hydrological characteristics of the watershed
- 48 subbasins – 1785 HRUs

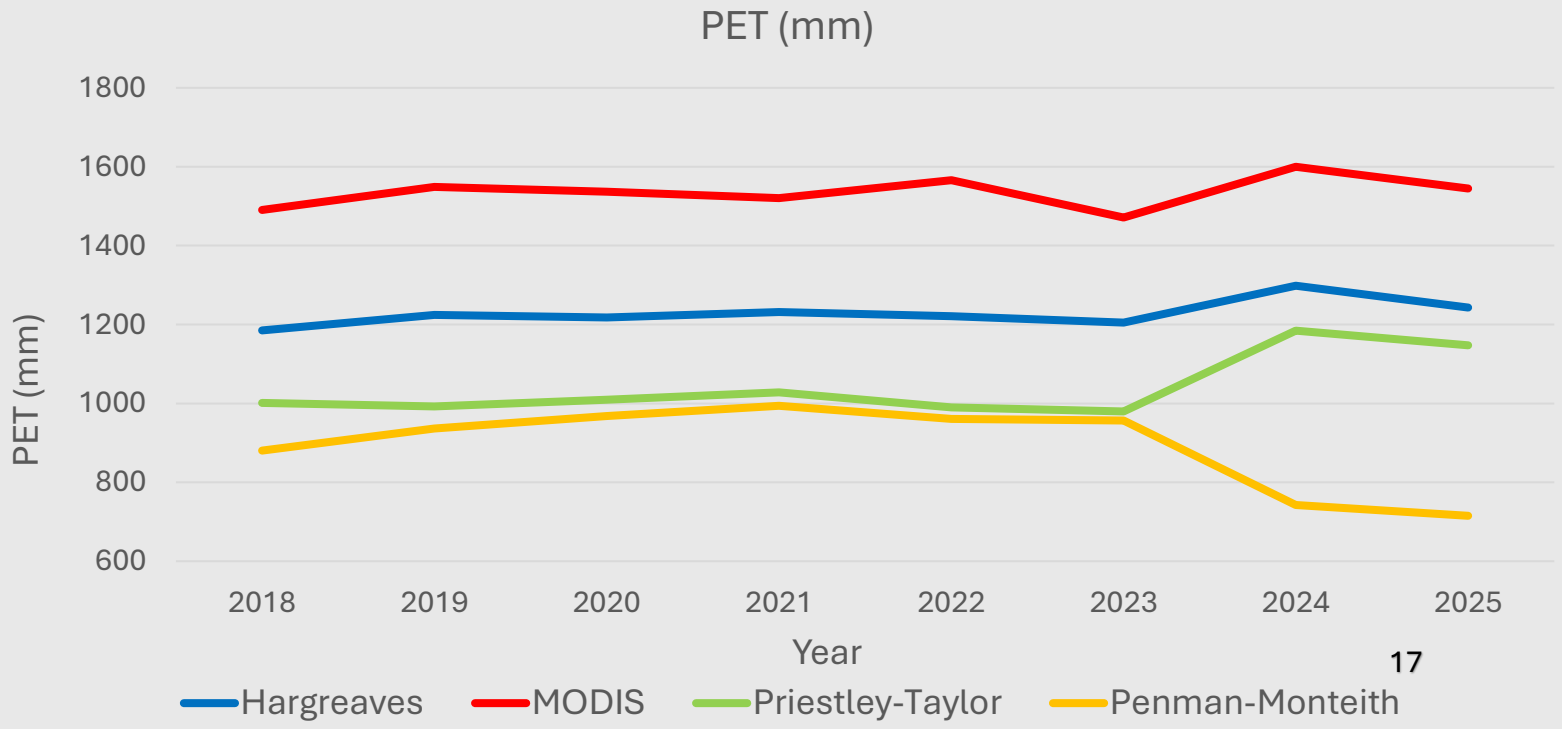




PET method comparison before calibration

PET 2018-2025	RMSE	PBIAS	R^2
Hargreaves	307.3	19.97	0.67
Priestley-Taylor	496.6	32.13	0.38
Penman-Monteith	652.2	41.74	0.20

- SWAT PET was compared with MODIS PET before calibration using the three PET methods available in SWAT
- Evaluation was performed at **annual basin scale**
- **Hargreaves** showed the closest agreement with MODIS PET
- Therefore, Hargreaves was selected for the subsequent simulations



