IWMI

AI driven Digital Twin for Water Management for Limpopo River Basin and Inclusive Integration with Citizen Science

Gaborone, Botswana
9–11 June 2025

Online Agenda

bit.ly/4jVtXgR

Republic of Botswana

LIMCOM
Limpopo Watercourse Commission

DIWASA

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Digital Earth Africa

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What is the Limpopo Digital Twin?

A cloud-based water management platform built on TerriaJS that creates a living, breathing digital replica of the Limpopo River Basin

Core Platform Features

- 3D globe visualization with time-series animation
- Interactive chart pop-ups for any location
- Custom feature templates for data exploration
- Polygon drawing tools for spatial analysis
- Multi-layer overlay with transparency control

Built-in Analytics

- WPS (Web Processing Service) for on-demand calculations
- CSV data export for any point or polygon

TerriaJS Foundation

3D Cesium Engine
Globe-based visualization

Time Dimension
Historical playback

WMS/WFS Support
Standard OGC services

JSON Configuration
Easy customization

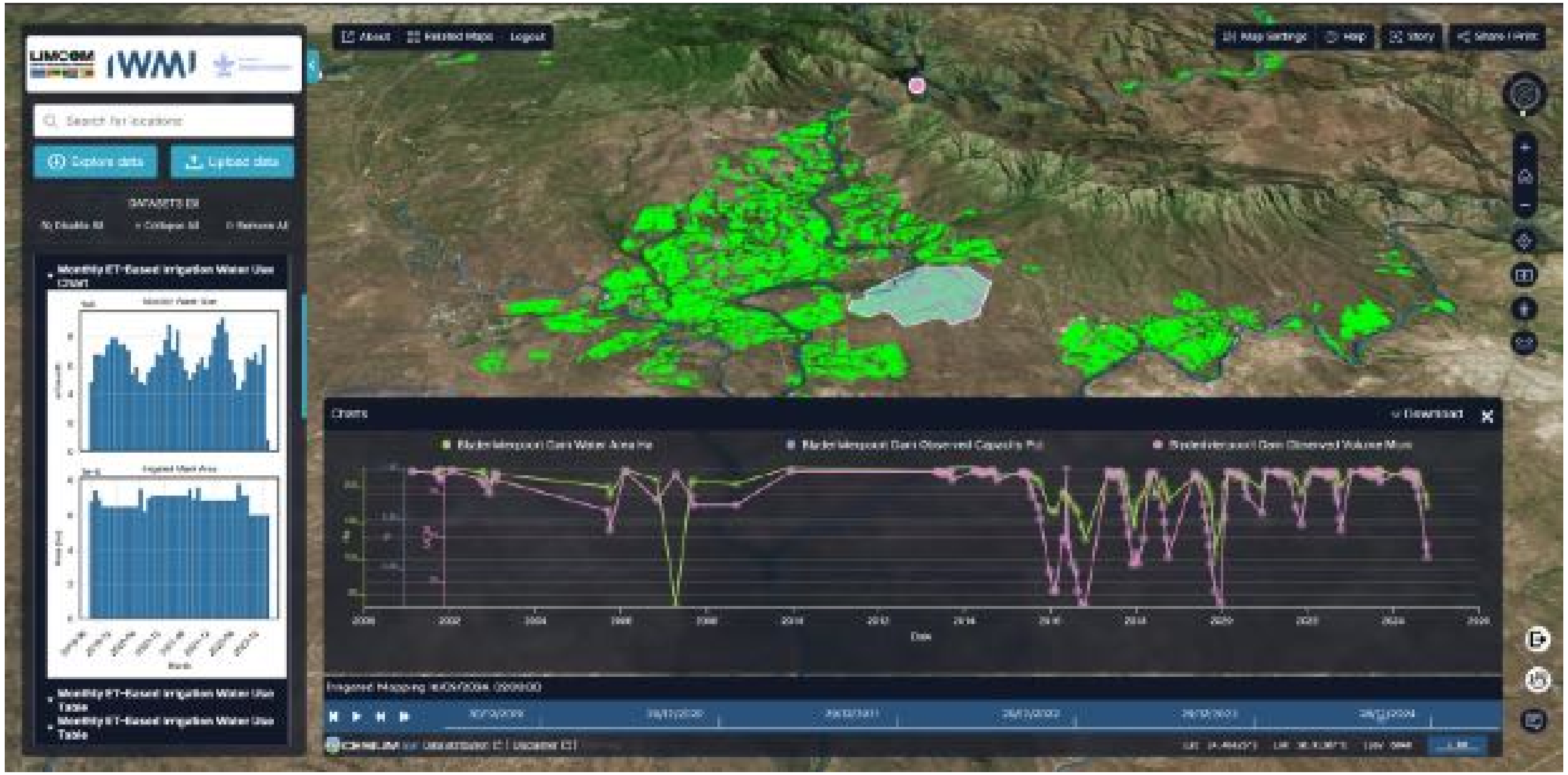
Data Integration Hub

Seamlessly combines multiple data streams:

- Satellite Imagery
- IoT Sensors
- Forecasts
- Model Outputs
- Field Data

"From raw data to actionable insights in a single, unified interface"

What does the Limpopo Digital Twin look like?



Key Interface Elements

Interactive 3D Globe
Pan, zoom, tilt to explore the entire basin from any angle

Layer Control Panel
Toggle 100+ data layers with transparency control

Time Slider
Navigate through historical data or view forecasts

Pop-up Charts
Click any feature for instant data visualization

Multiple Views for Different Needs

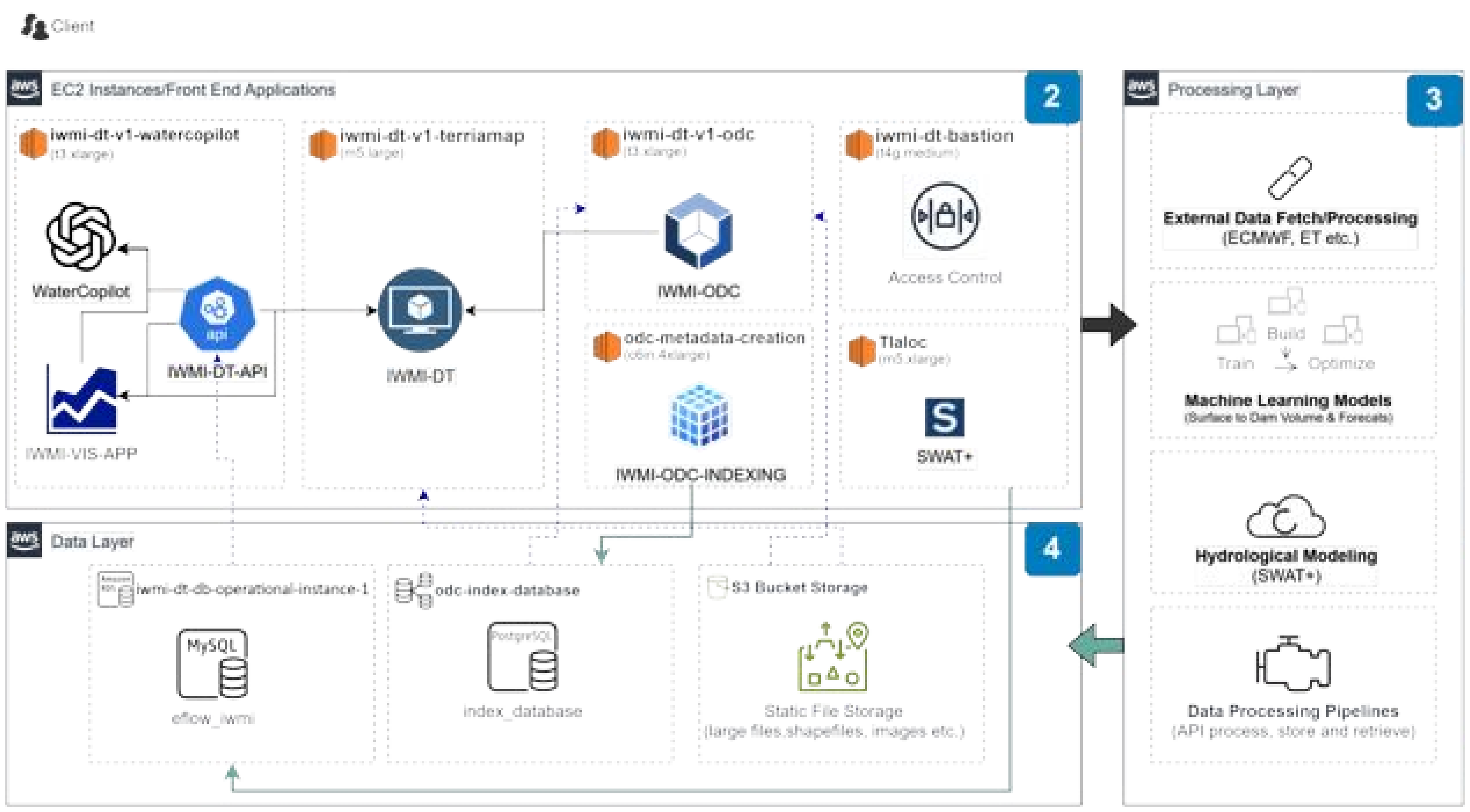
Basin Overview
Full catchment view

Data Analytics
Charts & time-series

Alerts
Real-time monitoring

Site Details
Location-specific data

How does it work?



1 The **LIMCOM Digital Twin Architecture** integrates front-end applications, data management, and advanced processing layers to support hydrological modeling and decision-making. The system is built on AWS infrastructure, ensuring scalability and reliability for environmental data analysis.

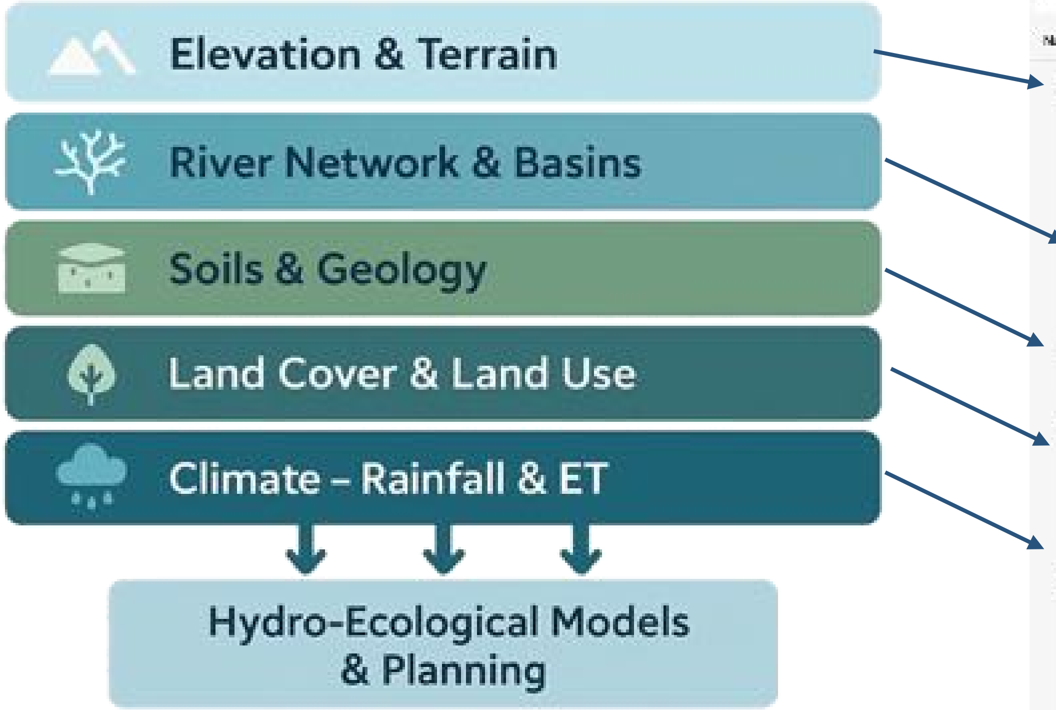
2 The **Front-End Applications & EC2 Instances** host various tools for data interaction and visualization. The **WaterCopilot** application connects to the **IWMI-DT API** for real-time data retrieval, while **TerriaMap** provides geospatial visualization. The **IWMI Open Data Cube (ODC)** facilitates large-scale environmental data analysis, and a secure **bastion host** ensures controlled access to system resources.

