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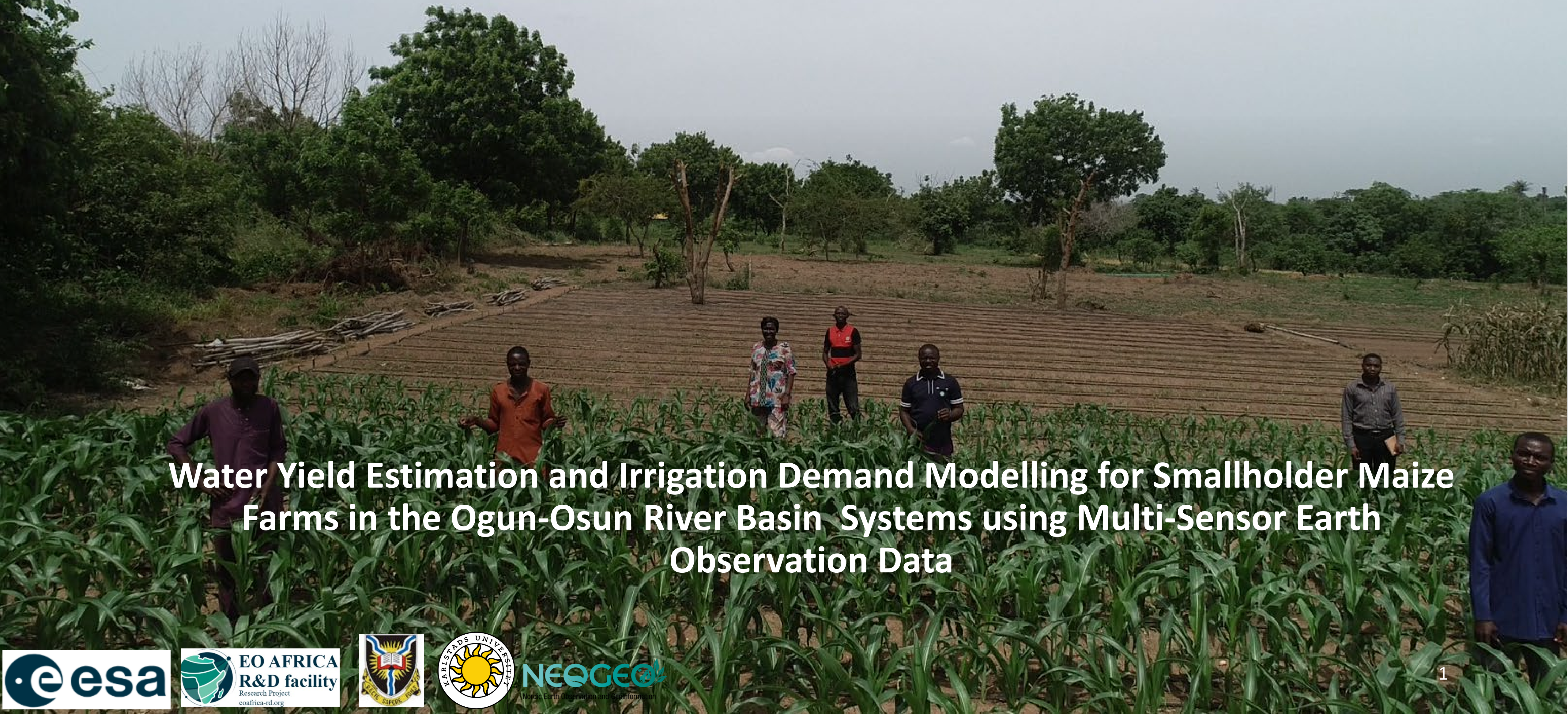


Water Yield Estimation and Irrigation Demand Modelling for Smallholder Maize Farms in the Ogun-Osun River Basin Systems using Multi-Sensor Earth Observation Data

EO AFRICA R&D facility
Research Project
eoafrica-rd.org

Introduction

- Rainfed smallholder farming systems dominate in Africa
- There is a decline in the crop yield from these rainfed systems
- The unpredictable nature of rainfall due to climate variability and climate change in Nigeria has limited productivity of smallholder systems despite abundant rivers
- Food insecurity, there were ~ **35 million facing acute food insecurity** in Nigeria as of 2026 (World Food Programme, 2026)

Aim

Irrigation potential of over 1.5 million hectares but less than 3% of Nigeria's croplands are irrigated

RiverWISE explores this vast untapped prospect in Southwestern Nigeria

Our study seeks to provide scientific input for harnessing irrigation using **Ogun-Osun River Basin** as case where irrigation use remains very limited

RiverWISE is promoting Earth Observation (EO)-based climate-smart irrigation for smallholder agriculture

Study Area

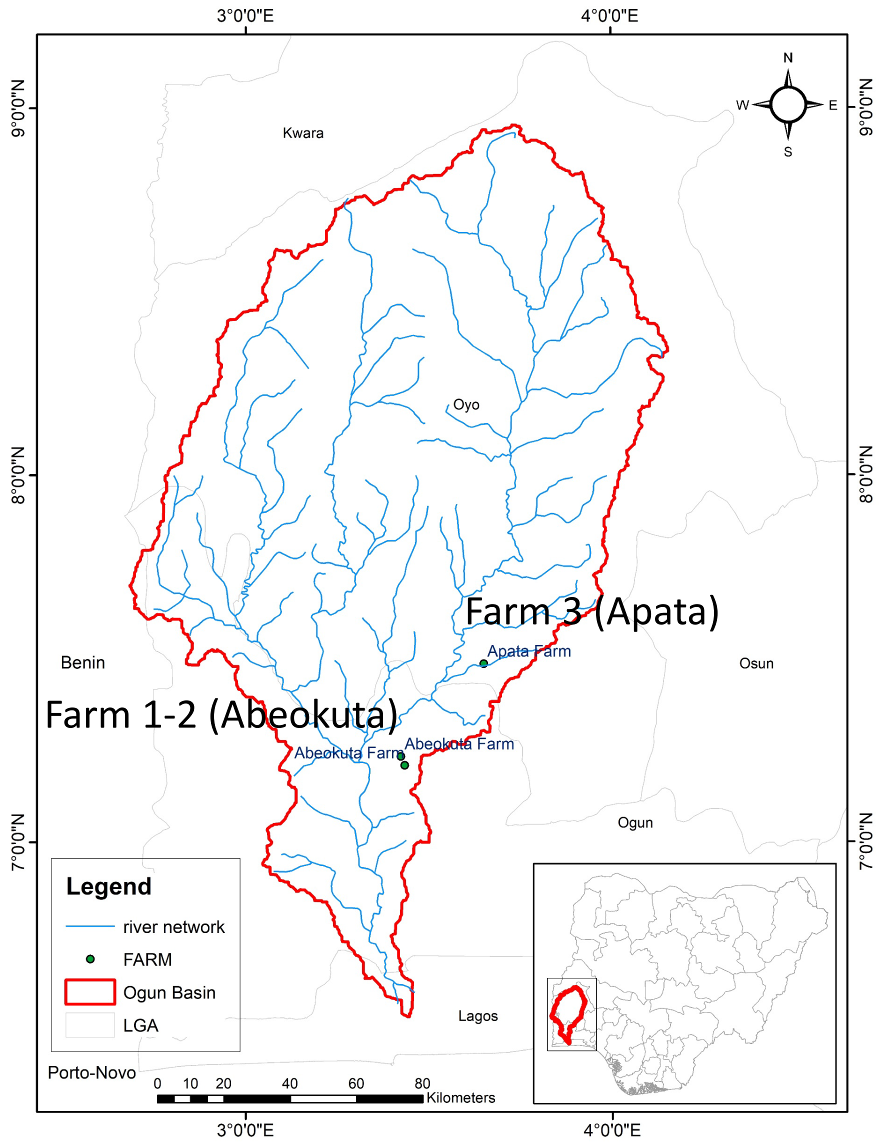


Plate. Irrigation dam for maize cropping in Apata, Ibadan (7.378431 ºN, 3.839249 ºE)

Objectives

Hydrogeomorphological analysis with SWAT and HEC-HMS models in the Ogun–Osun River Basin: Evaluate drainage patterns, slope, landform dynamics, land cover, and soil-water interactions, and their influence on **water yield and irrigation demand**

Estimating maize yield and irrigation demand to simulate optimal irrigation scheduling using the open-source AquaCrop-OSPy for crop-water modelling.