Hydrological calibration at the basin outlet

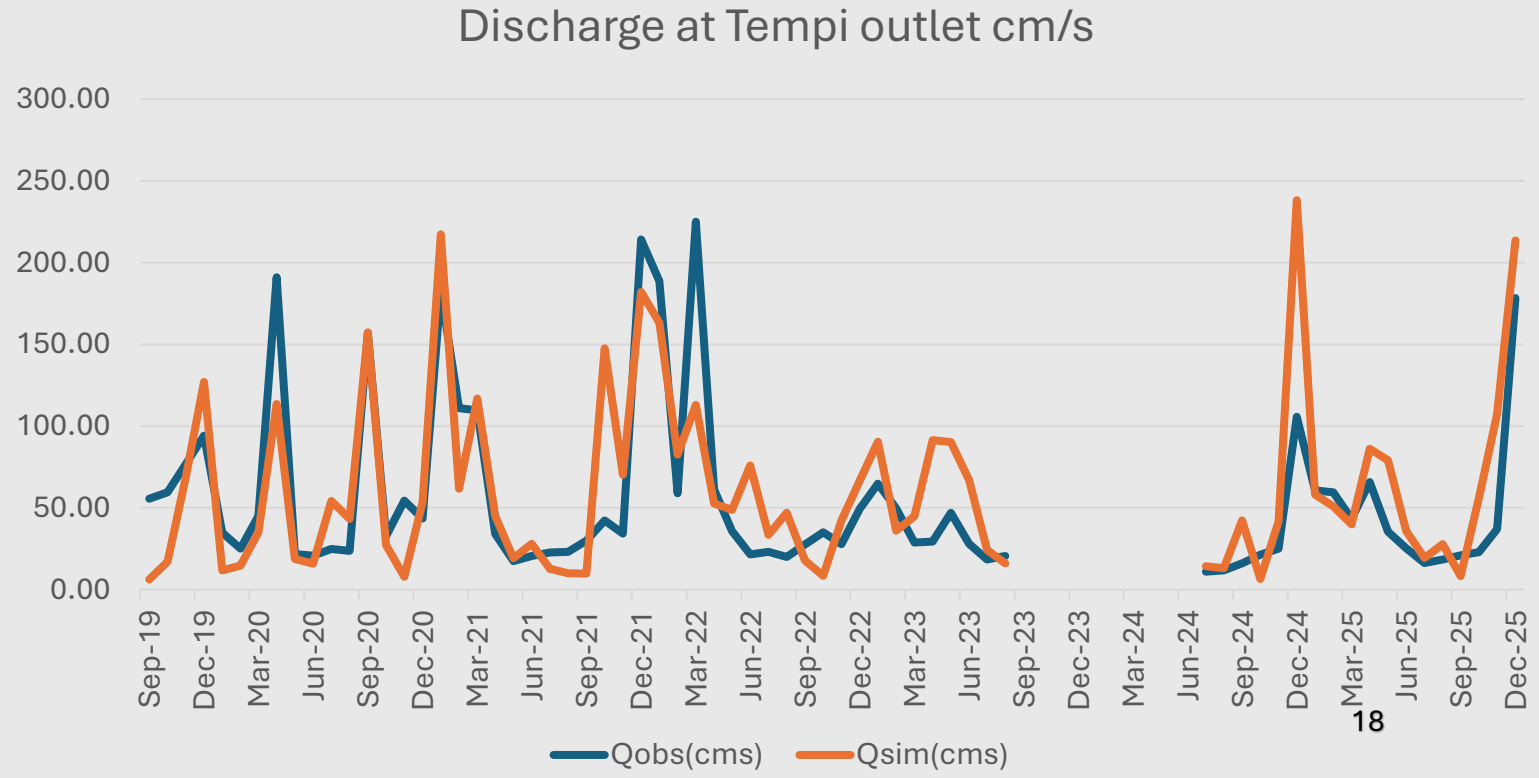
Discharge at Tempi outlet	Timeseries	NSE	RMSE	PBIAS	R^2
Calibration	2019-2023	0.59	35.68	-1.42	0.60
Validation	2024-2025	0.02	40.01	-47.04	0.76

Calibration provided an acceptable hydrological baseline

Validation was affected by the Daniel Storm data gap

Missing discharge observations: Sep 2023-Jun 2024

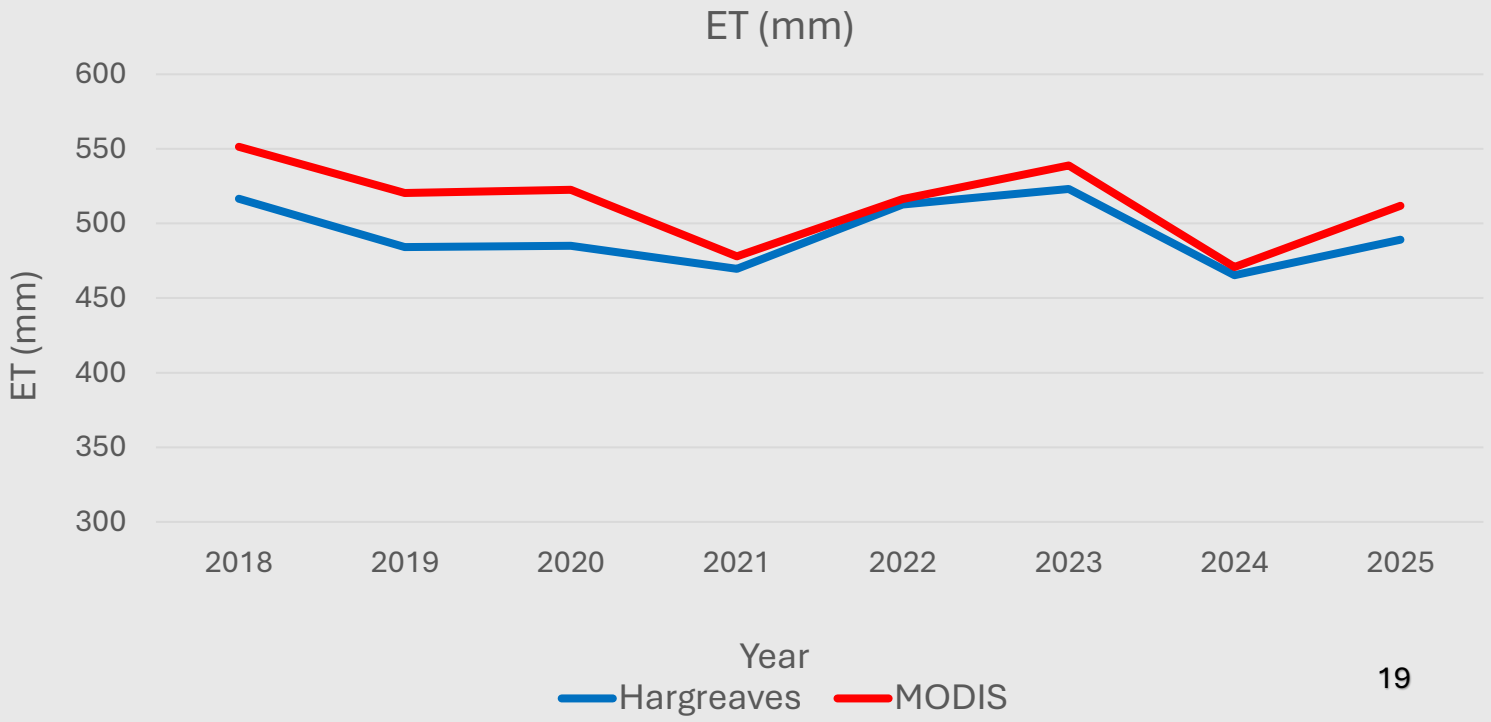
MODIS ET was used to better understand spatial ET patterns and support the evaluation of internal water-balance processes