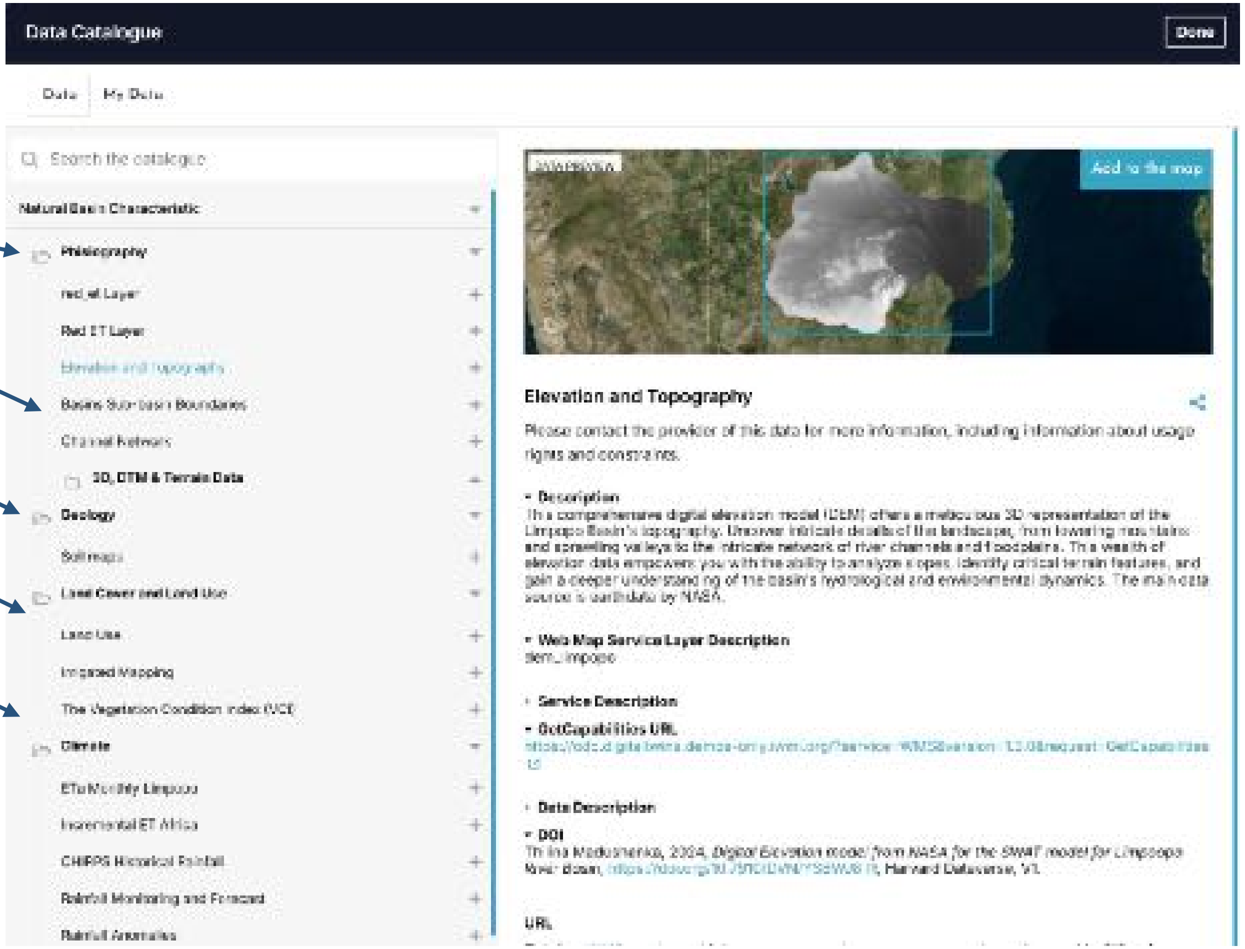
3 The **Processing Layer** is responsible for data-driven analysis and decision support. It includes **external data processing** from ECMWF and evapotranspiration models, **machine learning models** for predicting surface-to-dam volume relationships, and **hydrological modeling (SWAT+)** for simulating water distribution and quality. Additionally, **data processing pipelines** automate API interactions, ensuring seamless data flow and integration.

4 The **Data Layer** consists of a structured MySQL database (**eflow_iwmi**) for environmental flow data, a PostgreSQL database (**index_database**) supporting **ODC indexing**, and an **S3 bucket** for storing large datasets such as satellite imagery and hydrological model outputs. This layer enables efficient storage, retrieval, and management of spatial and temporal data.

Know the Landscape

Natural Basin Characteristics





Climate Signals in Real Time

Climate Hazards Center UC SANTA BARBARA

IHE DELFT Institute for Water Education

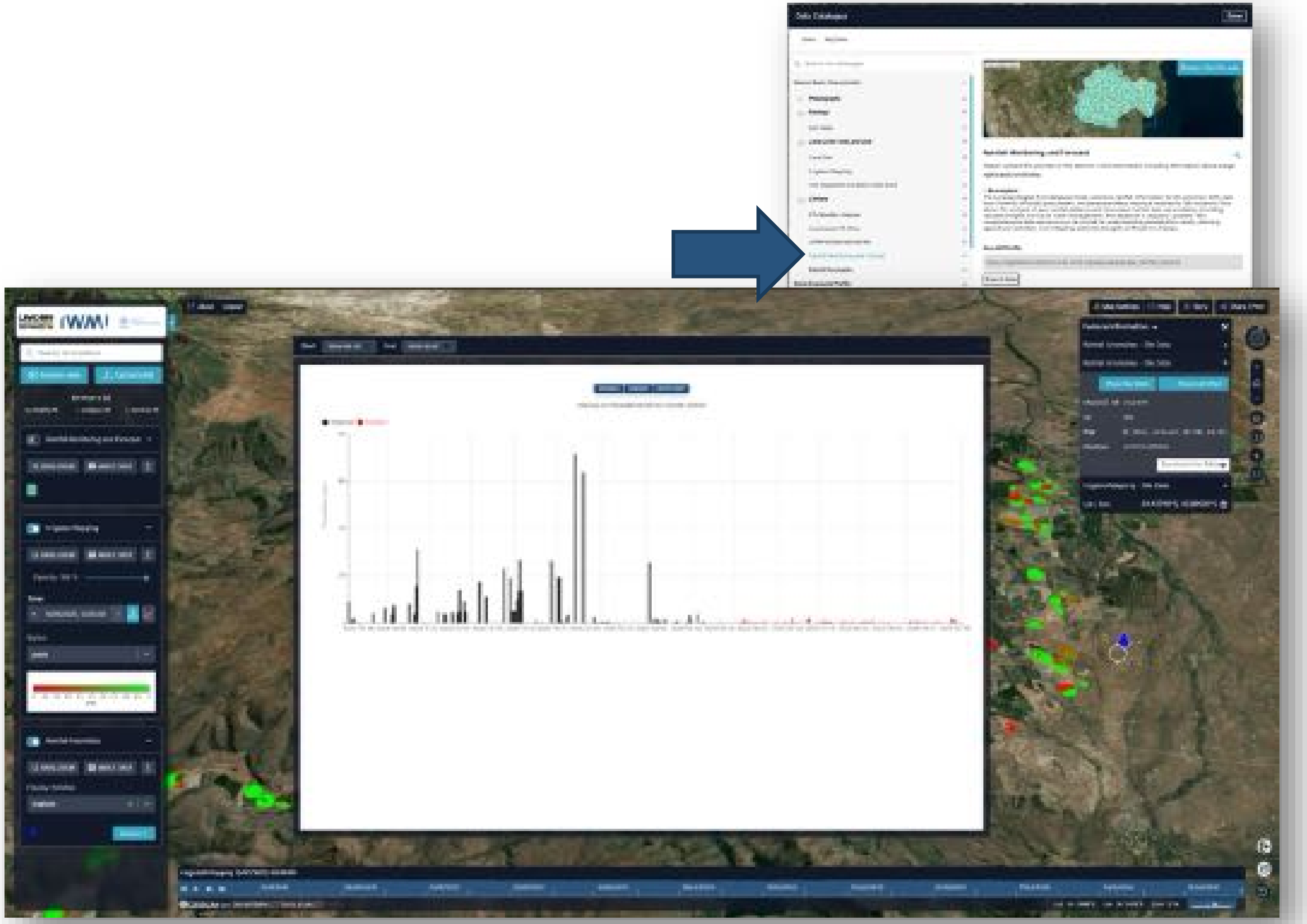
IWMI International Water Management Institute

