



TRANSCEND

Summer School 2026

TDPS Living Lab

October 2026



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1. Context

The Titicaca-Desaguadero-Poopo (TDPS) basins are one of the most critical yet vulnerable transboundary water resources in the Andean region, shared between Bolivia and Peru. These basins sustain agriculture, the dominant economic activity and water user (accounting for approximately 91% of total abstractions), as well as domestic supply, mining, energy, and fragile high-altitude ecosystems. However, they face acute challenges such as high spatial and temporal variability in precipitation [ranging from over 1,100 mm/year near Lake Titicaca to under 300 mm/year south west area in Puno (Peru) and La Paz (Bolivia) provinces], rising temperatures, increasing evapotranspiration (often exceeding 1,500 mm/year in southern areas), retreating glaciers and snowmelt contributions, land-use expansion (agriculture grew about 9.6% from 1992–2015), aquifer overexploitation, and the dramatic shrinkage of Lake Poopó.

Data limitations compound these pressures. Many hydrological variables (streamflow, groundwater levels, agricultural abstractions) rely on sparse in-situ gauges (e.g., only 28 hydrometric stations across the network) with limited public access and significant gaps in real-time satellite integration or crop-specific monitoring. Climate change and ENSO events amplify inter-annual variability, while water transfers and unregulated abstractions heighten competition and transboundary tensions. Stakeholders, including national agencies (ANA Peru, ministries of water and agriculture Bolivia, SENAMHI), basin committees, PET (Peru), regional governments, and agricultural producers, urgently require robust tools to move from reactive management to proactive, and evidence-based adaptation.

In this context, the TRANSCEND Summer School 2026 addresses a clear strategic need: to equip professionals, institutions, and stakeholders from Bolivia and Peru's agriculture and water resources sectors with integrated skills in hydrological modeling, economic analysis of critical Andean crops (such as quinoa, potato, barley, alfalfa among others) and satellite monitoring with remote sensing for crop classification.

2. The need of the Summer School

Hydrological models (building on existing WEAP models) combined with hydro-economic analysis enable scenario testing of water allocation, irrigation efficiency, and climate impacts on crop yields and farm incomes—directly supporting Transformational Adaptation Policies (TAPs) central to the TRANSCEND project goals.



Meanwhile, remote sensing techniques offer scalable, cost-effective solutions to overcome monitoring gaps: high-resolution satellite data for land-cover mapping, and precise crop-type classification across vast, hard-to-access catchments in TDPS area. These tools can track land-use changes, detect drought stress implications, optimize water abstractions, and inform equitable transboundary decisions in real time.

For farmers, water authorities, and policymakers in Bolivia and Peru, this training is not merely technical, it is strategic. It fosters data-driven decision-making to enhance food and water security, reduce vulnerability to climate extremes, promote sustainable intensification of rainfed and irrigated agriculture, and strengthen cross-border cooperation. By bridging monitoring deficiencies with actionable modeling and economic insights, participants will contribute directly to the TRANSCEND in the TDP living lab system and advance resilient, equitable water governance in the Andes.

The TRANSCEND Summer School of 2026 thus represents a timely investment in local capacity, empowering the next generation of water and agriculture professionals to translate scientific advances into tangible policies and practices that safeguard the region's water resources and agricultural livelihoods under deep uncertainty.

3. Topics

The TRANSCEND Summer School 2026 delivers a hands-on, interdisciplinary training programme tailored to the pressing challenges of water scarcity and climate uncertainty in the Andean transboundary basins of Bolivia and Peru. Developed through close collaboration between the Stockholm Environment Institute (SEI), the University of Manchester (UoM), the IMDEA Water Institute (Spain), and the Instituto de Investigaciones Agropecuarias y de Recursos Naturales (IIAREN) at the Universidad Mayor de San Andrés (UMSA, Bolivia). **(60 hours for academic credits for certification/IIAREN, SEI, UoM, IMDEA).**

Projected dates for the course: **12 to 18 October**

Participants: 30 – 35 Professionals – Agriculture

The topics for the summer school are:

- Hydrological and Economic Modelling Applied to Agriculture,
- Remote Sensing (RS) Fundamentals: Calculation of Spectral Indices Useful for Monitoring Crops,



- Land Use and Land Cover (LULC) Classification: Image Classification Based on Indices and Other Bands for Crop Mapping,
- Water Use and Consumption Mapping/Estimation with Earth Observation
- Mapping of Water Presence Associated with Water Sources
- Agronomic Balance of Crops.
- Monitoring and Control of Water Use Efficiency in Crops

Through a combination of theoretical lectures, practical exercises using real Andean datasets, group modelling workshops, and field-oriented case studies from the living labs, the Summer School equips professionals, researchers, and decision-makers from Bolivia and Peru with the integrated scientific and technical capacity needed to design, implement, and scale Transformational Adaptation Policies for resilient water and agricultural systems in the face of climate change and deep uncertainty.

3.1. Hydrological and Economic Modelling Applied to Agriculture

Participants will learn to build, calibrate, and apply coupled hydrological-economic models (building on established frameworks such as WEAP) to simulate water availability, allocation scenarios, and the economic performance of critical Andean crops (quinoa, potato, barley, maize, and alfalfa).

First, topics will be addressed on the fundamentals and main concepts of hydrological modeling, water resources systems analysis, and the integration of economic components into decision-support frameworks. Participants will learn how to conceptualize water balances (supply-demand), allocation rules, and scenario analysis under climate and land-use uncertainties. In order for participants to understand and associate these concepts with real-world applications, practical examples will be demonstrated using the Water Evaluation and Planning (WEAP) system, focusing on TDPS basins and representative crop systems.

In this context, topics related to the representation of hydrological processes (e.g., rainfall-runoff, evapotranspiration, reservoir operations), water allocation priorities, demand nodes for agriculture, and economic valuation of water use (crop yields, water productivity, net benefits, and cost-benefit indicators) will be addressed. Special emphasis will be placed on simulating the performance of critical Andean crops—quinoa, potato, barley, maize, and alfalfa—under different water availability and allocation scenarios, including drought, climate change projections, and adaptation strategies. During this stage, the activities in the course will be carried out using WEAP



complemented with supporting tools such as Excel, R and QGIS, for pre-and-post processing of the data.

Participants are required to download and install WEAP and create a project for the exercises and the content of the module. The course will include basic explanation of computational structure, key objects, and built-in algorithms focused on hydrological-economic simulation.

Among the proposed topics corresponding to concepts, theory and practice are:

1. Basic WEAP modelling of basins and crops
 - What are coupled hydrological-economic models and why integrate them?
 - Key concepts: water balance, allocation priorities, scenarios, and uncertainty
 - Overview of established frameworks (WEAP and linkages with economic modules)
 - Best practices for model design in Andean agricultural contexts
2. Getting started with model building in WEAP
 - Data requirements and sources (hydrometeorological series, crop parameters, economic data)
 - Creating a new WEAP model: schematic, time steps, and geographic context
 - Defining hydrological components (catchments, rivers, evapotranspiration)
 - Setting up agricultural demand nodes for key crops (quinoa, potato, barley, maize, alfalfa)
3. Calibration, Validation and Scenario Analysis
 - Model calibration and validation techniques (historical flows, observed yields)
 - Incorporating economic performance indicators (yield response to water, water productivity, gross margins, net benefits)
 - Building and running allocation scenarios (reference, climate change, adaptation options)
 - Post-processing results: time series analysis, water productivity curves, economic trade-off evaluation, and visualization
 - Sensitivity analysis, Monte Carlo methods, and interpretation for decision support

3.2. Remote Sensing (RS) Fundamentals

This module introduces the principles of satellite remote sensing and provides practical training in the computation and interpretation of key spectral indices (e.g., NDVI, NDWI,



EVI) for crop health, stress detection, and phenological monitoring. Participants will work with freely available satellite data to generate timely information on vegetation dynamics in data-scarce high-altitude and arid environments.

Initially, topics covering the fundamentals and main concepts of Remote Sensing will be addressed, including spatial, spectral, radiometric, and temporal resolution. To ensure participants can fully understand and associate these concepts with their respective sensor systems, practical examples will be demonstrated using image collections from Landsat, Sentinel, and MODIS.