Annual basin-scale ETa evaluation after calibration

ET 2018-2025	RMSE	PBIAS	R^2
Hargreaves	19.84	2.88	0.74

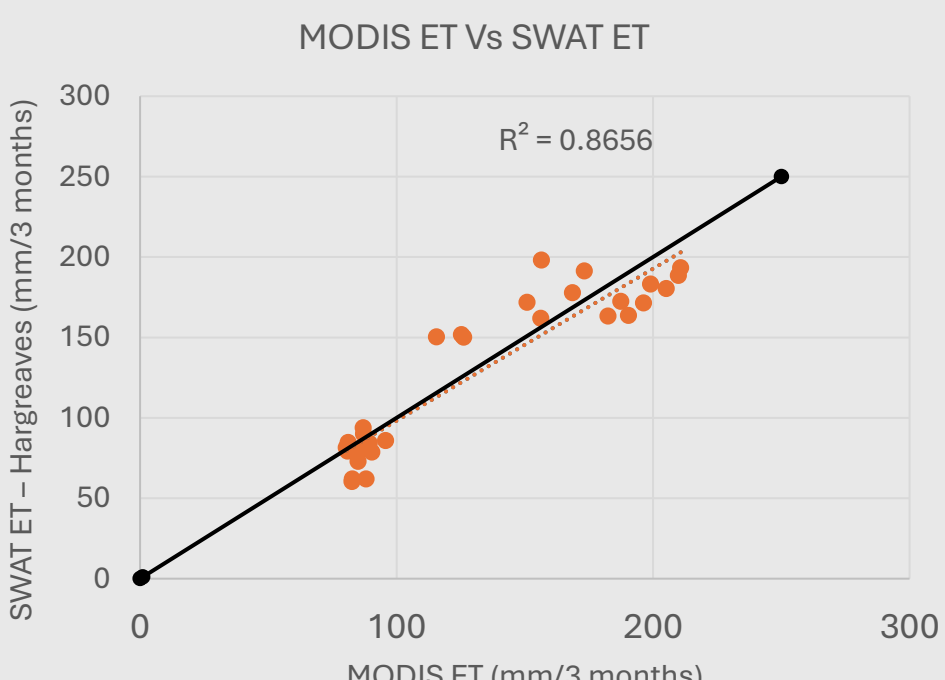
- SWAT ET was re-evaluated against MODIS ET after calibration
- ESCO and EPCO were adjusted uniformly across the whole basin during hydrological calibration
- Annual basin-scale ET changed only slightly after calibration
- This motivated further seasonal and spatial ET analysis