Rainfall Observations

ETa Anomalies

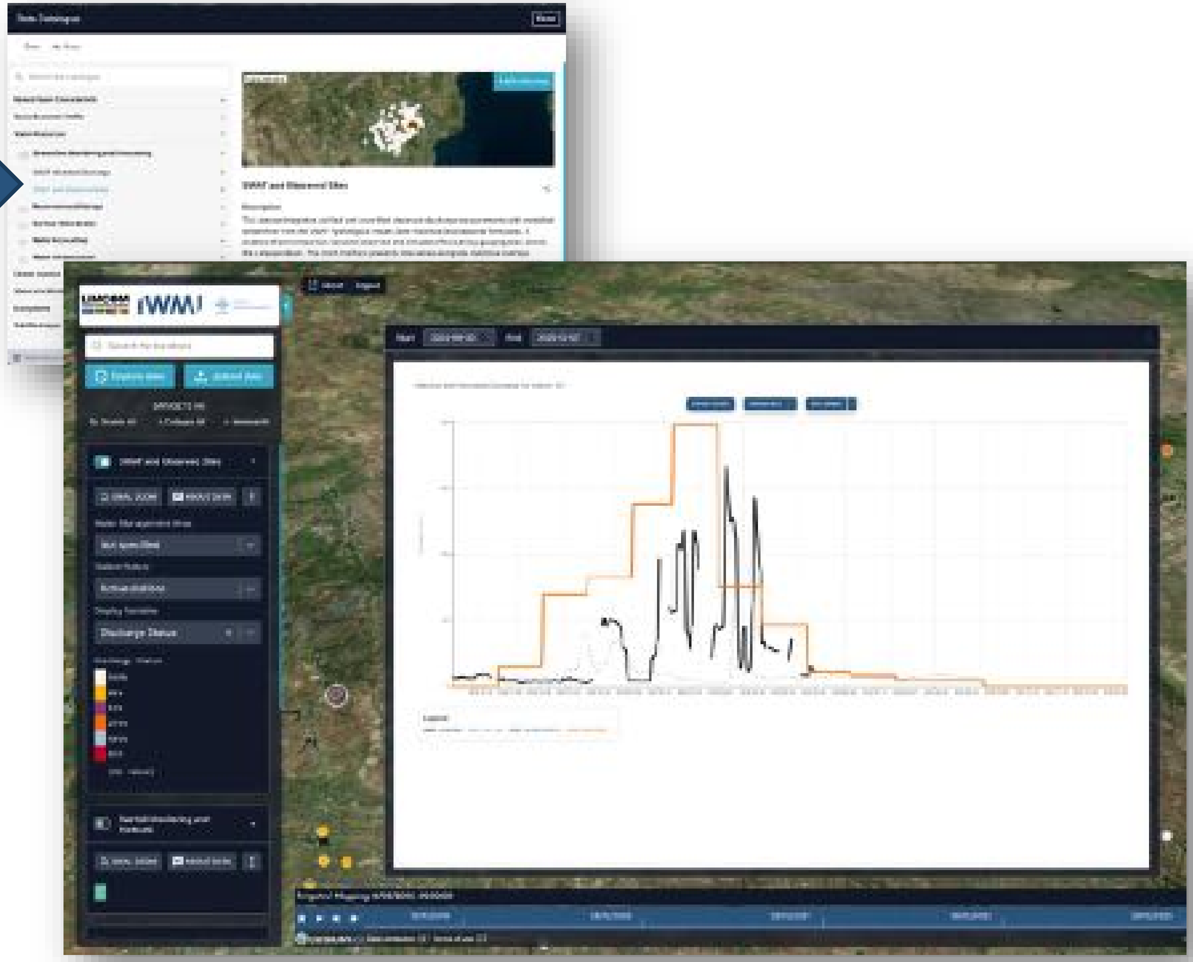
Forecasts

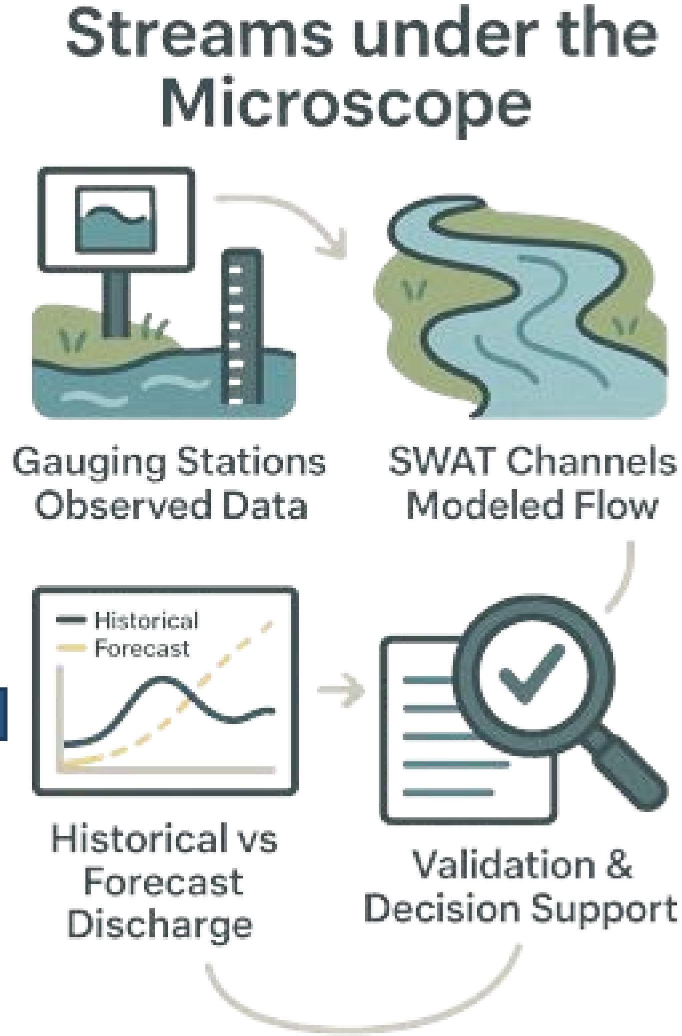
Early Warning



Observed vs Modelled Discharge

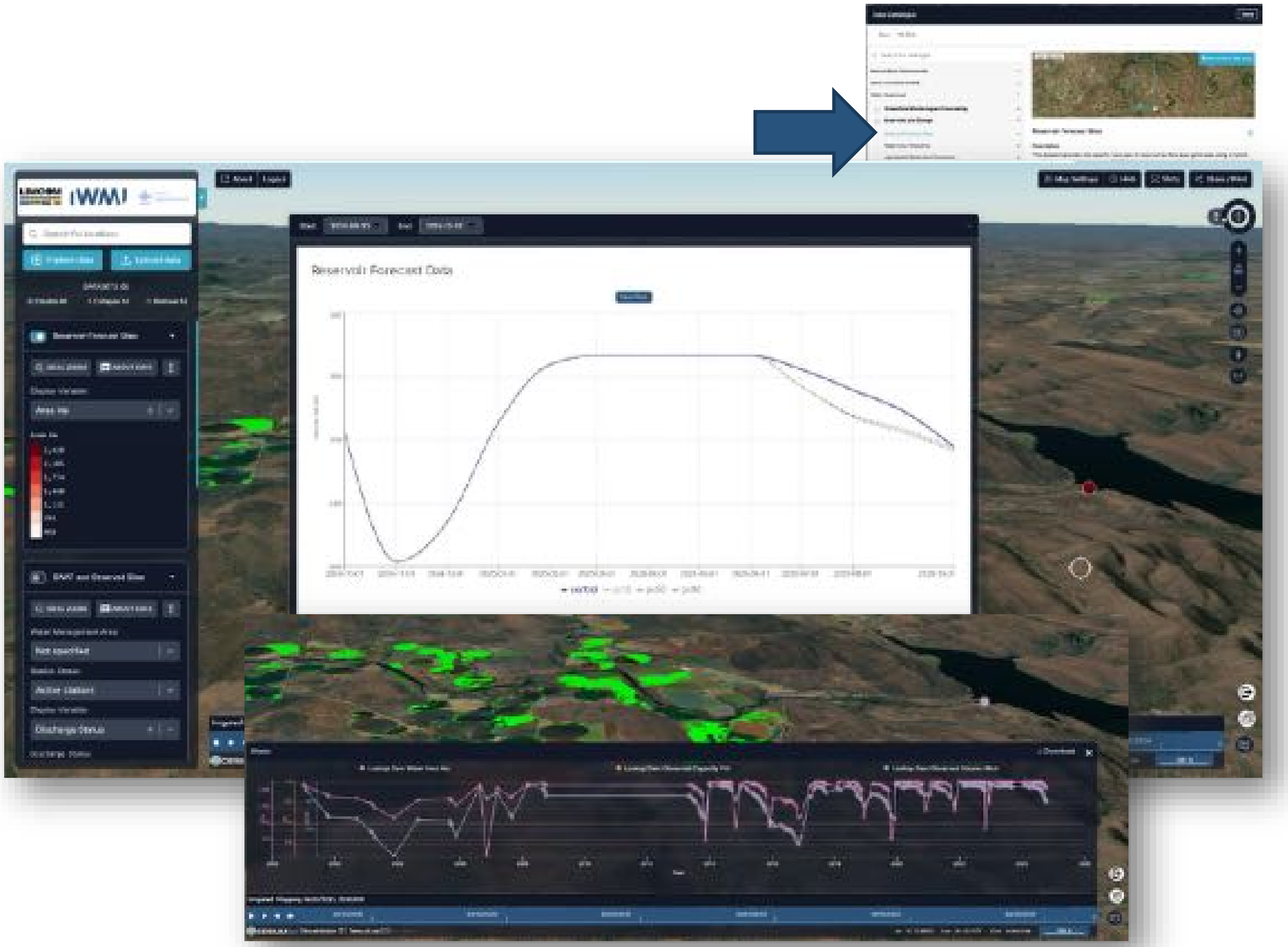
SWAT+
SOIL & WATER ASSESSMENT TOOL



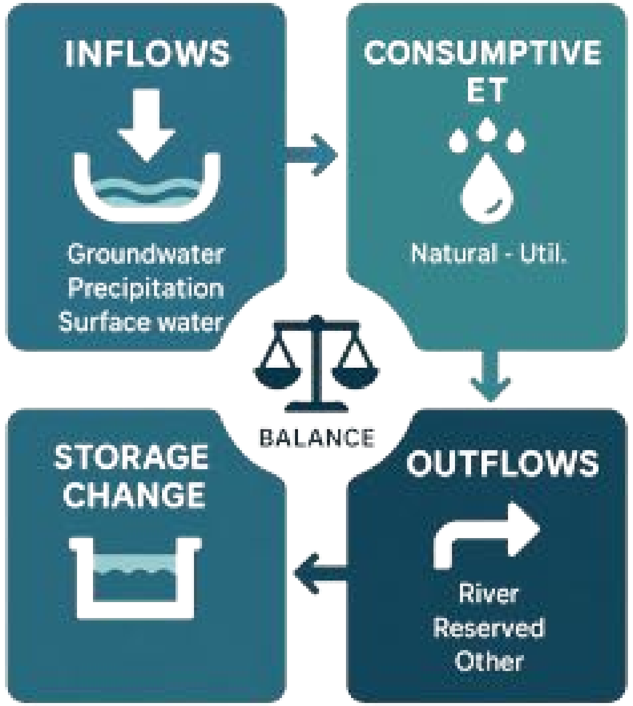


Reservoir Storage & Outlook

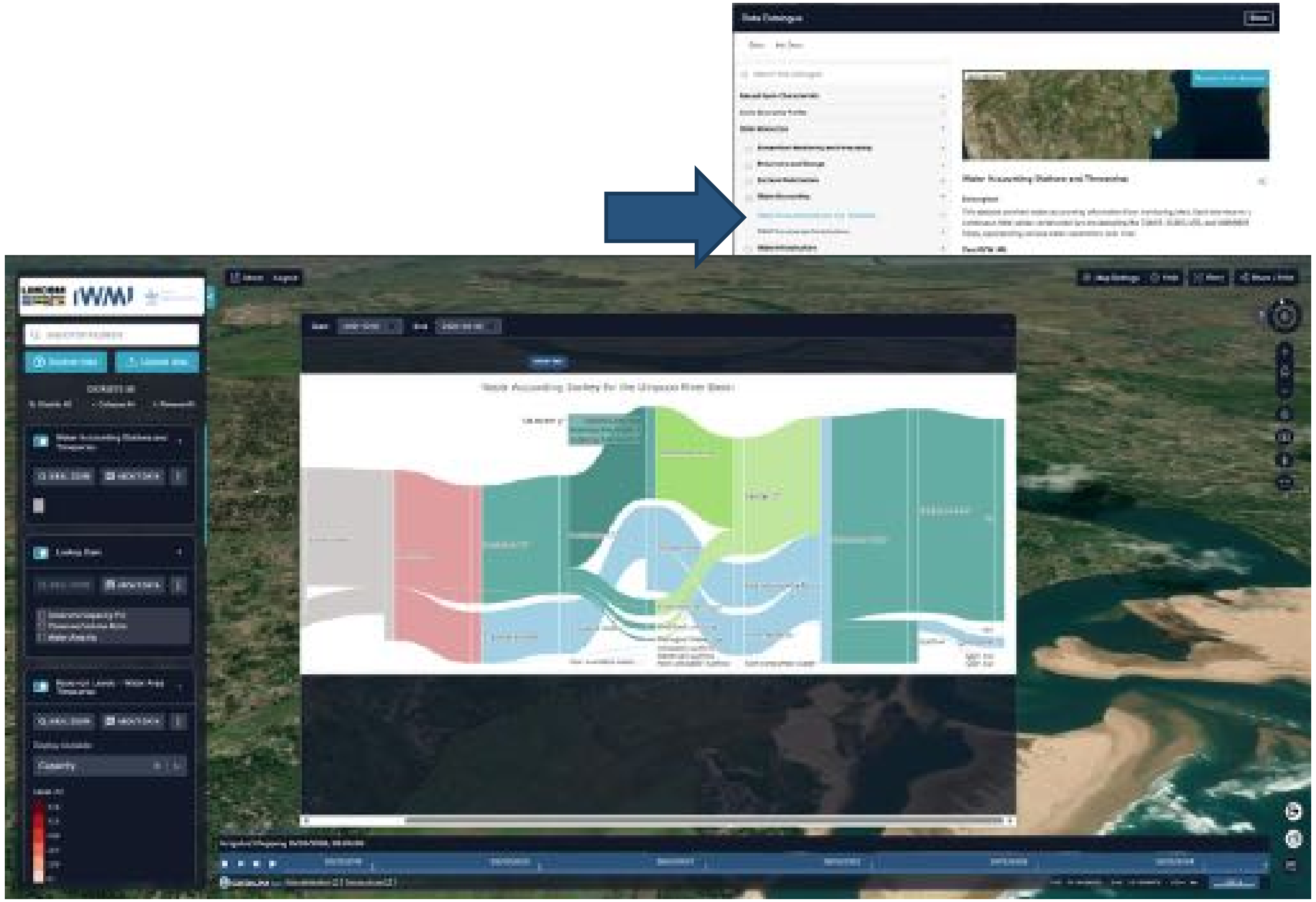
water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA



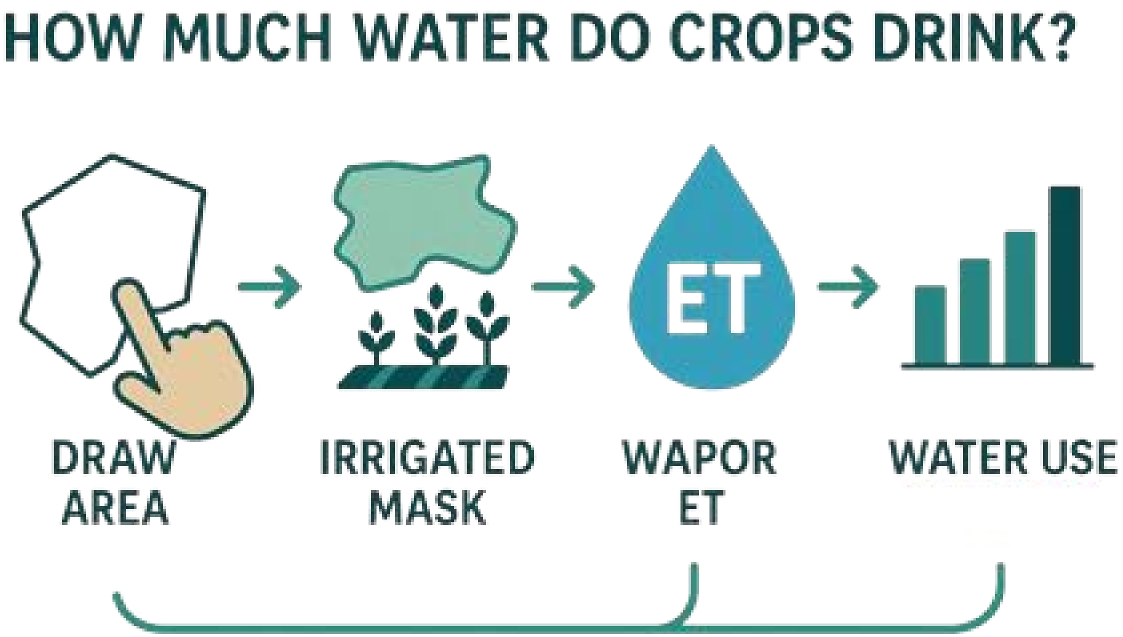
Basin Water Accounting

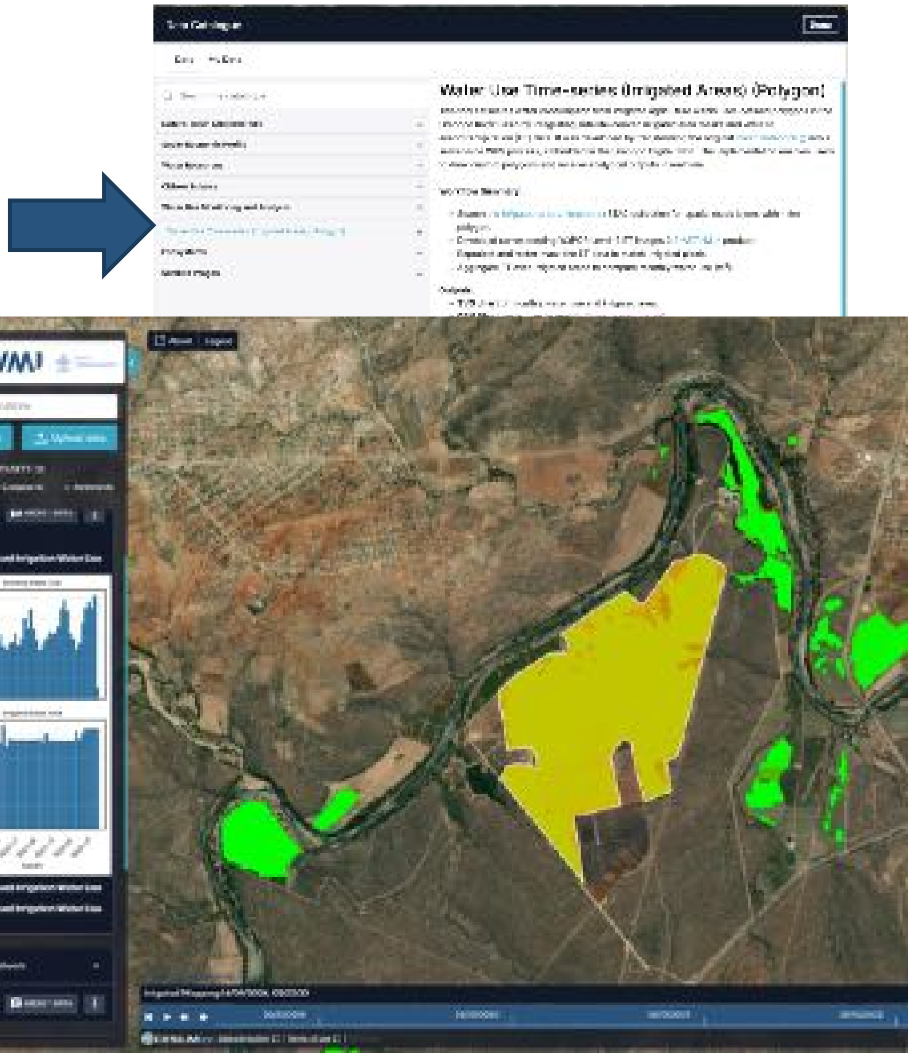


30+ standard categories

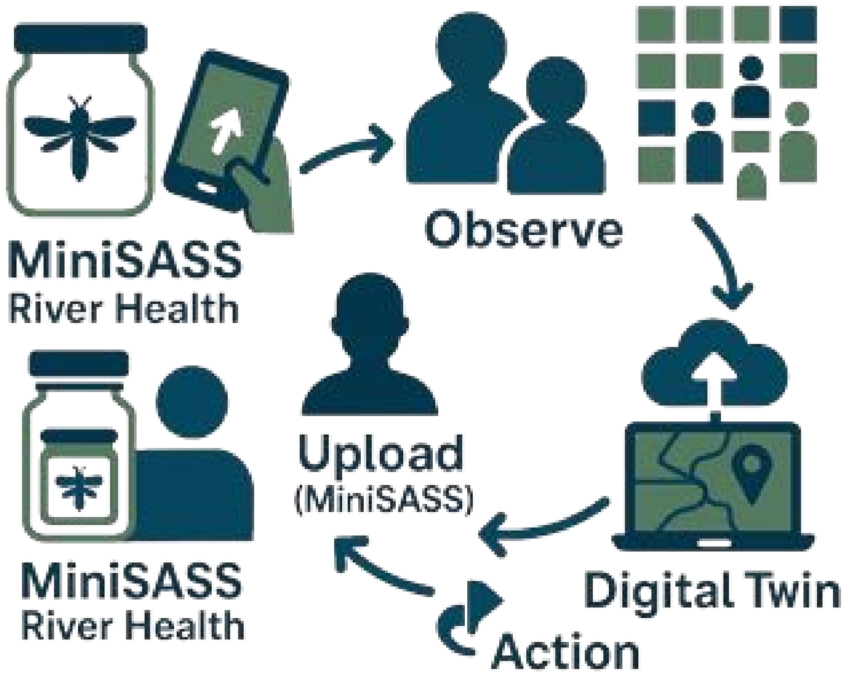


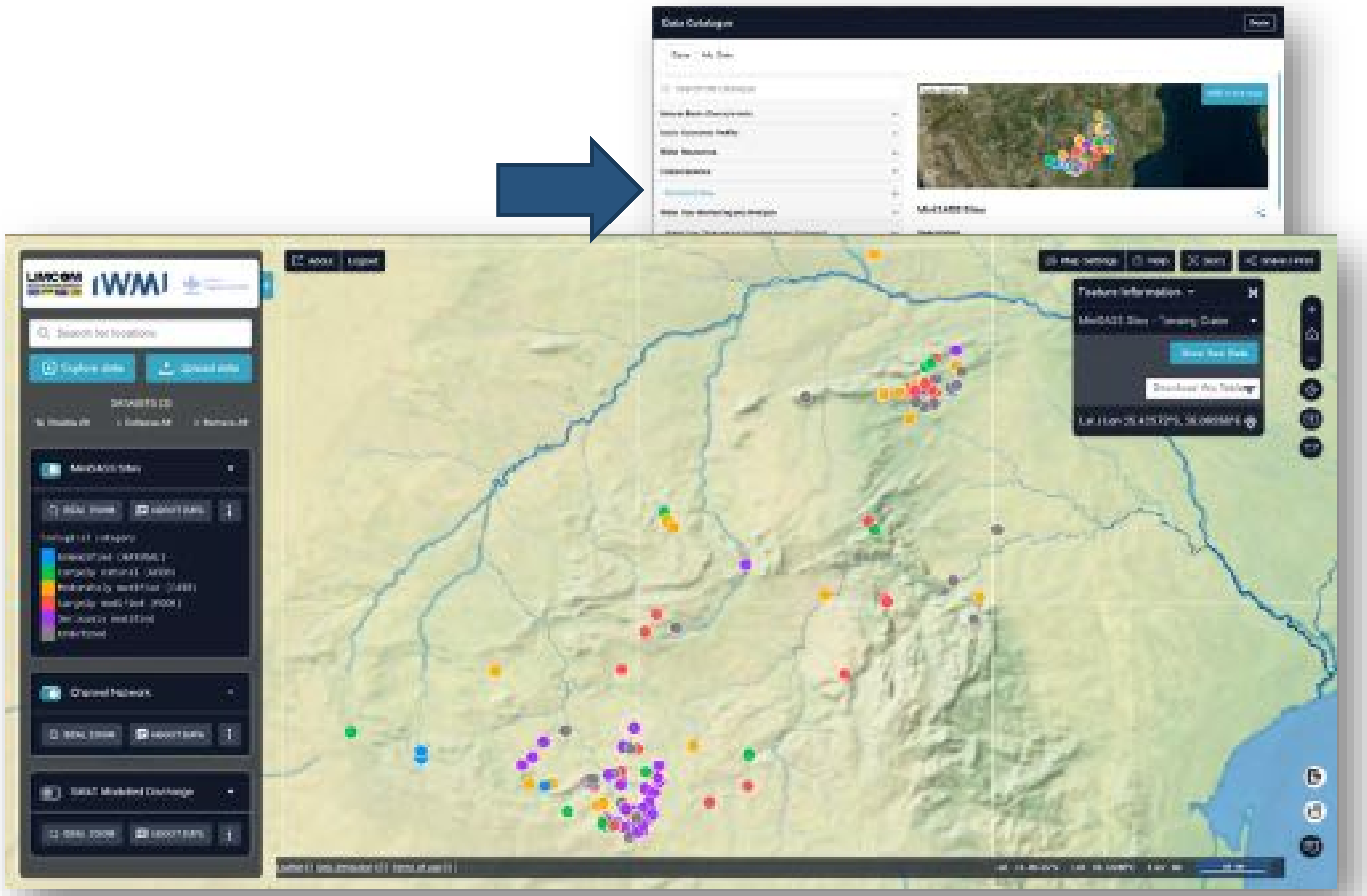
On-Demand Irrigation Water-Use Tool



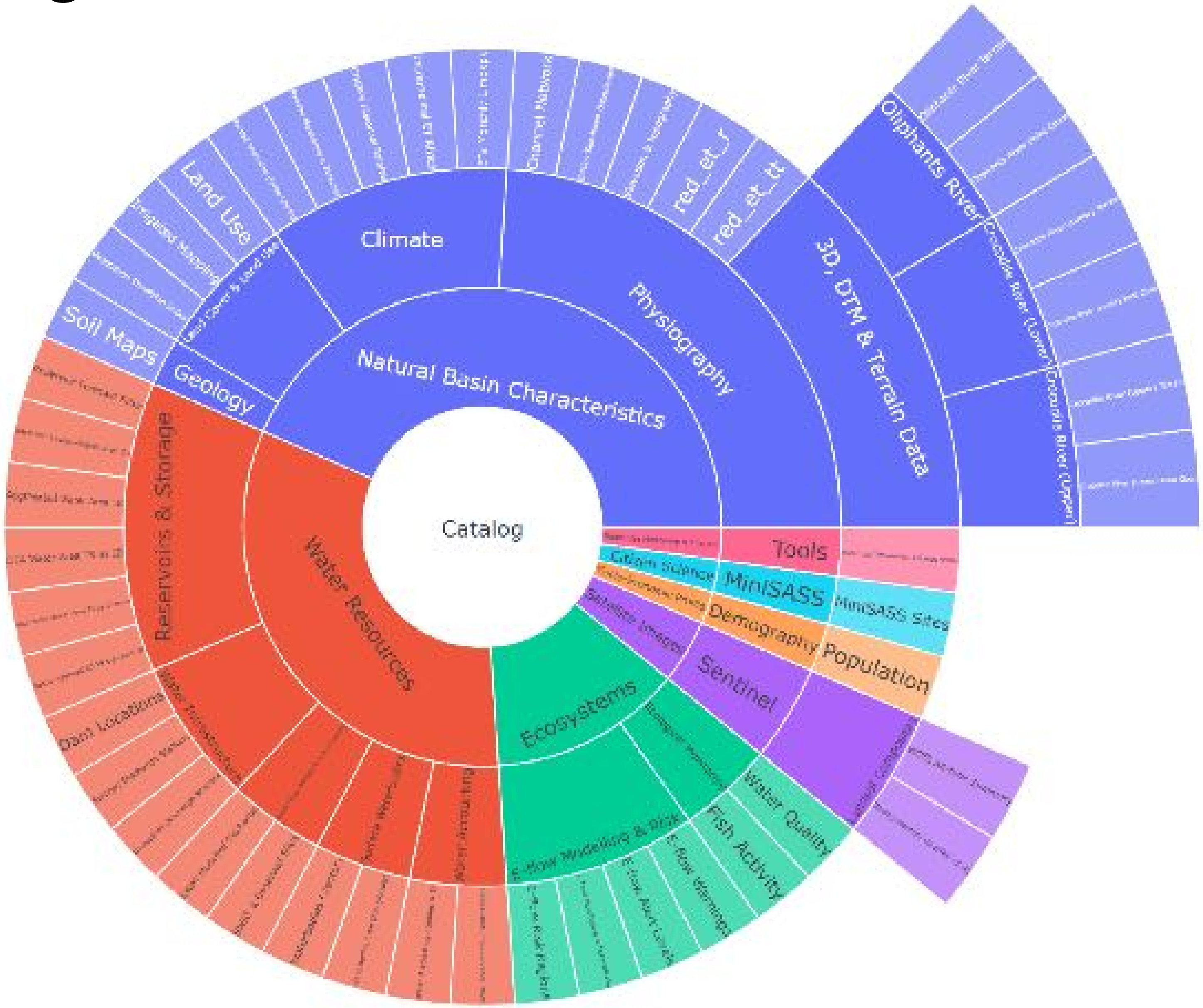


Citizen Science Matters





An ever growing catalog!