Training stakeholders (e.g. basin officials, farmers and researchers) on EO-based irrigation management of smallholder farming systems

Why Maize?

- Extensive cultivation
- Highly susceptibility to rainfall variability
- High economic value and a major food staple
- Current project focus is on maize monocropping
- In mixed-farming systems, maize is often intercropped with cassava

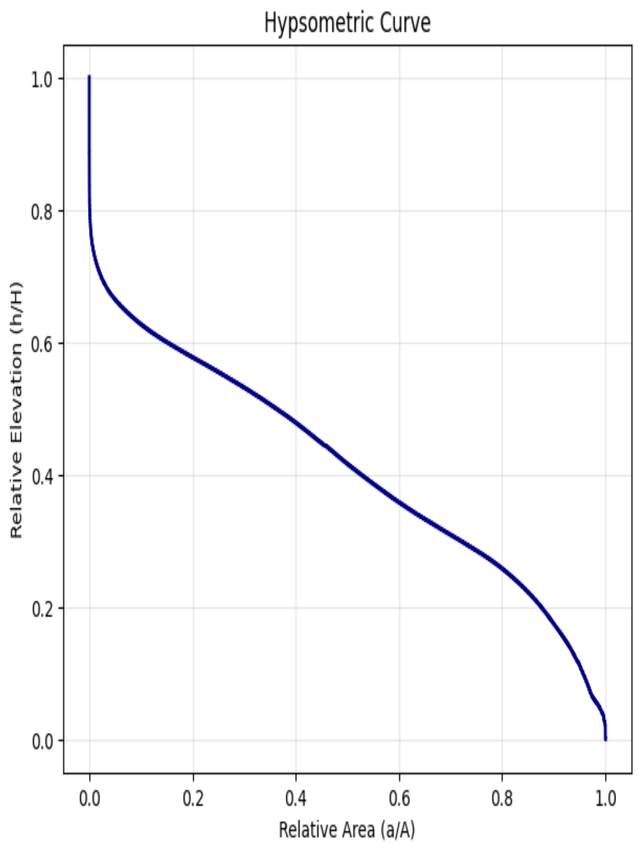
Tasks, Methods and Data in RiverWISE

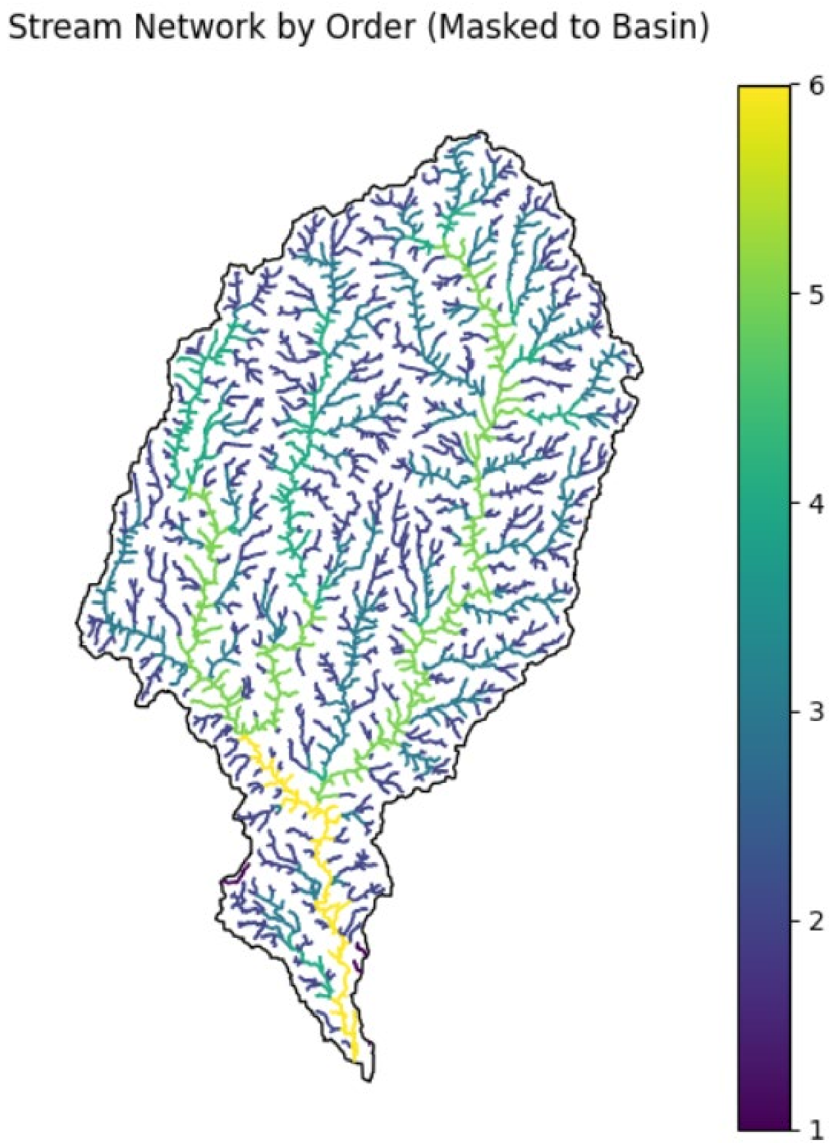
HYDROGEOMORPHOLOGICAL ANALYSIS	Basin delineation, terrain analysis, slope classification, and groundwater recharge assessment	SWAT, HEC-HMS, QGIS, SRTM DEM, pysheds **Sentinel 2 data**
CLIMATE & WEATHER DATA PREPARATION	Preparation of rainfall, temperature, and evapotranspiration datasets	**CHIRPS, ERA5-Land Daily, Copernicus Climate Data Store**
SOIL & LAND COVER MAPPING	Mapping of soil properties and land cover characteristics	**ISRIC SoilGrids, LucFRes land cover data**
CROP–WATER MODELLING	Simulation of irrigation demand and maize yield under irrigation scenarios	AquaCrop-OSPy, Jupyter Notebook, **ERA5-Daily Tmax, Tmin, Et0, Prep, soil moisture sum**
CROP STATS & FIELD DATA INTEGRATION	Integration of crop yield, UAV mapping, and field management data	LucFRes maize data, UAV imagery, field survey
CLIMATE SCENARIO ANALYSIS	Simulation of irrigation scheduling and drought adaptation strategies	**Sentinel 1-2 datasets, statistical climate data**
TOOL DEVELOPMENT	Development of GIS and Python-based decision-support tools	Python scripts, Jupyter notebook
CAPACITY BUILDING	Training workshops for farmers, extension officers, and researchers	Open-access tutorials, EO-ready workflow for smart irrigation
DISSEMINATION	Preparation of reports, scientific publications, and open repositories	Technical reports, peer-reviewed articles

Hydrogeomorphological Analysis of the River Basin

.py Environment

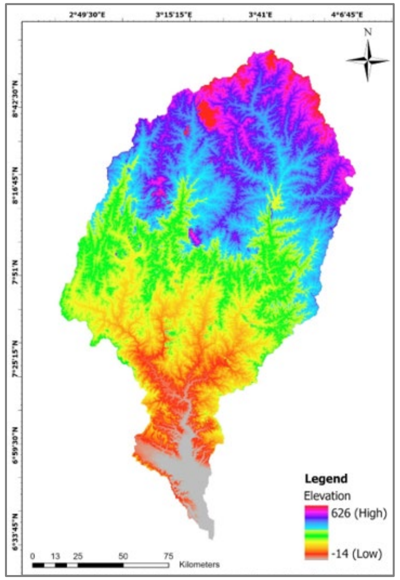
```
# Cell 9: Vector stream network, assign order, stream length, and view
branches = grid.extract_river_network(fdir, streams_raster)
features = branches.get("features", [])
if len(features) == 0:
    raise ValueError("No vector stream branches found. Lower STREAM_THRESHOL

stream_gdf = gpd.GeoDataFrame.from_features(features, crs=basin.crs)
stream_gdf = stream_gdf[stream_gdf.geometry.notna() & ~stream_gdf.geometry.i
stream_gdf = gpd.clip(stream_gdf, basin)

inv_t = ~transform

def sample_order(line, n=11):
    if line.is_empty:
        return np.nan
    if line.geom_type == "MultiLineString":
        line = max(line.geoms, key=lambda g: g.length)
    vals = []
    for t in np.linspace(0, 1, n):
        p = line.interpolate(float(t), normalized=True)
        col, row = map(int, inv_t * (p.x, p.y))
        if 0 <= row < order_np.shape[0] and 0 <= col < order_np.shape[1]:
            v = order_np[row, col]
            if np.isfinite(v) and v > 0:
                vals.append(int(v))
    return np.nan if len(vals) == 0 else max(vals)

stream_gdf["order"] = stream_gdf.geometry.apply(sample_order)
stream_gdf = stream_gdf.dropna(subset=["order"]).copy()
stream_gdf["order"] = stream_gdf["order"].astype(int)
stream_gdf["length_km"] = stream_gdf.length / 1000

TOTAL_STREAM_COUNT = int(len(stream_gdf))
```