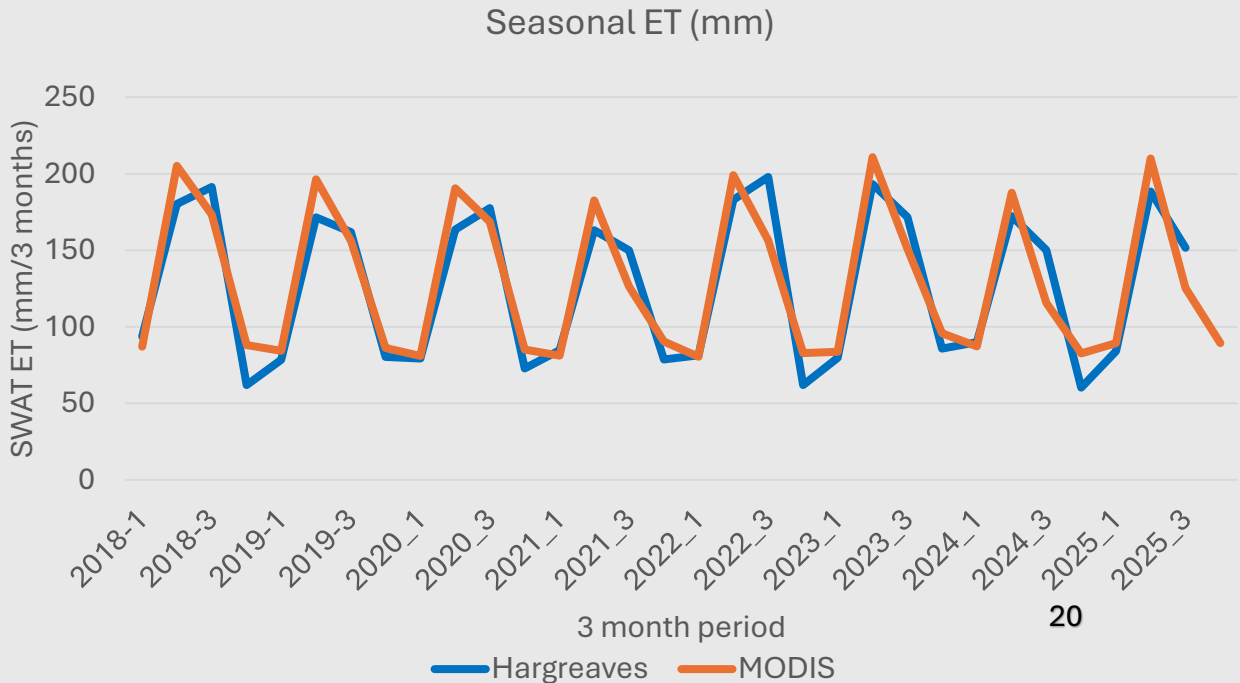


Seasonal basin-scale ET after calibration

- 3-month ET was used to examine seasonal ET patterns
- Hargreaves-based SWAT ET followed the main seasonal MODIS-ET pattern
- This basin-scale agreement was further examined through subbasin and landuse level ET analysis