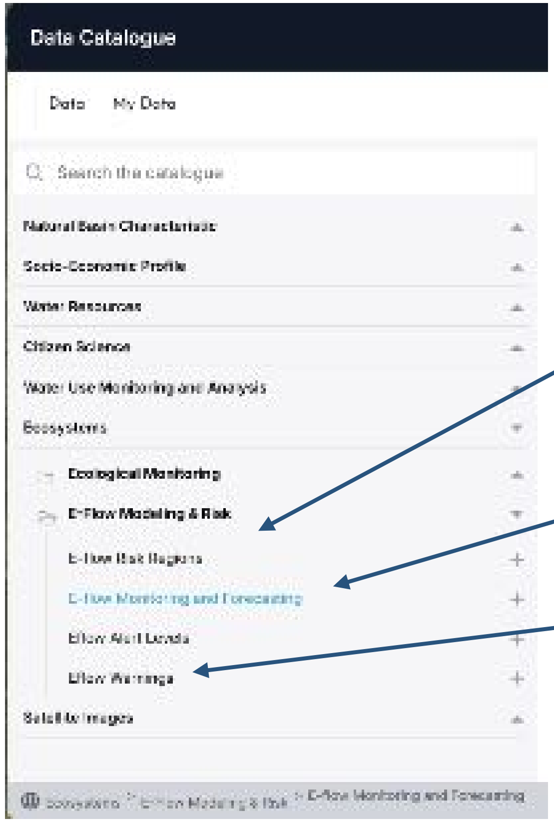


Quick demo of various features and functionalities

Let's get hands on with some case studies!

Use Case 1: Environmental-Flow Compliance and water availability

Use the Digital Twin to check whether present flows meet required e-flow targets at any one of the basins e-flow sites, in addition summarise the eflow alerts for the current hydrological year (2024-10-01 to today) across the basin.



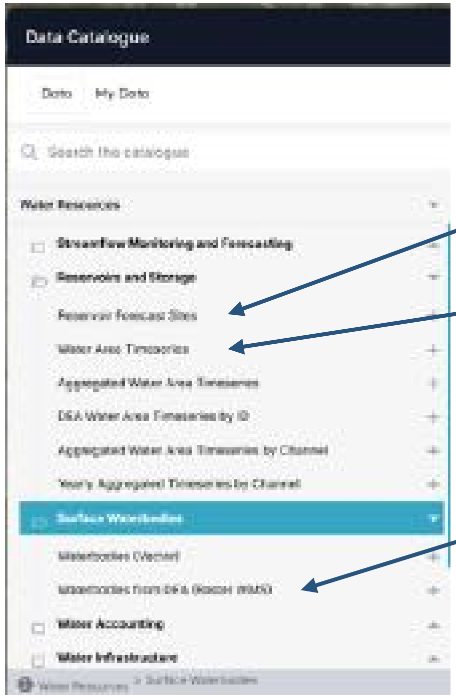
Maps areas of ecological and socio-economic risk related to insufficient environmental flows (e-flows)

Natural flow, present flow, and required e-flow

Alert levels for environmental flows (e-flows)

Use Case 2 – Dams, Lakes and Surface Water Body Monitoring

Using the Digital Twin platform, analyze the surface water extent changes for Massingir Dam over the past 6 months. What are the rainfall projections for coming months? What do the rainfall Anomalies tell us for the current year in relation to last year?



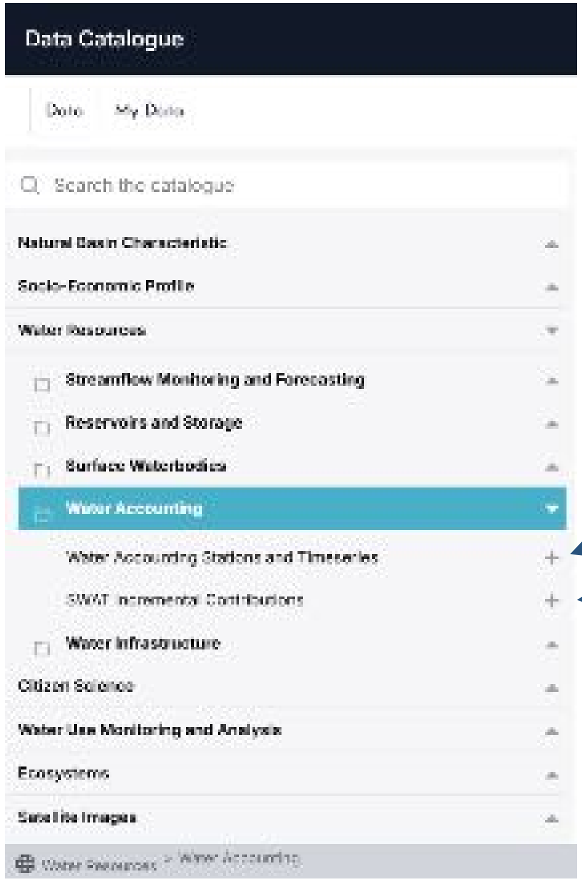
SWAT hydrological outputs with machine learning techniques

Detailed monthly time-series of surface water area

Maps persistent and seasonal water bodies and the change in their water surface area over time

Water Accounting

Using the Digital Twin platform, explore the water accounting framework implemented for the Limpopo Basin. Document the water accounting components and identify the areas of the basin that have the greatest negative balance (hint look at the incremental contributions).



Provides water accounting information for the basin

Simulated incremental contributions per channel

Case study: Irrigated area mapping

- --> Introduction
- --> Study area
- --> Method for mapping irrigated agriculture
- --> Results and discussion
- --> Model operationalization
- --> Output dissemination and next steps
- --> Hands-on demo

Introduction

→The Limpopo River Basin (LRB) is considered as one of the **largest transboundary river** basins and water scarce regions in the Southern Africa.

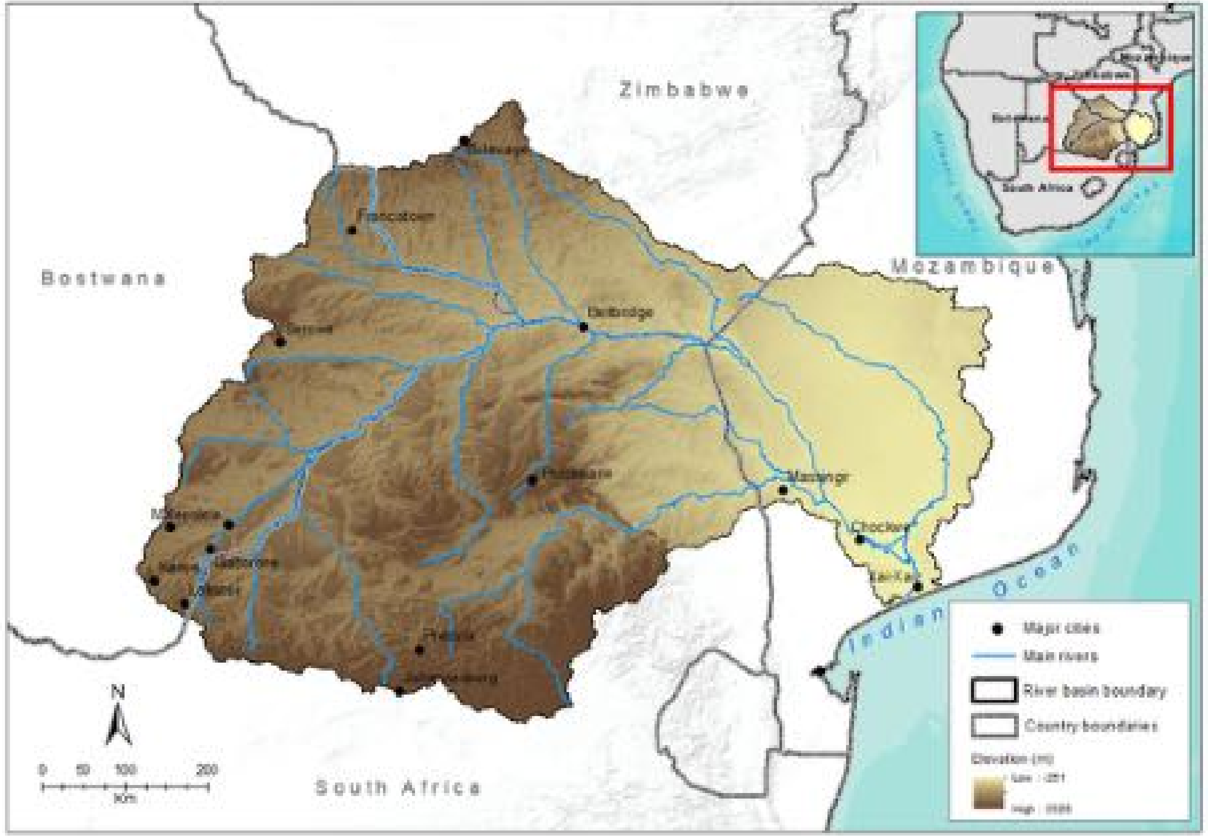
→Most of the **Limpopo River sub-basins** are currently in deficit and are classified as "**very stressed**".

→Strategies for distributing water resources in a sustainable way among all the stakeholders are therefore paramount within the basin.

→Most of the studies map irrigated areas on an annually basis, **failing to capture fine dynamic changes in irrigated land**.

→Aim of study: a) monitor monthly irrigated areas in the LRB as a part of the river basin Digital Twin (DT); b) estimate water use for irrigated area from 2019 to 2024.

Study area



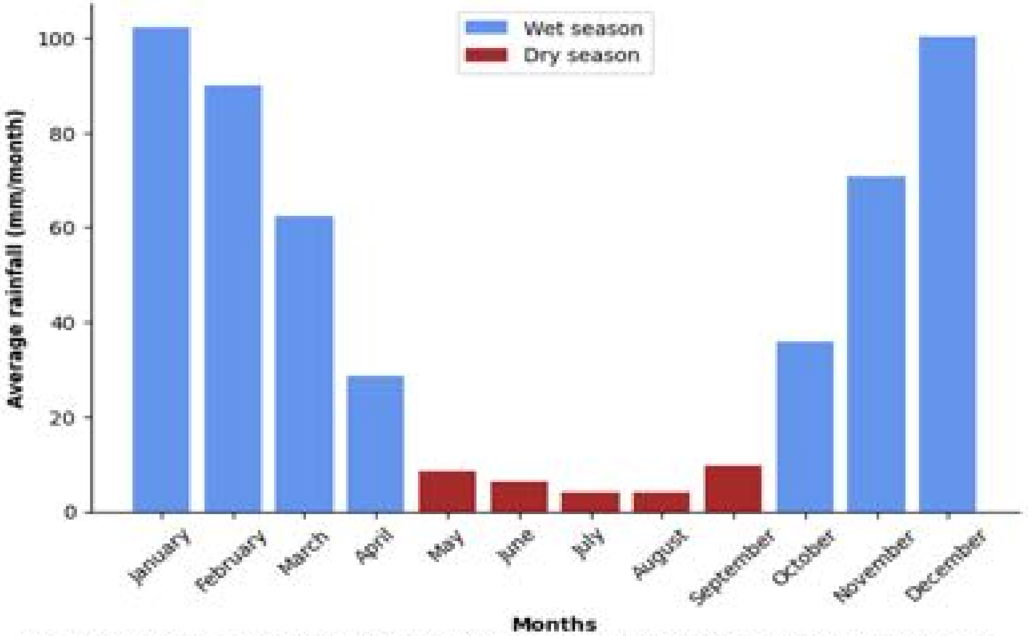


Figure 2 Mean monthly average rainfall in the Limpopo River Basin from 1981 to 2024 derived from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)

- **18 million** people depend on the agriculture sector.
- The climatic conditions: **arid to semi-arid**. **Sub-humid** climate the central part.

Method for mapping irrigated agriculture

Sentinel-2 Imagery (key characteristics)

1. Spatial Resolutions

10 m: Bands B2 (Blue), B3 (Green), B4 (Red), B8 (Near-Infrared)

20 m: Bands B5, B6, B7 (Red Edge), B8A (Narrow NIR), B11, B12 (SWIR)

60 m: Bands B1 (Aerosols), B9 (Water Vapor), B10 (Cirrus, used for atmospheric correction)

2. Spectral bands

13 bands covering visible, near-infrared (NIR), and short-wave infrared (SWIR) wavelengths, optimized for land monitoring, vegetation, and coastal applications.