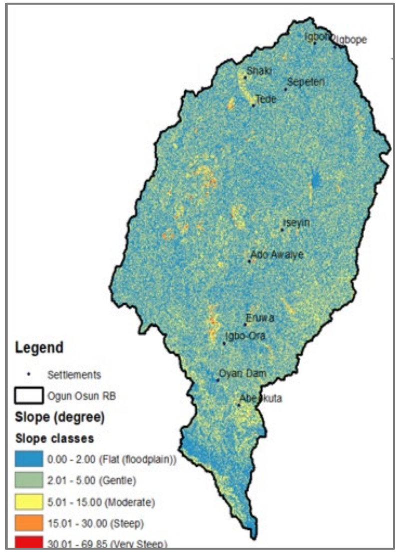



```
Total stream segments: 2721
Total stream length (km): 7908.3868
```

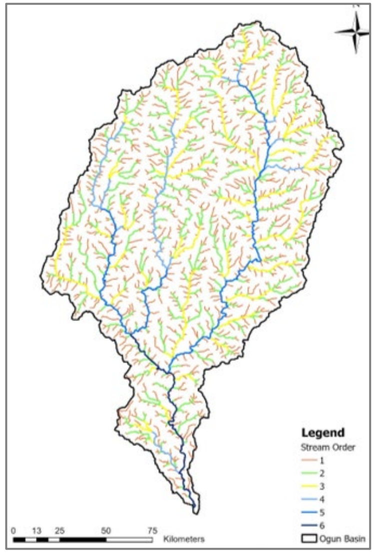
Basin Morphometry



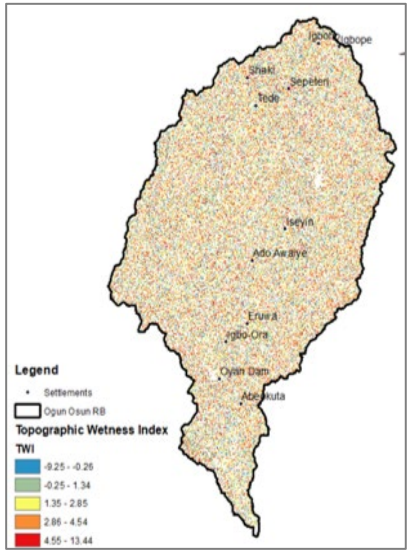
Elevation



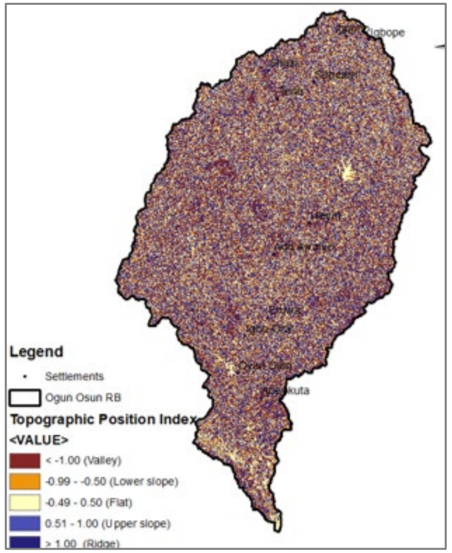
Slope (degree)