ET	RMSE	PBIAS	R^2
2018-2025	65.46	2.66	0.87

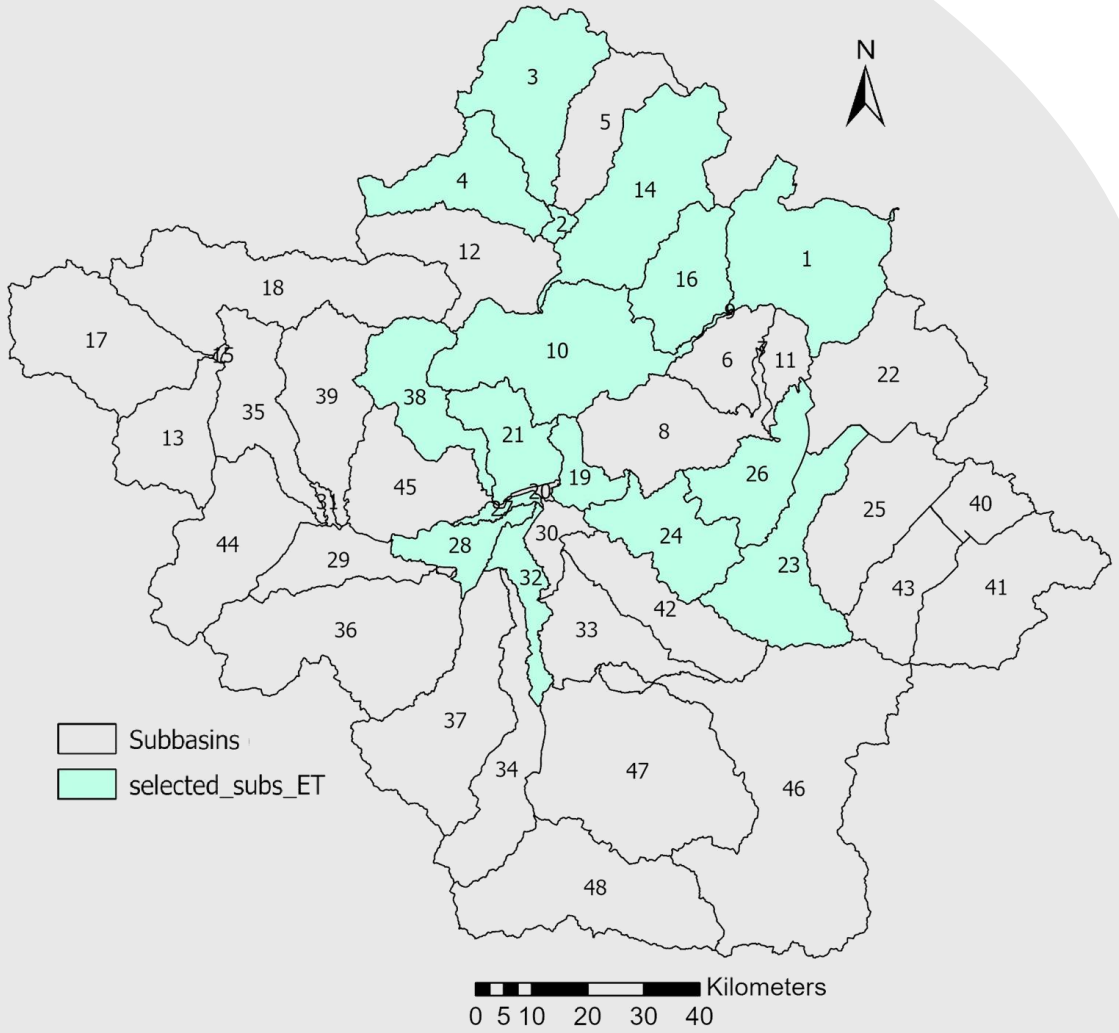




Spatial ET calibration by landuse

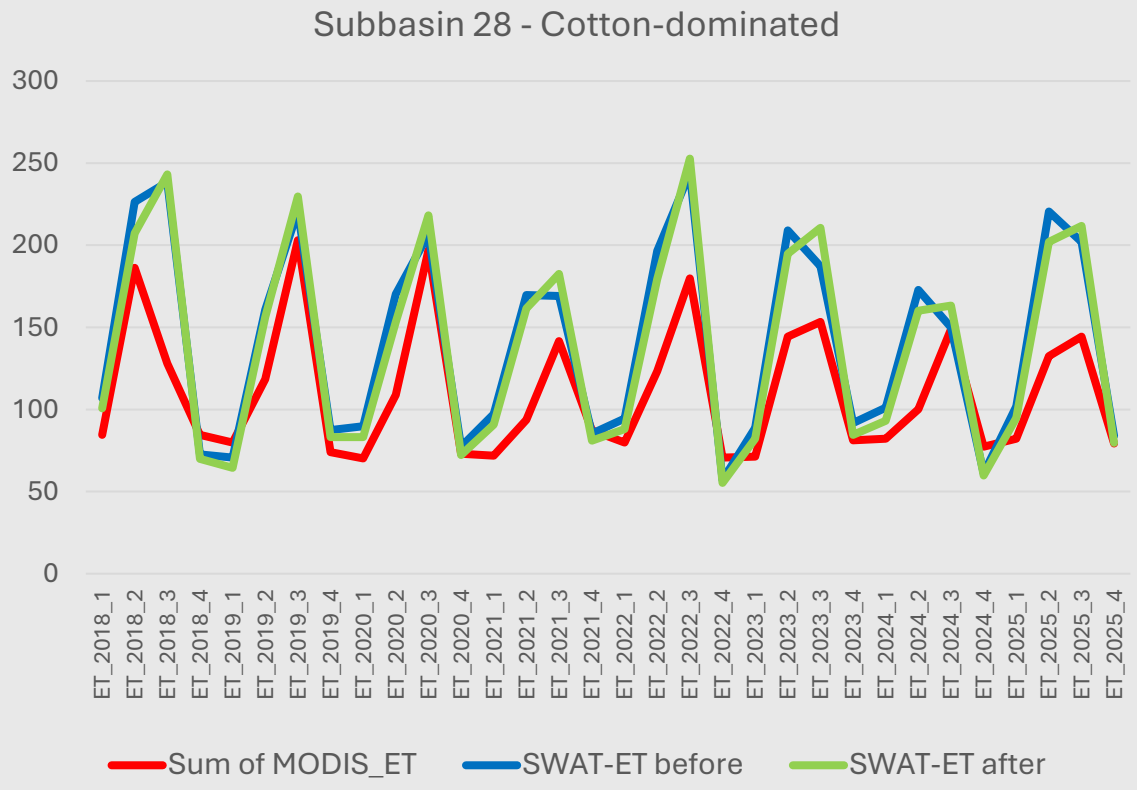
- Subbasins were grouped according to their dominant landuse class
- Only subbasins where the dominant landuse class covered >70% of the area were selected
- MODIS ET was then used to guide calibration at subbasin and landuse level (ESCO & EPCO calibration)

Subbasin	Dominant LU	Subbasin	Dominant LU
1	Pasture	21	Pasture
2	Pasture	23	Wheat
3	Pasture	24	Wheat
4	Pasture	26	Wheat
10	Pasture	27	Cotton
14	Pasture	28	Cotton
16	Pasture	32	Cotton
19	Pasture	38	Pasture