3. Temporal Resolution: 5-day revisit time at the equator with two satellites (Sentinel-2A and 2B) operating in tandem.

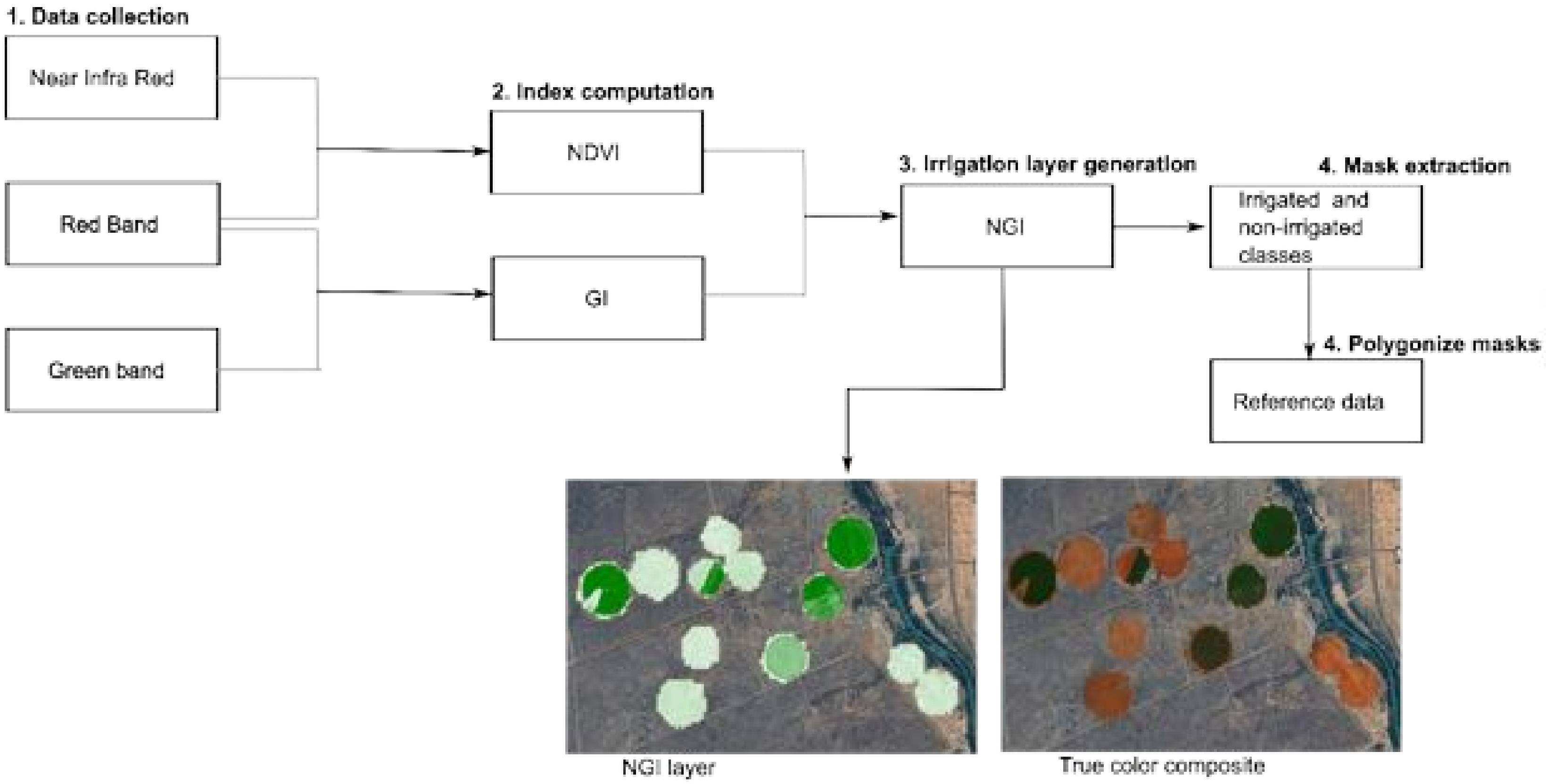
4. **Swath Width**: 290 km, enabling wide-area coverage.

5. Data Format: Multispectral imagery delivered in Level-1C (top-of-atmosphere reflectance) and Level-2A (bottom-of-atmosphere reflectance, atmospherically corrected).

6. Applications: Land use/land cover monitoring, agriculture, forestry, disaster management, water quality assessment and environmental studies.

7. Data Access: Freely available via the Copernicus Open Access Hub or other platforms like Google Earth Engine, AWS Open Data Registry

Method for mapping irrigated agriculture



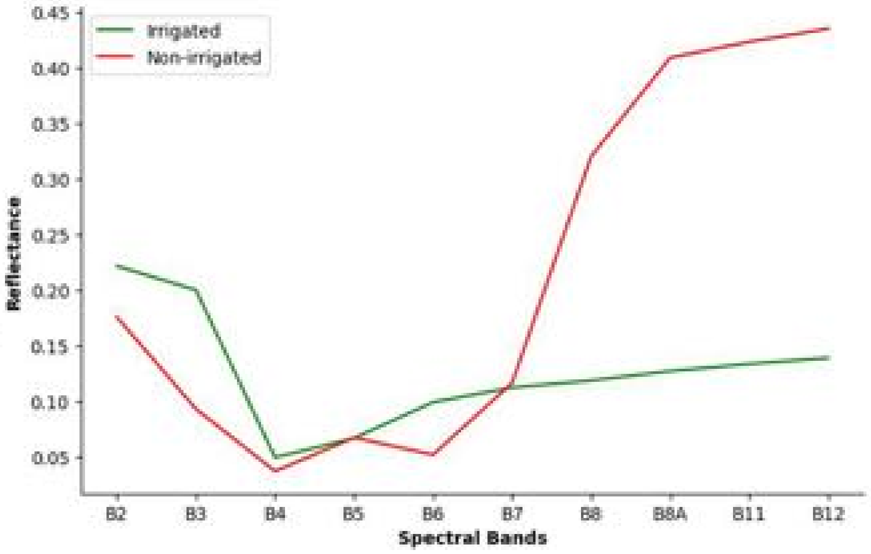


Figure 3 Workflow for generating reference data

Method for mapping irrigated agriculture

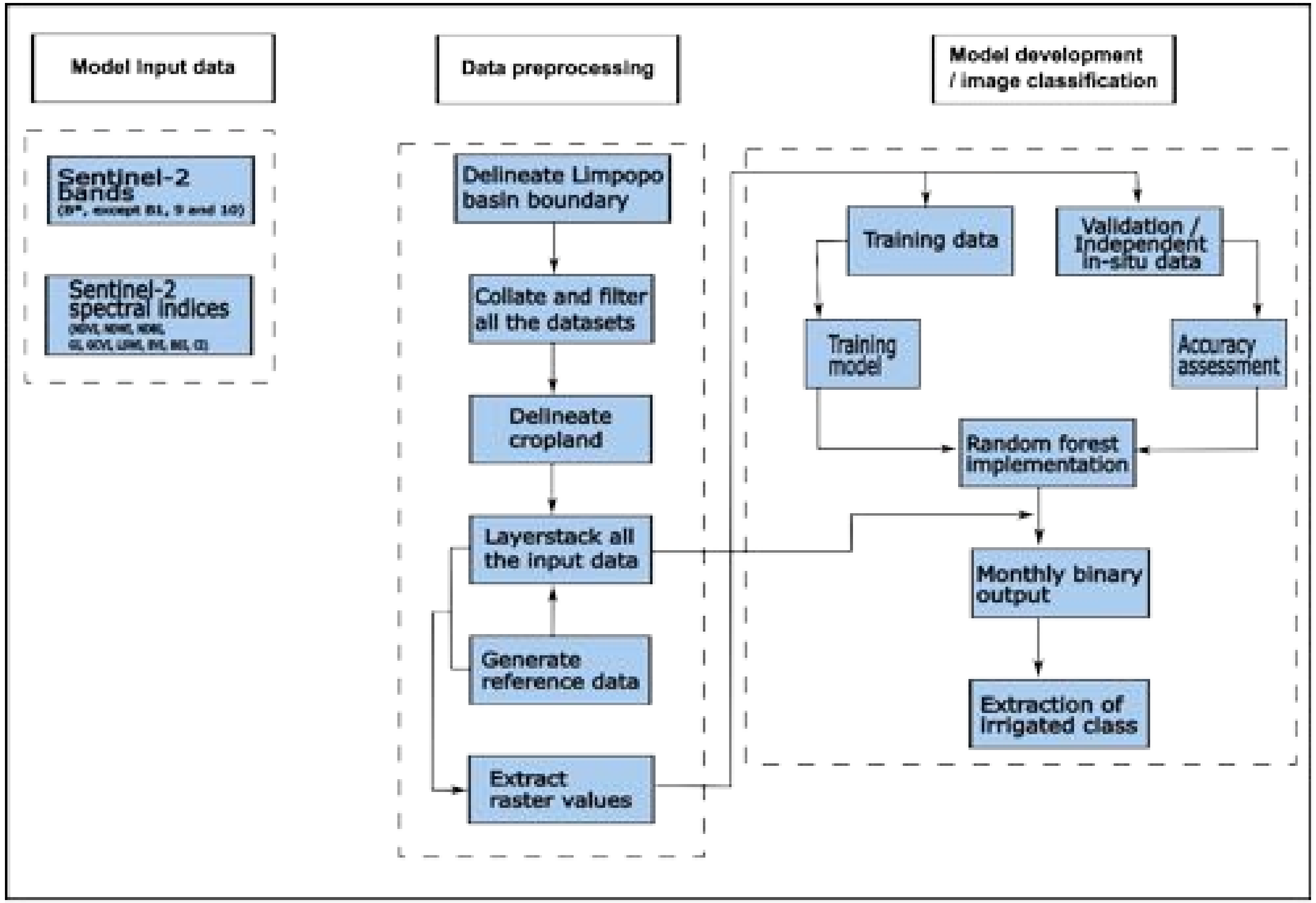


Figure 5 Workflow of image classification

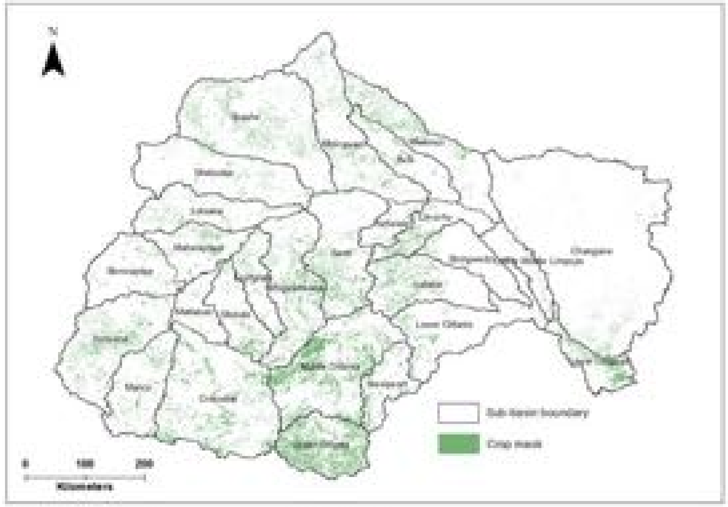


Figure 8 Cropland mask of the Limpopo River Basin.

Method for mapping irrigated agriculture

- → To decrease the number of these false positives in the classified image, time-lagged regression was implemented.
- → The time-lagged regression analysis focuses on quantifying agriculture dependence on rainfall over time.
- → Areas with a slope greater than 5 degrees were also removed (Ragettli and Siegfried, 2018)