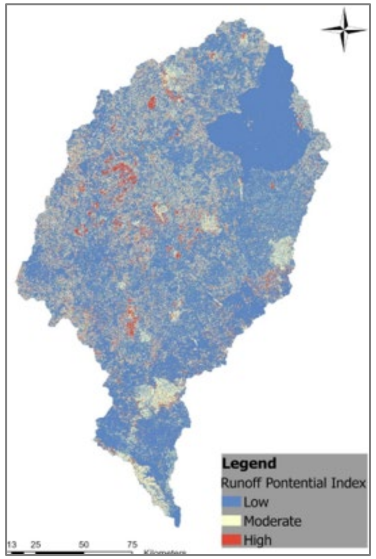
Stream Order



Topographic Wetness Index

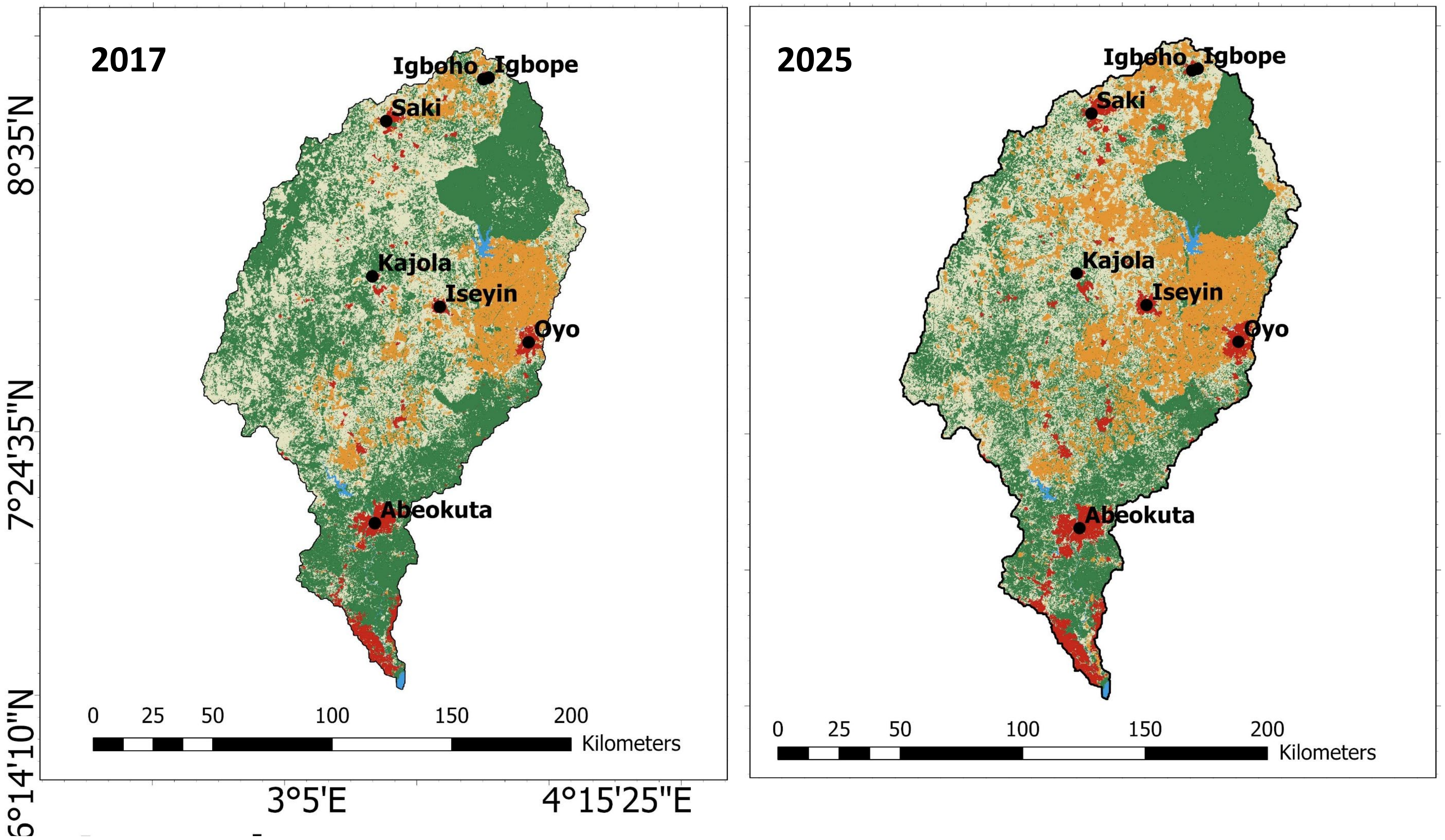


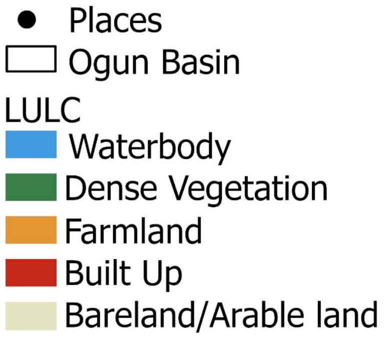
Topographic Position Index

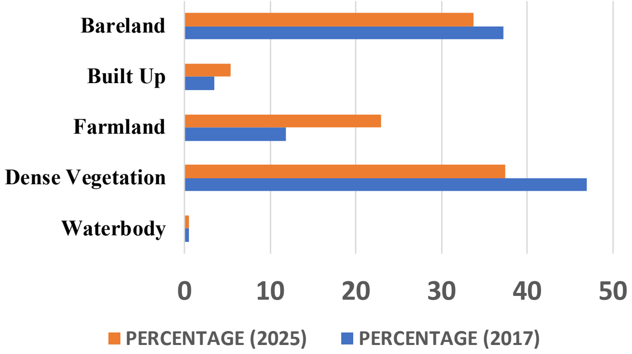


Runoff Potential Index

Basin land use







ESRI Sentinel 10 m

SWAT MODEL & HEC-HMS Parameterization

SWAT+ MODEL — OGUN-OSUN RIVER BASIN

PARAMETER	VALUE
Project Name	RiparianOgunRiverBasin
Basin	Ogun-Osun River Basin
Country	Nigeria
Simulation Period	1986-2022 (37 years)
Warm-up Years	3 years (1986-1988)
Calibration Period	1989-2007
Validation Period	2008-2022
Watershed Area (ha)	2,181,359.97
Watershed Area (km^2)	21,813.60
Number of Subbasins	119
Number of HRUs	1,744
Number of Channels	255
Number of LSUs	255
Number of Aquifers	120

Software Required

Software	Version	Purpose	Download
QGIS	3.28.9 LTR ONLY	GIS preprocessing & QSWAT+	qgis.org
QSWAT+	3.1.2	SWAT+ model setup	Via QGIS Plugin Manager
SWAT+ Editor	3.1.4	Model parameterization & run	swatplus.org
HEC-HMS	4.13	Flood hydrology simulation	hec.usace.army.mil
Microsoft MPI	Latest	Required for TauDEM	microsoft.com
Google Earth Engine	Web	Data extraction & preprocessing	code.earthengine.google.com
Python	3.9+ (via OSGeo4W Shell)	Data processing scripts	Included with QGIS
Python packages	See Section 3.1	rasterio, pandas, sklearn, openpyxl	pip install

Basin Water Balance & Runoff Modelling (in progress)

SWAT Model Pre-Calibration Water Balance

Component	Simulated	Expected	Status
Mean Annual Rainfall	1,213 mm	900-1,400 mm	Good
Actual ET	610 mm (50% of P)	55-70% of P	Slightly low
Surface Runoff	5.99 mm	8-20% of P	Too low
Average CN	44.73	55-75	Too low
Baseflow/Total Flow	0.99	0.30-0.70	Too high
Percolation	594 mm	20-35% of P	Too high

Climate Statistics (1986-2022)

Parameter	Value
Mean annual rainfall (CHIRPS)	1,215 mm
Min annual rainfall	885 mm
Max annual rainfall	1,484 mm
Max daily rainfall	55.3 mm
Mean Tmax (ERA5-Land)	31.8°C
Mean Tmin (ERA5-Land)	22.8°C
Max Tmax	39.2°C
Min Tmin	16.8°C

Prepare HEC-HMS Parameters

67. Run hms_prep.py — generates HMS_Subbasin_Parameters.csv and HMS Subbasin parameters:

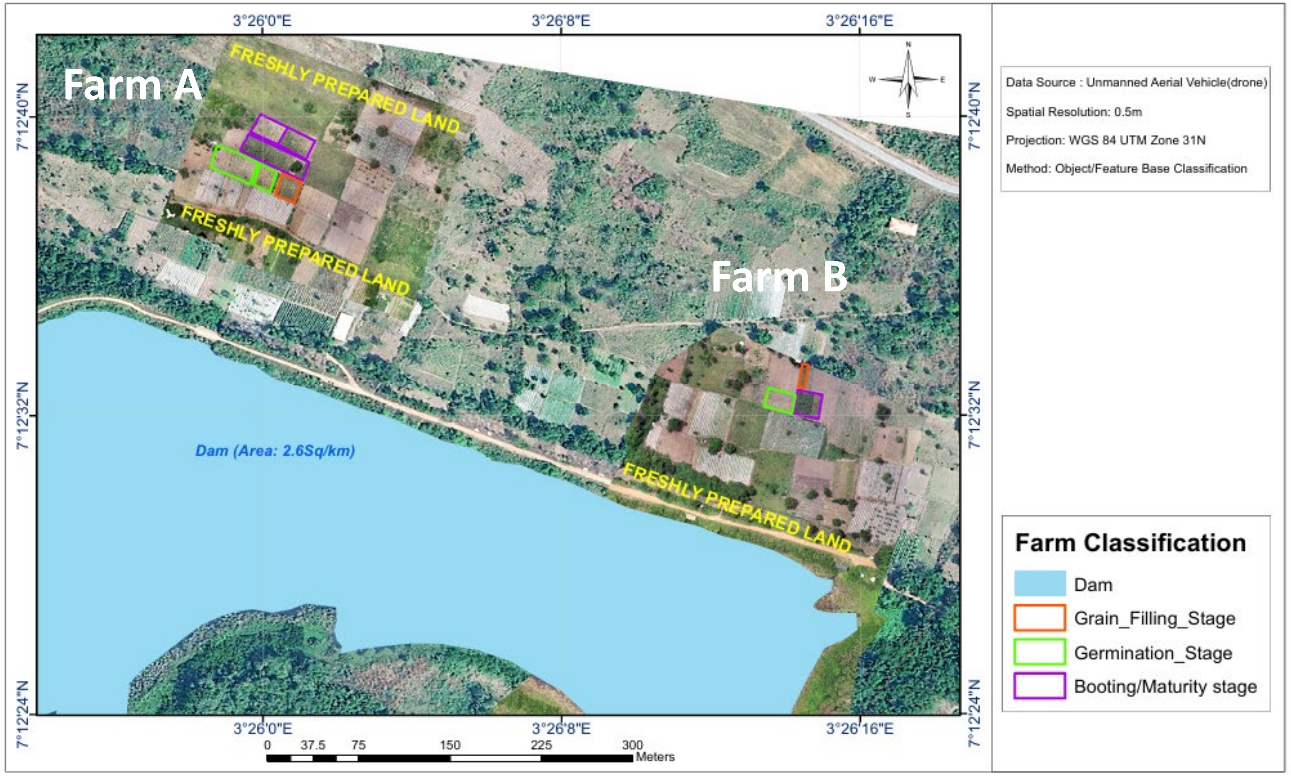
Subbasin	Area (km2)	CN	IA (mm)	Lag (min)
SUB1_Upper_Ogun	4,500	52	10.16	684
SUB2_Mid_Ogun	5,200	58	18.38	871
SUB3_Osun_Upper	4,800	60	16.93	763
SUB4_Confluence	4,314	65	13.65	899
SUB5_Lower_Ogun	3,000	72	9.87	747