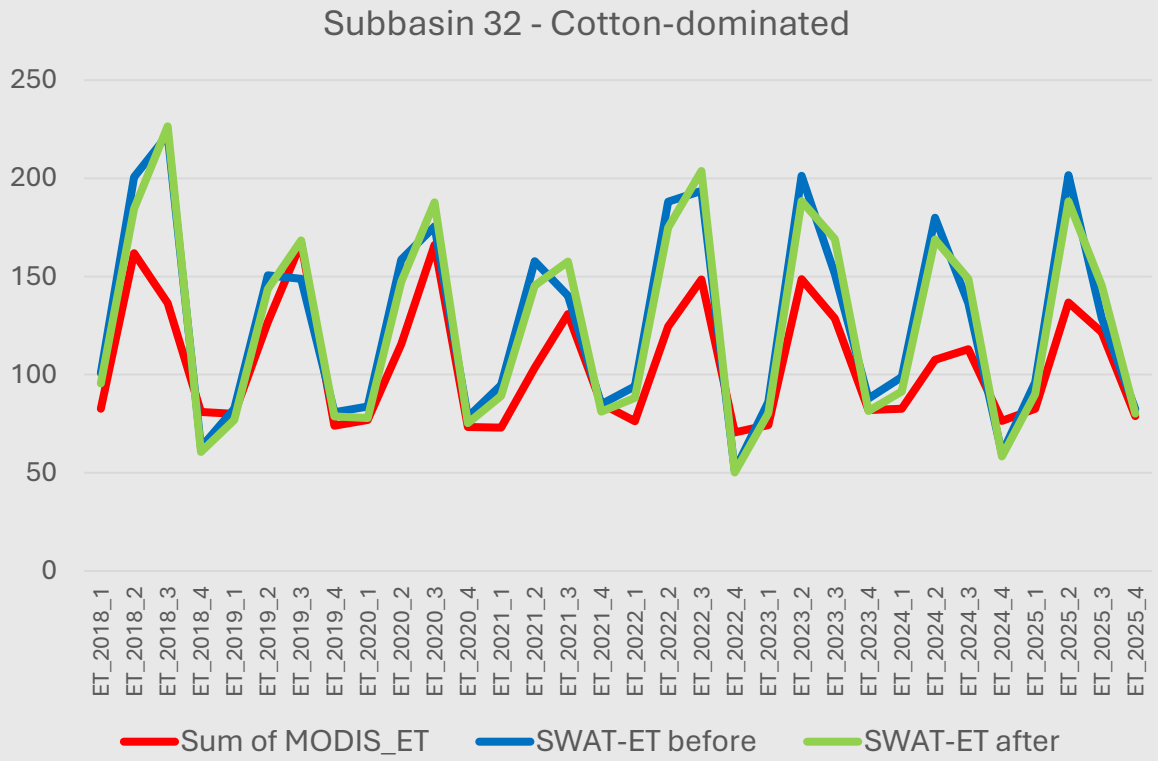


Cotton dominated subbasins: ET before and after calibration

Calibration improved ET bias and seasonal agreement, with some remaining peak-period overestimation



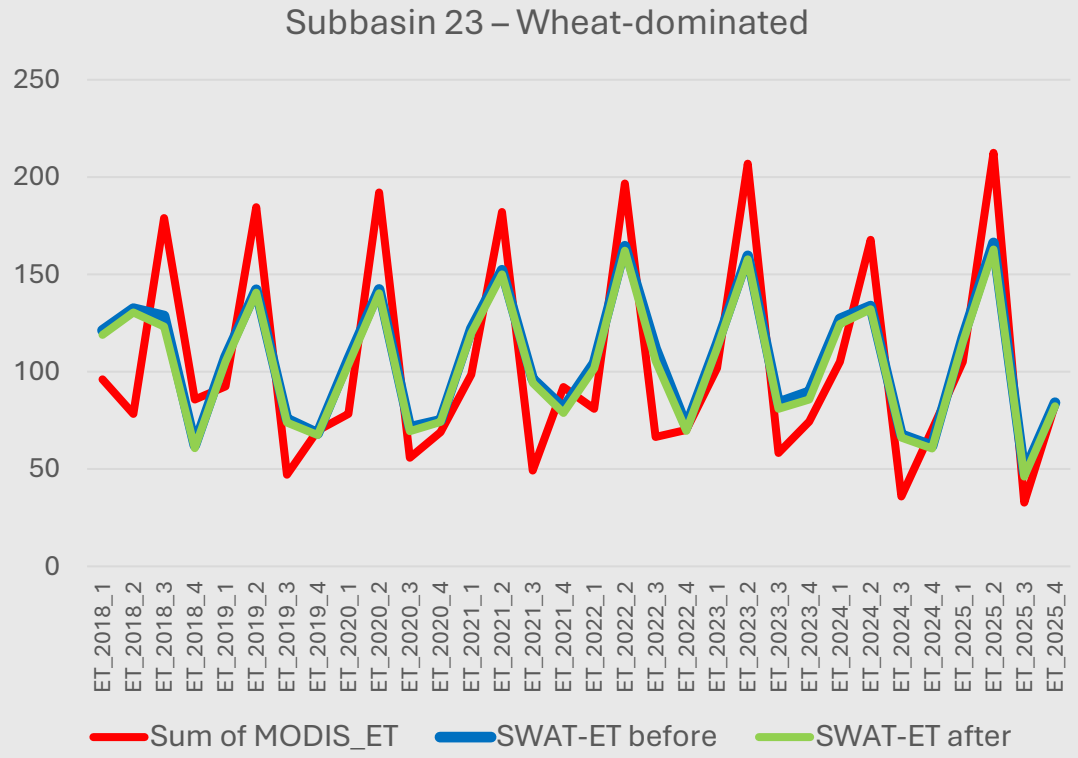
	PBIAS	R^2	RMSE
Before calibration	27.00	0.75	43.77
After calibration	24.12	0.81	41.22