https://github.com/iwmihq/dt_irrigation_mapping

Method for mapping irrigated agriculture

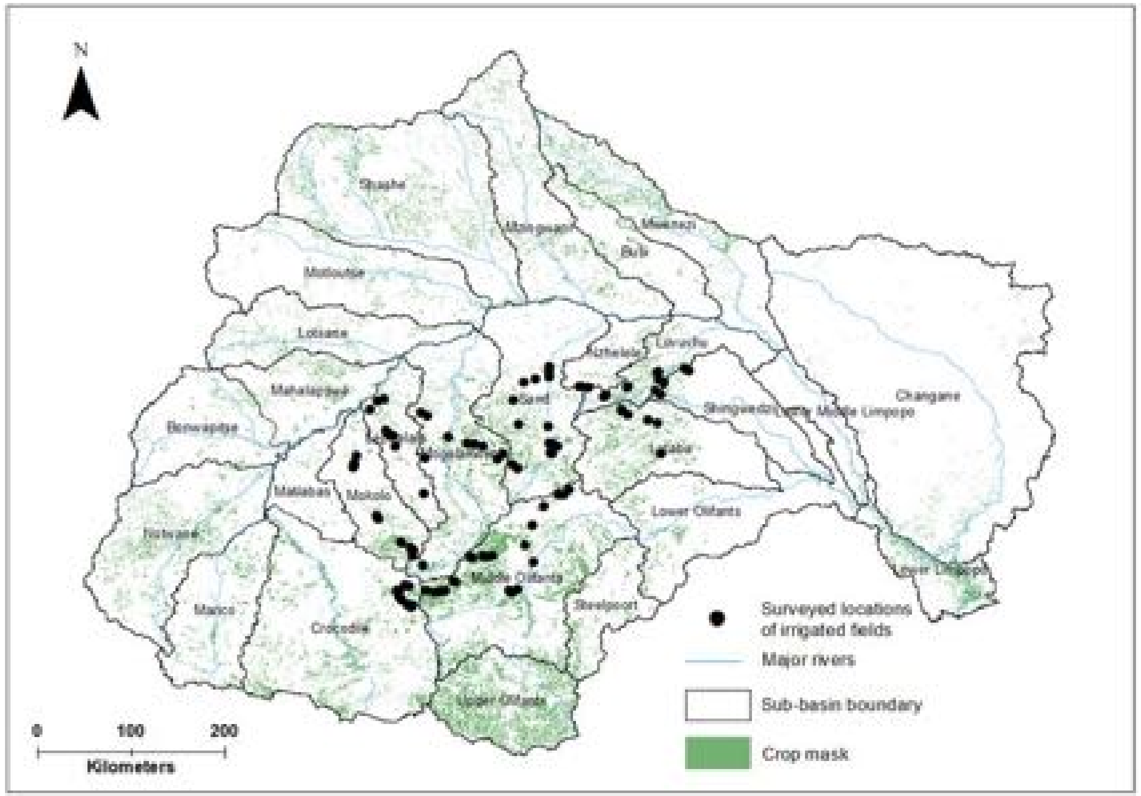


Figure 6 Locations of surveyed irrigated fields

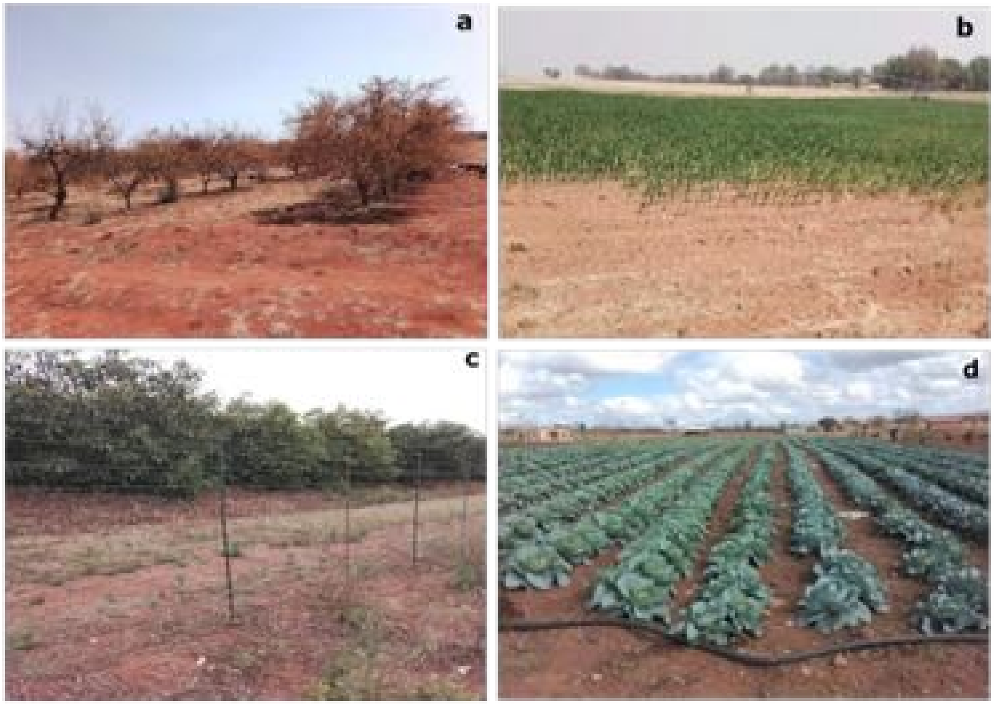


Figure 7 Field observation photographs of non-irrigated (a, c) and irrigated crops (b,d)

In total, data from **120 agricultural plots** (Fig. 6) were collected which included **ten farmer interviews.**

Results and discussion

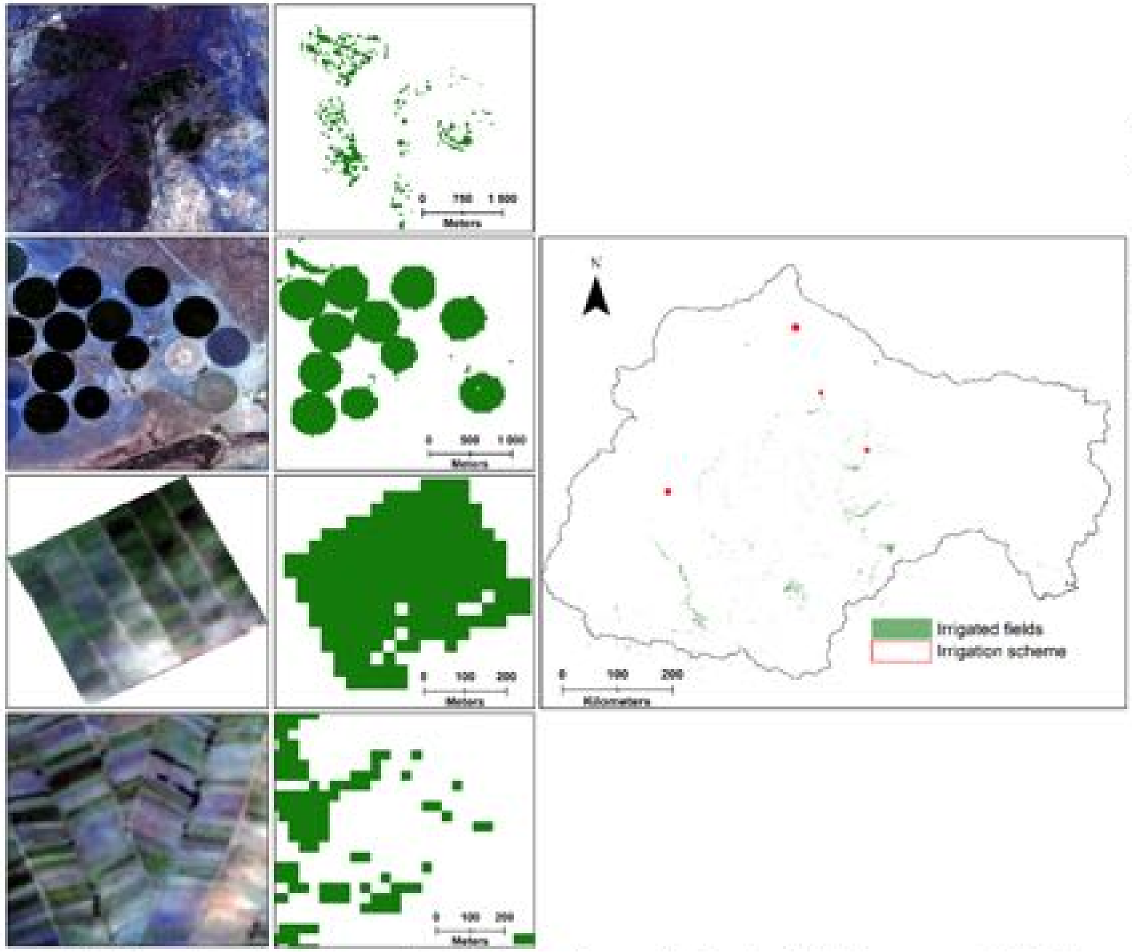


Figure 10 Map showing the spatial distribution of irrigated fields versus their true color composite within the basin for September 2024.

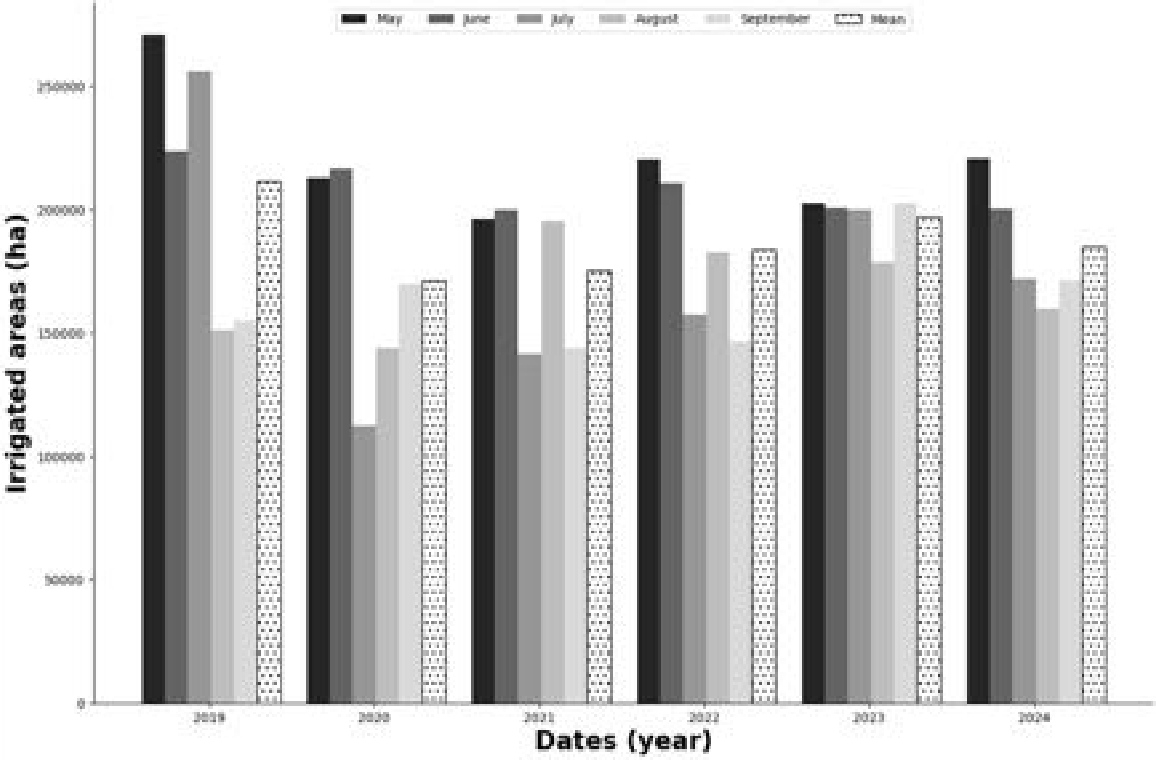
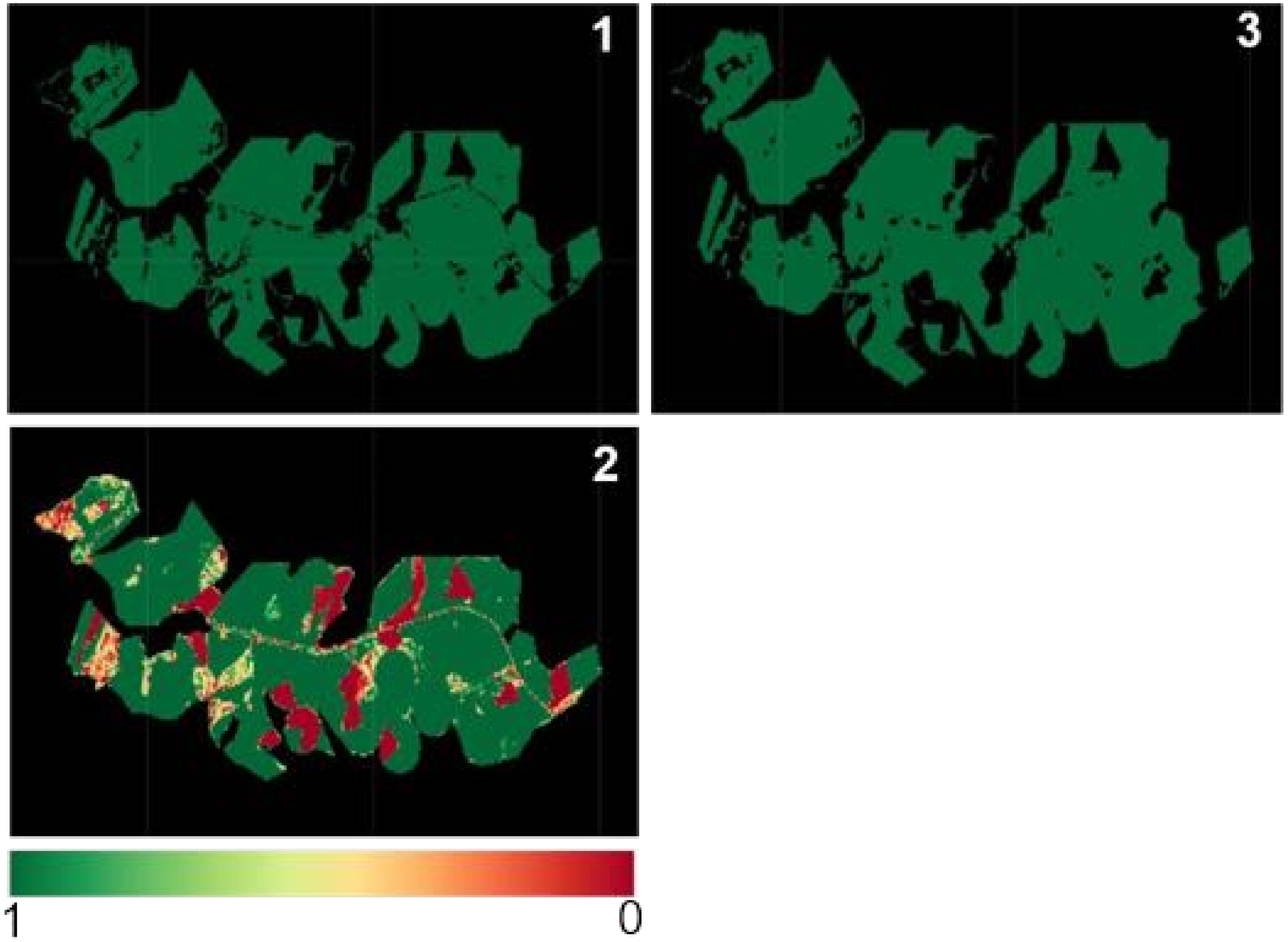