NOTE: *IA = Initial Abstraction = 0.2 x S where S = (25400/CN) - 254*

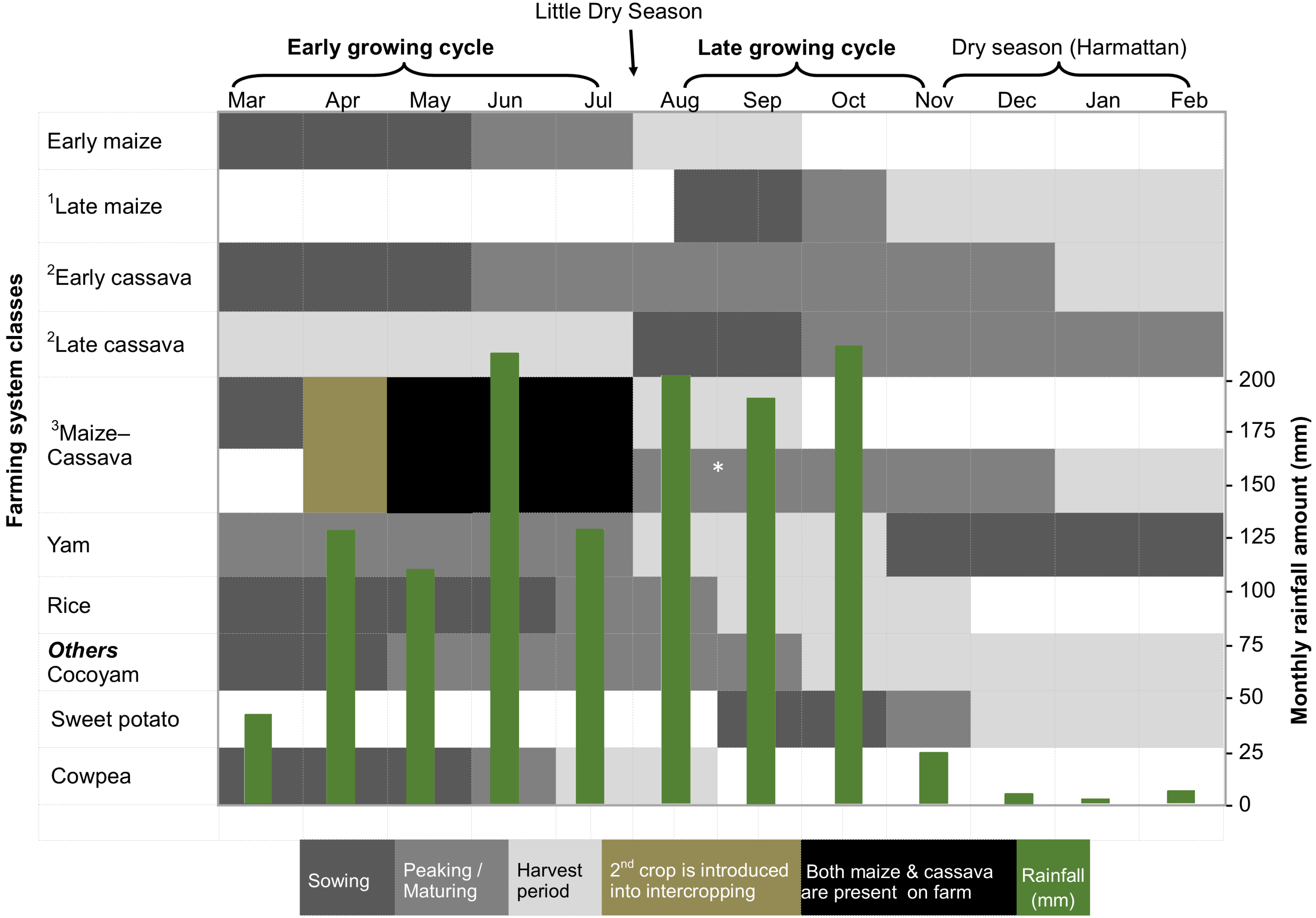
Maize farm land use classification

Maize farm land use classification from UAV data

Farm UAV Survey (17 Feb. 2026)

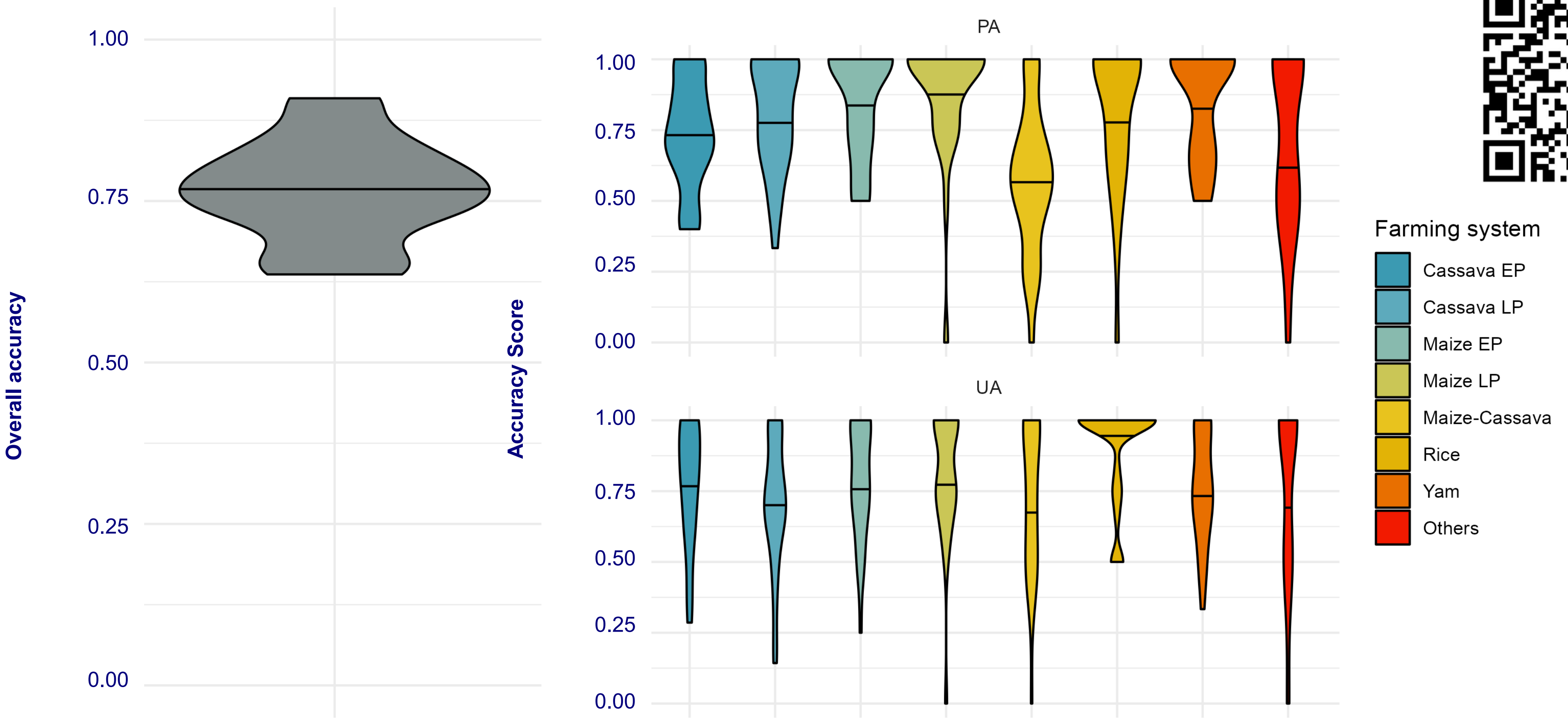


Cropping calendar and farmers' farm management practices



Akinyemi et al., 2026. Mapping crop types across multiple growing cycles in smallholder mono- and intercropping systems with multi-sensor data. Science of Remote Sensing, 100416. https://doi.org/10.1016/j.srs.2026.100416