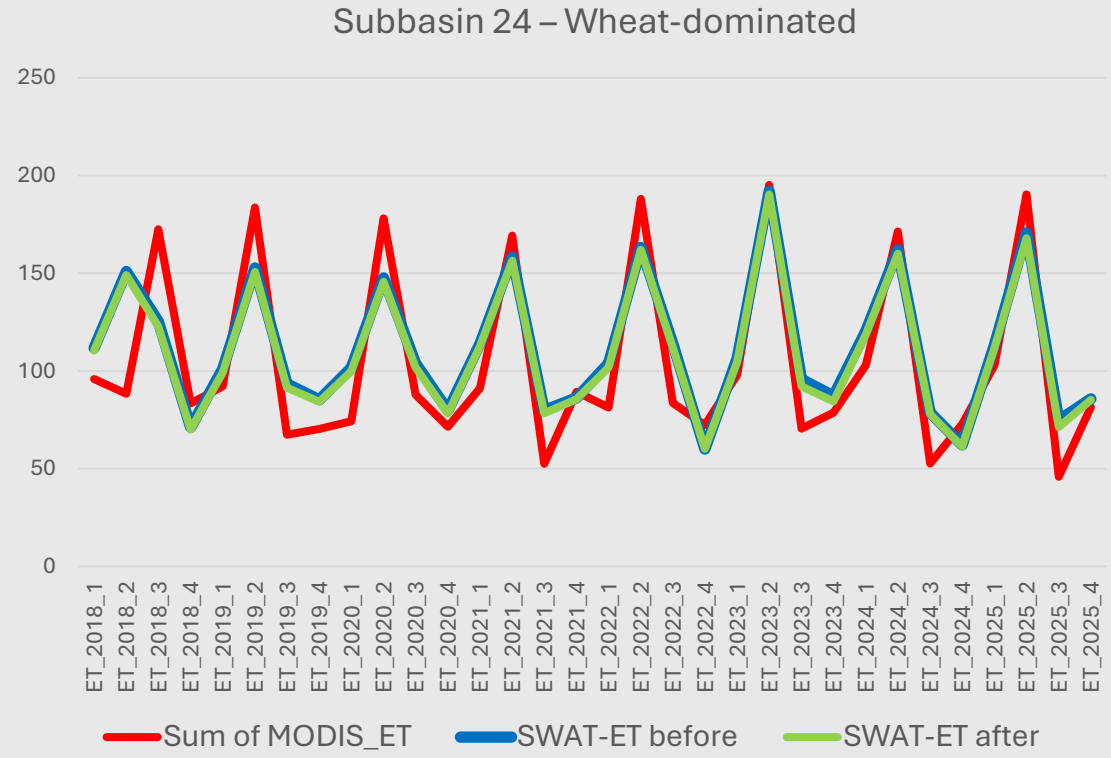
	PBIAS	R^2	RMSE
Before calibration	19.88	0.76	34.01
After calibration	18.22	0.84	31.57

Wheat dominated subbasins: ET before and after calibration

Calibration reduced ET bias without degrading the seasonal ET pattern



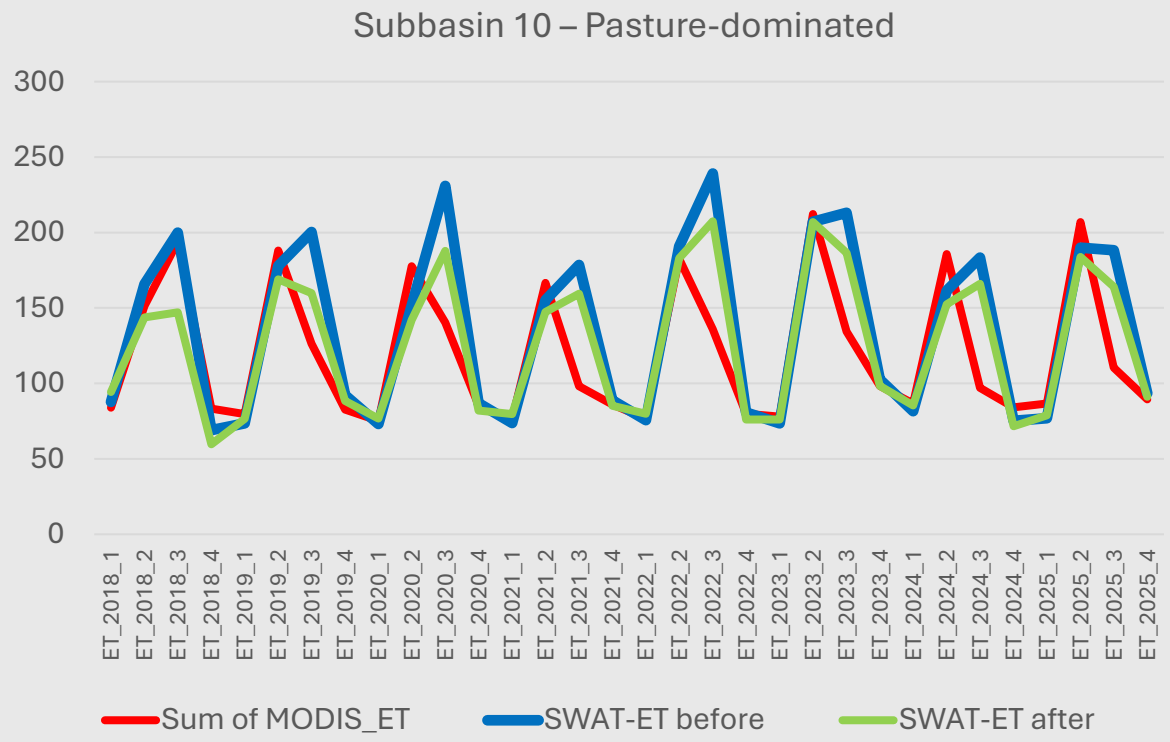
	PBIAS	R^2	RMSE
Before calibration	2.22	0.75	30.12
After calibration	-0.05	0.75	29.95