Figure 11 Estimates of irrigated area between 2019 and 2024

Results and discussion



Three types of measurements of irrigated area maps

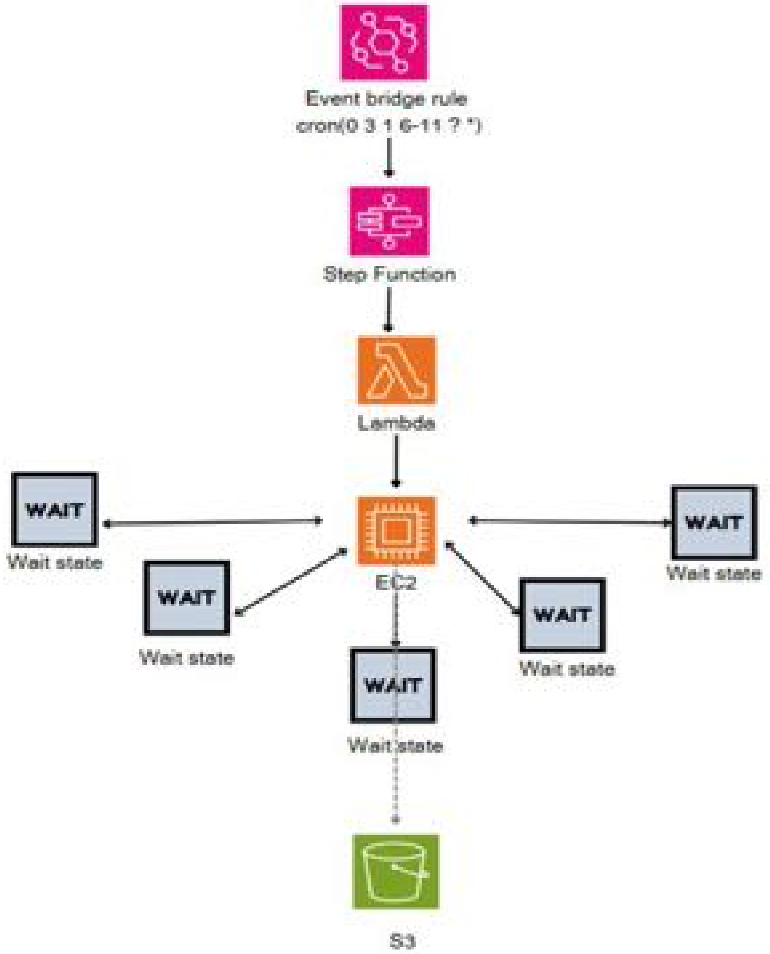
1. Raw classified map
2. Filtered map
3. Probability map

Key findings

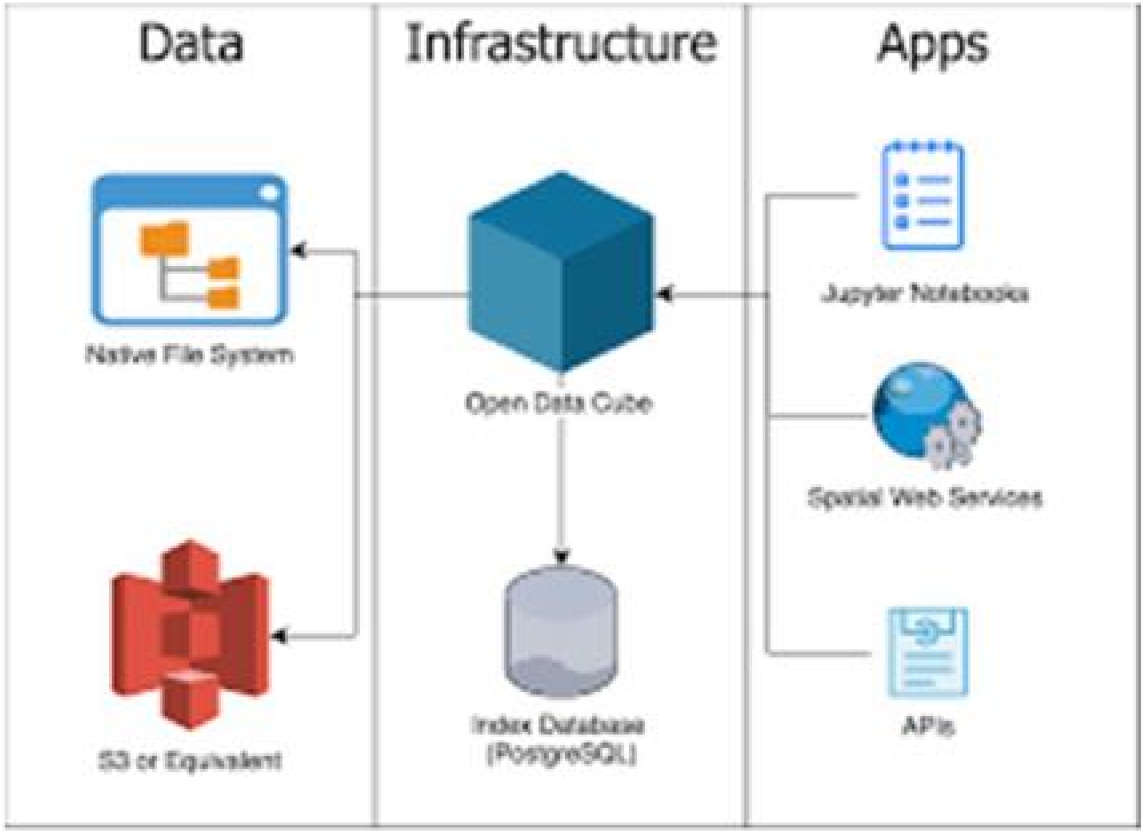
- **Irrigated Area Estimation**: The proposed methodology effectively estimates irrigated areas, contributing to the understanding of spatial and temporal variations.
- **Spatial Distribution**: Irrigated areas constitute approximately **0.4%** of the basin's total area, with significant concentrations in the Middle Olifants sub-basin.
- **Temporal Trends**: Irrigated areas have **declined** from 2019 to 2024, with peak irrigation activities observed at the onset of the dry season (May and June).
- **Water Consumption**: Water use by irrigated agriculture is notably high in **May and September**, with an increase in annual mean water use from 2020 to 2024.
- **Sub-basin Variability**: Irrigation is nearly absent in several sub-basins, including Lotsane, Changane, Lower Middle Limpopo, Bubi, Bonwapitse, and Mahalapswe.

Model operationalization

OPEN DATA CUBE



Automation workflow on AWS



Output dissemination and way forward

- → Downscaling WaPOR ETa
- → integrating ODC into Water Copilot
- → Paper (under internal review)

References

- **Garcia Andarcia, M., Dickens, C., Silva, P., Matheswaran, K., & Koo, J.** (2024). Digital Twin for management of water resources in the Limpopo River Basin: a concept. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on Digital Innovation. 4p.
- **Afham, Abdul; Silva, Paulo; Ghosh, Surajit; Kiala, Zolo; Retief, H.; Dickens, Chris; Garcia Andarcia, Mariangel.** 2024. Limpopo River Basin Digital Twin Open Data Cube Catalog. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on Digital Innovation. 22p.
- **Kiala, Zolo; Matheswaran, Karthikeyan**. 2024. Status of irrigated area in the Limpopo River Basin: July 2024. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on Digital Innovation. 5p.

Hands-on demo

Tutorial 1: Visualize an Irrigation Scheme with the LRB DT

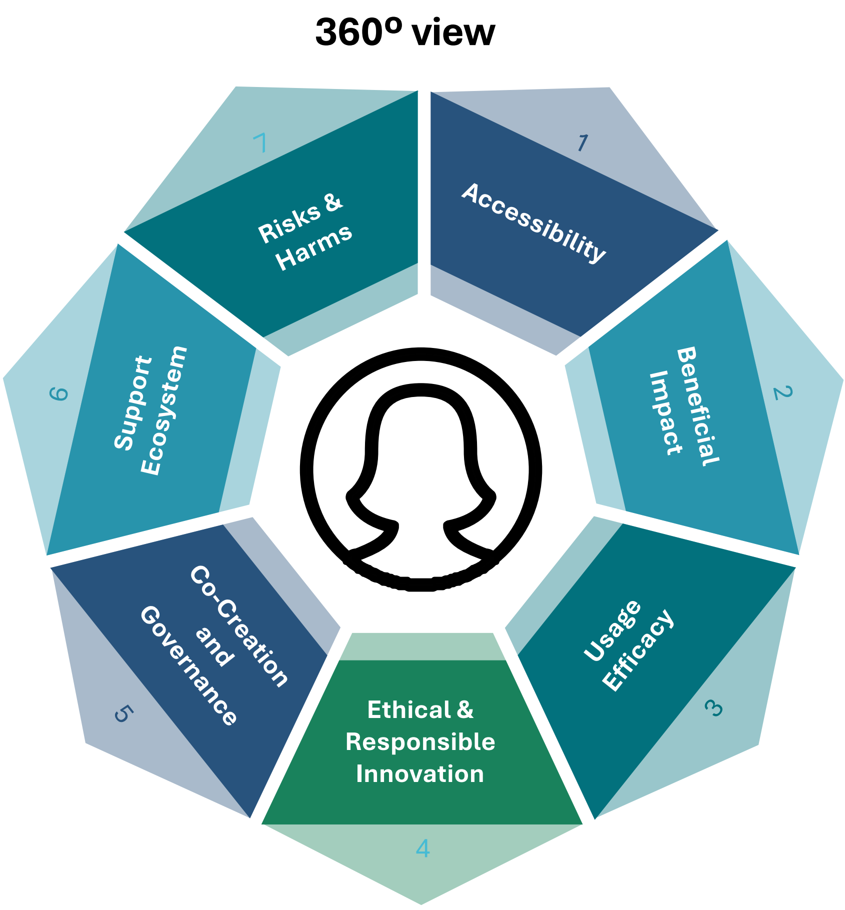
Tutorial 2: Performing basic analyses within the DT

[Tutorial day-1.docx]

The social implications of using the digital twin for water management

- **Tool users**: Will this tool introduce inequalities in our community?
- **Rural communities**: Will the large-scale adoption and use of the tool lead to degradation of our natural resources?
- **Women**: Are the tools visuals and functions representative of women?
- **People with minimal formal education:** Will this tool replace our skills and knowledge?
- **Young people:** Have we participated meaningfully in the development of this tool?

The MDII Framework



Innovation Usage

1. **Accessibility:** Measures availability and accessibility of digital resources for underrepresented groups.

3. **Usage Efficacy:** Assesses the ease and effectiveness of digital tool and service usage among underrepresented users.

6. **Supportive Ecosystem:** Supports the seamless adoption and sustained use of digital solutions.

Social Consequences

2. **Beneficial Impact:** Evaluates the positive impacts of digital innovations on underrepresented users.

7. **Risks & Harms:** Evaluation of the potential negative impacts that digital innovation products might have on users.

Stakeholder relationships

4. **Ethical & Responsible Innovation:** Ensures ethical practices and responsible innovation in digital initiatives.

5. **Co-creation & Governance:** Encourages collaborative innovation and inclusive governance in digital initiatives.

MDII Survey

IWMI
International Water Management Institute

Digital Inclusiveness - Form for Tool Users (Ex-Ante Version)

Feedback Session for Digital Twin Applications

Feedback

Mentimeter Survey here

International Water
Management Institute

SCAN FOR MORE
INFORMATION

THANK YOU!

Research and Innovation for Water Security

Driving Action • Propelling Change

CGIAR