Mapped 8 crop types with Sentinel-1 & 2 data

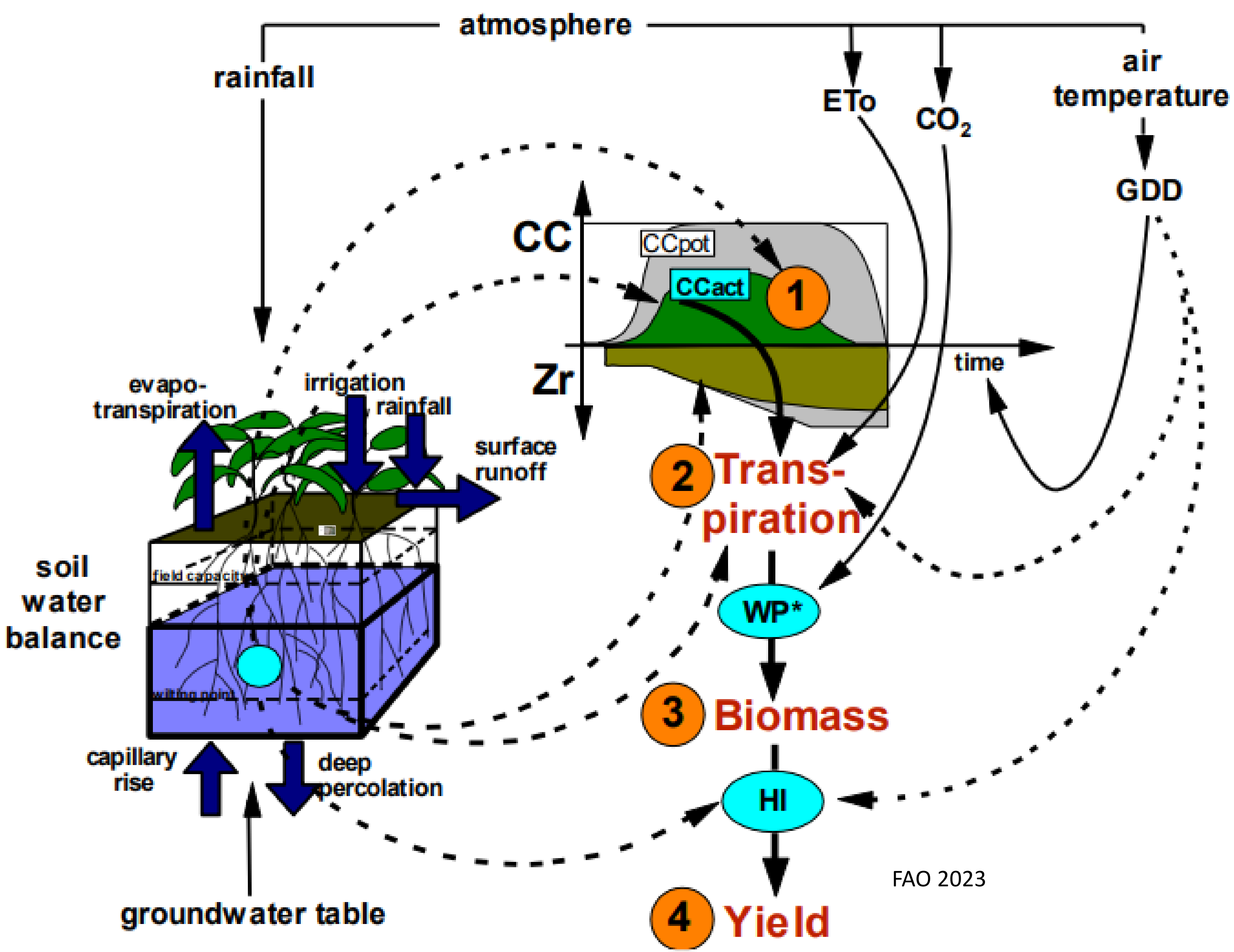


Overall accuracy (left) and class-wise PA (right, top) and UA (right, bottom). Scores derived from 30-fold cross validation. Vertical lines in violins represent median score.

Akinyemi et al., 2026. Mapping crop types across multiple growing cycles in smallholder mono- and intercropping systems with multi-sensor data. Science of Remote Sensing, 100416. https://doi.org/10.1016/j.srs.2026.100416

Modelling crop responses with AquaCrop

- Climatic variables
- Soil physico-chemical properties
- Crop properties
- **Farm management**
- Water management



FAO 2023

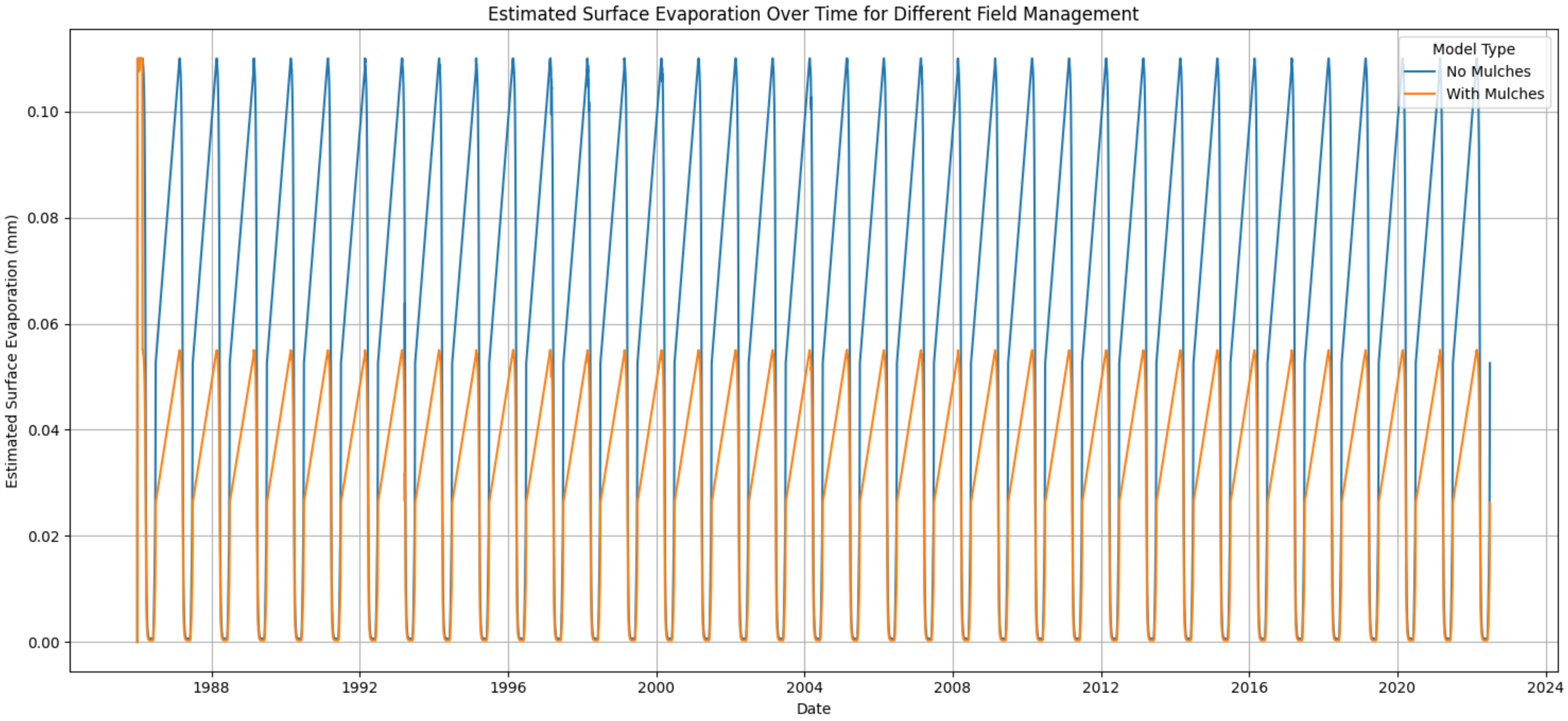
Farm management

- Model scenario with mulches and
- Model scenario without mulches

Impacts of farm management on dry yield

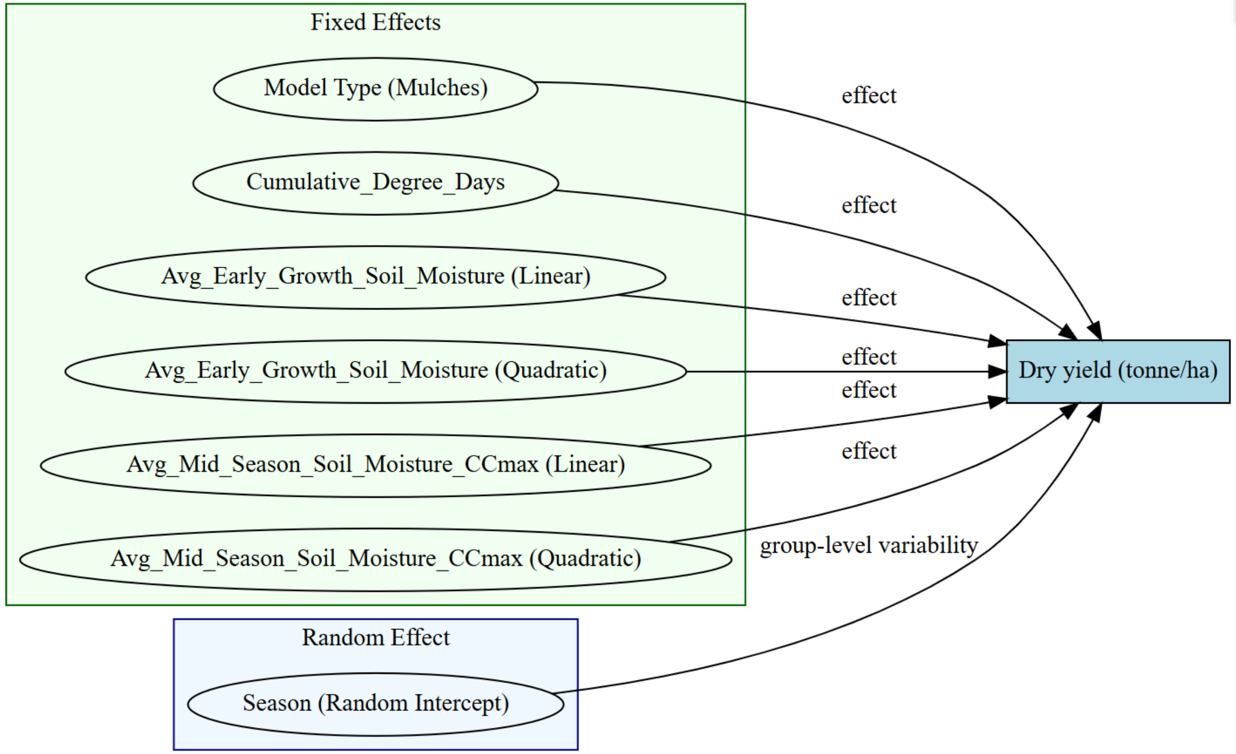
Dry yield (tonne/ha):