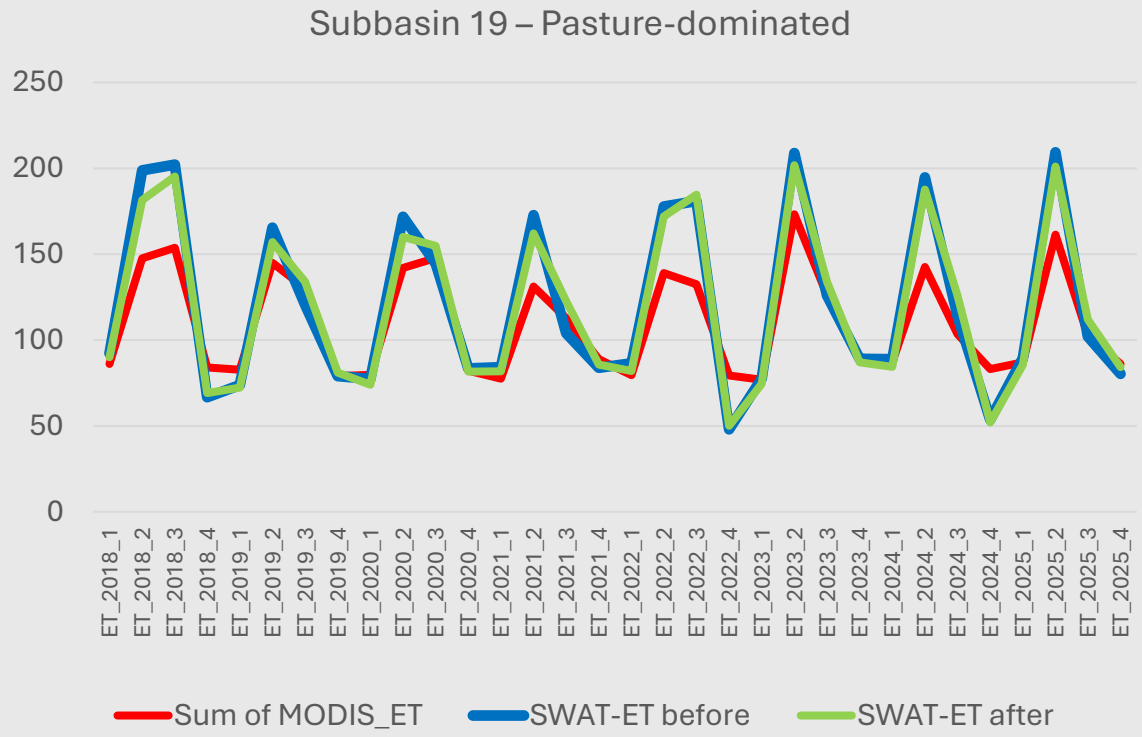
	PBIAS	R^2	RMSE
Before calibration	3.64	0.61	26.58
After calibration	1.27	0.60	26.57

Pasture dominated subbasins: ET before and after calibration

Calibration brought SWAT ET closer to MODIS ET



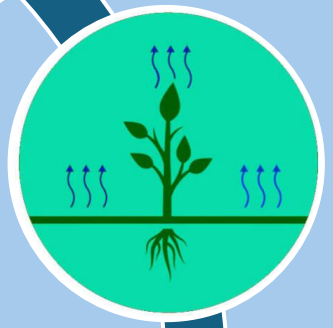
	PBIAS	R^2	RMSE
Before calibration	13.00	0.56	40.81
After calibration	4.35	0.62	30.40



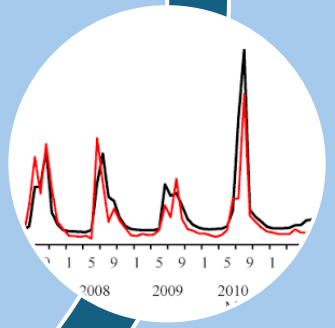
	PBIAS	R^2	RMSE
Before calibration	9.32	0.90	25.56
After calibration	8.58	0.93	22.11

Conclusions

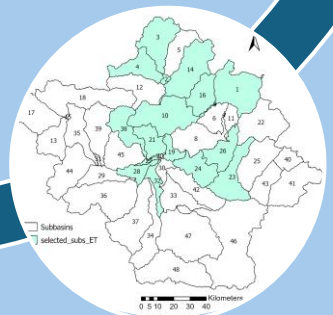
Remote Sensing datasets improved the spatial representation of land use, crop patterns, soils and ET in SWAT



Hargreaves was selected as the PET method that produced the best agreement between SWAT simulated ET and MODIS ET



Hydrological calibration provided an acceptable baseline, but MODIS ET was needed for additional spatial evaluation of ET across the basin



Subbasin/landuse level ET calibration improved SWAT ET simulations in cotton, wheat and pasture dominated subbasins

Future work

- Integrate additional Remote Sensing datasets: LAI and soil moisture
- Improve calibration of crop growth, ET and soil-water processes
- Extend the framework to nutrient transport modelling
- Use Remote Sensing data for chlorophyll-a for Lake Karla reservoir and support future simulation of reservoir water-quality indicators
- Support SUSTAIN-R water-quality, restoration and ecosystem-services applications

Thank you for your attention

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The project “SUSTAIN-R”

A few words about the project…

- Research project focused on nutrient recovery and aquatic ecosystem restoration
- **Funding: Water4All Partnership - 2023** Joint Transnational Call, co-funded by the **European Union** and **national funding organisations**

- **Consortium:** multidisciplinary European partnership with expertise in nutrient recovery, water treatment, monitoring, modelling and ecosystem restoration

- **Main objective:** to develop and demonstrate innovative tools, methodologies and technologies for aquatic ecosystem restoration

- **Greek case study:** Pinios River Basin, Thessaly, an intensively cultivated basin where water quantity and quality are strongly affected by agricultural activity

- **Aim of this work:** The present work contributes by developing a remote sensing supported SWAT modelling framework, providing the hydrological basis for future nutrient and water quality simulations

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