total biomass produced by the crop, excluding its water content, measured at the time of harvest. It represents the actual amount of dry matter (e.g., grain) harvested from a hectare of land.



Linear Mixed-Effects Model

```
RangeIndex: 74 entries, 0 to 73
Data columns (total 25 columns):
 #   Column                            Non-Null Count  Dtype
---  ------                            --------------  -----
 0   Season                            74 non-null     int64
 1   crop Type                         74 non-null     object
 2   Harvest Date (YYYY/MM/DD)         74 non-null     datetime64[ns]
 3   Harvest Date (Step)               74 non-null     int64
 4   Dry yield (tonne/ha)              74 non-null     float64
 5   Fresh yield (tonne/ha)            74 non-null     float64
 6   Yield potential (tonne/ha)        74 non-null     float64
 7   Seasonal irrigation (mm)          74 non-null     int64
 8   Model Type                        74 non-null     object
 9   Year                              74 non-null     int32
 10  Total_Precipitation               74 non-null     float64
 11  Average_MinTemp                   74 non-null     float64
 12  Average_MaxTemp                   74 non-null     float64
 13  Average_ReferenceET               74 non-null     float64
 14  Cumulative_Degree_Days            74 non-null     float64
 15  Days_Above_35C                    74 non-null     int64
 16  Days_Below_10C                    74 non-null     int64
 17  Number_of_Rainy_Days              74 non-null     int64
 18  Number_of_Dry_Days                74 non-null     int64
 19  Longest_Dry_Spell                 74 non-null     int64
 20  Soil_Moisture                     74 non-null     float64
 21  Longest_Dry_Spell_Early_Growth    74 non-null     int64
 22  Avg_Early_Growth_Soil_Moisture    74 non-null     float64
 23  Avg_Mid_Season_Soil_Moisture_CCmax 74 non-null    float64
 24  Avg_Early_Growth_ReferenceET      74 non-null     float64
```



Linear Mixed-Effects Model

- **Dry yield (tonne/ha)** as the dependent variable
- ~74 variables, e.g. climate variables - total precipitation, average temperature, ReferenceET, soil moisture at different growth stages **as fixed effects**
- Season to account for within-season/year variability as a random intercept

```
print(lme_results_nonlinear.summary())
```

```
                     Mixed Linear Model Regression Results
=====================================================================================
Model:                        MixedLM      Dependent Variable:      Q('Dry yield (tonne/ha)')
No. Observations:             72           Method:                  REML
No. Groups:                   36           Scale:                   0.0025
Min. group size:              2            Log-Likelihood:          -15.5938
Max. group size:              2            Converged:               Yes
Mean group size:              2.0
-------------------------------------------------------------------------------------
                                          Coef.  Std.Err.    z    P>|z|  [0.025  0.975]
-------------------------------------------------------------------------------------
Intercept                                 73.523   42.816  1.717 0.086 -10.395 157.441
Q('Model Type')[T.With Mulches]            0.057    0.012  4.834 0.000   0.034   0.081
Q('Cumulative_Degree_Days')                0.000    0.001  0.706 0.480  -0.001   0.002
Q('Avg_Early_Growth_Soil_Moisture')        0.019    0.012  1.543 0.123  -0.005   0.043
Q('Avg_Early_Growth_Soil_Moisture_sq')    -0.000    0.000 -1.459 0.145  -0.000   0.000
Q('Avg_Mid_Season_Soil_Moisture_CCmax')   -0.286    0.177 -1.618 0.106  -0.634   0.061
Q('Avg_Mid_Season_Soil_Moisture_CCmax_sq') 0.000    0.000  1.753 0.080  -0.000   0.001
Group Var                                  0.217    1.653
```

Irrigation scheduling is ongoing

Results of interview with farmers:

- Irrigation schedule varied according to weather conditions and heat intensity
- **Under normal weather conditions:** of irrigation in the morning – 30 minutes irrigation in the evening – 30 minutes
- **Under heat stress conditions:** irrigation in the morning – 1 hour
  irrigation in the evening – 1 hour
- Important to maintain soil moisture and reduce heat stress on crops.

- Demonstrating daily irrigation with constant water depth daily of 2.1 - 3.8mm for 3-4 times daily

Scenarios

- Rainfed IrrMethod = 0
- IrrMethod = 5 with 100% soil moisture targets (SMT) of %TAW (total available water) to maintain crops in each growth stage

Principal Farm Parameters

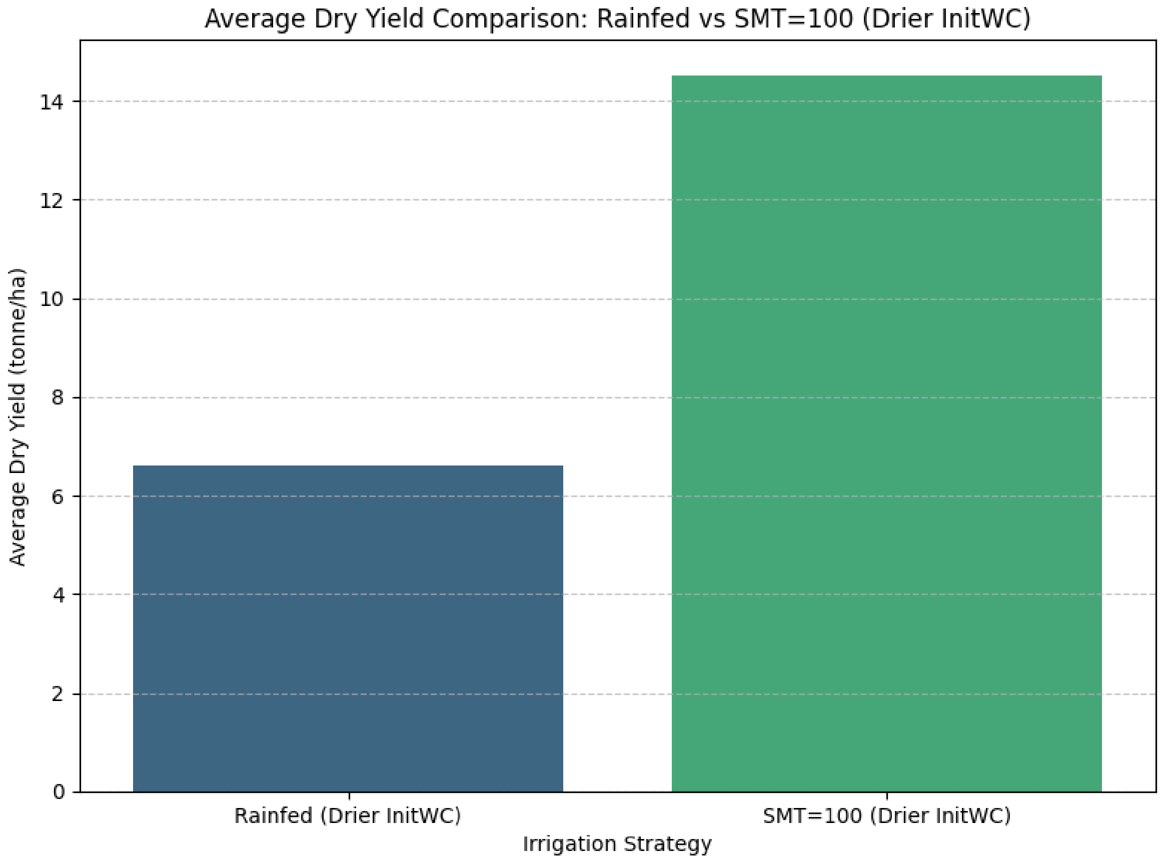
Observation Area	Key Findings
Irrigation Method	Drip irrigation with single emitters
Water Discharge	0.3 liter/hour per crop
Supply Pipe Size	2 inches
Drip Point Size	3 mm
Irrigation Frequency	3–4 times daily, depending on heat conditions
Water Source	Dam-supported irrigation
Plant Spacing	80 cm × 30 cm
Crop Maturity	70–75 days
Plant Population	16, 900 plants/acre and 25,000 plants/acre
Major Challenges	Heat stress, excess rainfall, fungal infection
Adaptation Measures	Drip irrigation, heat-tolerant seeds, irrigation sch
Seasonal Yield	1.5 tons (wet season), 800 kg (dry season)

Scenarios

We set the initial soil water to a lower percentage of Total Available Water (TAW). For example, for Farm 1 (Abeokuta) and Farm 3 (Apata), we compared rainfed and a daily n irrigated simulation.

Strategy	Average Dry Yield (tonne/ha)	Total Seasonal Irrigation (mm)
Rainfed (Drier InitWC)	6.616725	0.000000
SMT=100 (Drier InitWC)	14.509829	3693.993353

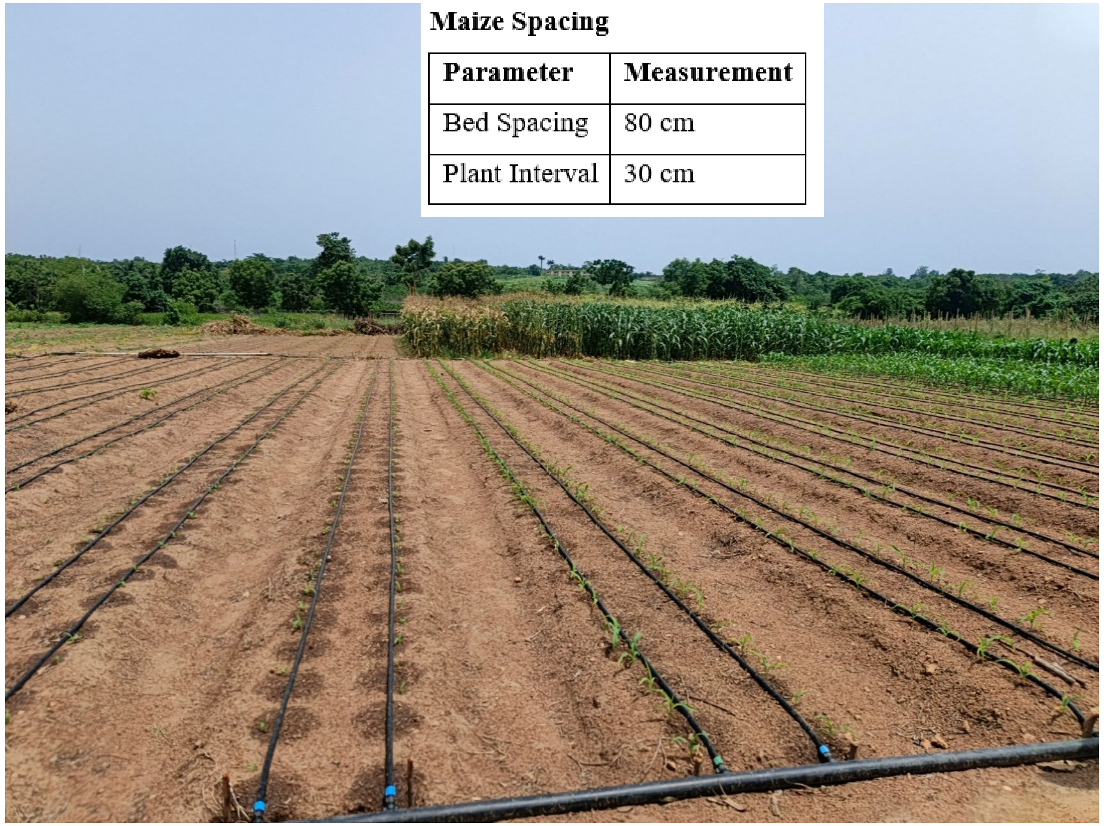
Strategy	Average Dry Yield (tonne/ha)	Total Seasonal Irrigation (mm)
Rainfed (Drier InitWC)	5.971824	0.000000
SMT=100 (Drier InitWC)	14.509830	3689.302148



Farm A demonstrates how changing the initial soil water content can lead to differentiated yields.

Crop production and planting arrangement

- Approximately 4,800 seedlings/seeds were planted.
- Maturity period ranged from 70–75 days. The crops were planted in rows with organized spacing patterns.
- Drip tapes were carefully aligned along planting rows to ensure effective water delivery.



Maize Spacing

Parameter	Measurement
Bed Spacing	80 cm
Plant Interval	30 cm

Estimated maize density & irrigation water use

- The following estimates were derived using the observed drip irrigation configuration, planting geometry, irrigation scheduling
- Water application rate: 0.3 liters every 20 minutes per plant/emitter
- Crop maturity period (70–75 days)

Comparative Summary

Parameter	Farm A	Farm B
Plant population	~16,900 plants	25,000 plants
Water/day (3 cycles)	15,210 L	22,500 L
Water/day (4 cycles)	20,280 L	30,000 L
Seasonal demand (3 cycles)	1.14 million L	1.69 million L
Seasonal demand (4 cycles)	1.52 million L	2.25 million L
Annual demand (3 cycles)	2.28 million L	3.38 million L
Annual demand (4 cycles)	3.04 million L	4.50 million L
Wet season yield	1.3–1.5 tons	~1.5 tons
Dry season yield	0.7–1.0 tons	0.8–1.1 tons

Irrigation Demand and Yield

Comparative Summary

Parameter	Farm A	Farm B
Plant population	~16,900 plants	25,000 plants
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Annual demand (4 cycles)	3.04 million L	4.50 million L
Wet season yield	1.3–1.5 tons	~1.5 tons
Dry season yield	0.7–1.0 tons	0.8–1.1 tons

Mature maize plants (45-55 days) in Farm A, Abeokuta

Current Status

Work Completed

- ✓Site selection and reconnaissance
- ✓Stakeholder engagement activities conducted
- ✓ Hydrogeomorphological analysis
- ✓Field and geospatial mapping
- ✓Basin land use and land cover analysis
- ✓Acquisition of soil & field management parameters
- ✓Initial SWAT and HEC model setup and preprocessing completed
- ✓Dry yield simulation of Maize in AquaCrop is completed

Ongoing Activities

SWAT Water Balance Model Calibration

- Calibration of the SWAT hydrological water balance model is currently pending

HEC Model Calibration and Validation

- HEC model parameter calibration and performance validation remain outstanding

Hydrological Data Acquisition

- Awaiting **river discharge data** from the Ogun–Osun River Basin Development Authority (OORBDA) to support:
  - SWAT calibration and validation
  - HEC hydraulic simulations
  - Flow routing and water balance assessment
  - Improved model accuracy and reliability.
- Irrigation Scheduling and still awaiting maize crop yield data needed for calibration

Capacity Building Component

Component	Activity	Output
Stakeholder Engagement	Workshop for farmers, extension officers, and basin managers on irrigation use	Improved stakeholder awareness and enhance support capacity
Research Training	Training for early-career researchers and postgraduate students	Enhanced technical and analytical skills
Open Access Tools and Codes	Adoption and use of EO tools, Python scripts, and training modules	Shared lab-ready codes and learning resources through repositories

References

- World Food Programme, 2026. Accessed 24.05.2026 https://www.wfp.org/countries/nigeria#
- FAO 2023 https://openknowledge.fao.org/server/api/core/bitstreams/86803695-ff90-4f6c-bbce-4dd24389ed66/content

Institutional Collaboration (MOU) with NASRDA
(Through the Centre for Life Space Science)

- Strengthened institutional collaboration
- Enhanced geospatial and EO capacity
- Improved research and academic integration
- Increased stakeholder engagement and technical expertise

RIverWISE NG_SE EOAC4

The RiverWISE team would like to thank ESA, EO AFRICA R&D Facility with the African Union Commission (AUC) for funding and support

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