In this context, topics related to the spectral behavior of targets, crop health, stress detection and phenological monitoring, band composition, phenological and water spectral indices, as well as their respective applications, will be addressed.

During this first stage, in addition to theoretical presentations, practical activities will be carried out using the cloud satellite image processing platform, Google Earth Engine (GEE), and also QGIS Desktop 3.44 Long Term Release (LTR) to understand how to perform band composition, analysis of the band histogram, and raster processing. Furthermore, the main topics concerning Google Earth Engine (GEE), its computational structure, initial commands, and the first algorithms focused on remote sensing practices will be introduced.

Regarding the QGIS Desktop software, participants must download and install the recommended 3.44 Long Term Release (LTR) version directly from the official project website (<https://qgis.org/en/site/forusers/download.html>). Since QGIS operates locally on the user's machine, unlike cloud-based tools, it requires a minimum computational structure to function effectively. We recommend a desktop or notebook computer equipped with at least 8 GB of RAM (16 GB is highly recommended for optimal raster processing), a standard multi-core processor, and sufficient local storage space to handle and process the downloaded datasets smoothly.

To use GEE in JavaScript or the Python API, it is essential for users to create an account on the platform in advance. When registering, users must select the non-commercial use option and choose the "Community" plan. This category is completely free and specifically aimed at students, educational purposes, and workshop participants. From this Community account, the user will be linked to a cloud project, establishing the credentials and authentication necessary to securely access the GEE API remotely within the Python scripts. Official information regarding eligibility criteria



and access for creating a free account is available on the Google Earth Engine non-commercial use page (<https://earthengine.google.com/noncommercial/>), and registration can be initiated directly through the official GEE registration portal (<https://code.earthengine.google.com/register>).

Additionally, to ensure the optimal organization of the files and codes utilized throughout the summer school, a repository (e.g., "/transcend/summerschool/") will be shared with the participants. Through this shared environment, everyone will have direct access to all the scripts used during the practical classes. The repository will be structured progressively, starting from basic-level scripts and advancing to more complex applications.

To fully leverage the analytical power of GEE, our practical activities will be conducted using its Python API, which allows for seamless integration with robust data science, machine learning, and geospatial libraries. Consequently, users will need access to Google Colab (available for free) using a standard Gmail account. For those unfamiliar with the platform, we recommend exploring the official "Welcome to Colaboratory" guide beforehand. Google Colab provides a more democratic environment by allowing users to leverage cloud-based virtual machines and seamlessly access files stored in their personal or shared Google Drives. The Colab notebook environment supports the creation of Markdown for detailed comments, image insertion, and step-by-step documented code for comprehensive data analysis.

Moreover, integrating GEE with Python packages significantly enhances the potential for advanced geostatistical analyses. It is important to note that users will need to run an authentication step within the notebook to link their GEE accounts. Regarding computational characteristics, the free tier of Colab provides temporary virtual machines typically equipped with around 12 GB of RAM and access to hardware accelerators (GPUs). Because these instances are ephemeral and disconnect after a period of inactivity, users must ensure that their final processed data is actively saved or exported back to their Google Drive. In terms of computational infrastructure, participants will only require a desktop or notebook computer with internet access to successfully reproduce the codes and routines designed for the classes.

A repository "/transcend/summerschool/", for example, will be shared with the participants, where everyone will have access to the scripts used during the classes. This repository will be structured from scripts with a basic level to more complex applications.



Among the proposed topics corresponding to concepts, theory and practice are:

1. Basics of Remote Sensing

- What is Remote Sensing?
- Data Acquisition and different sensor systems
- Understanding the different resolutions
- Best practices for working with Remote Sensing

2. Getting started with satellite imagery processing

- Available datasets and levels of data processing
- How to import an image, preview, and metadata.
- Highlight, brightness, and contrast in digital images
- Composition of bands with different sensor systems.

3. Vegetation Indices, Water, Functions and Statistical Analysis

- Contextualization of the NDVI, EVI, SAVI and NDWI indexes, NDMI
- Performing the Calculation of Normalized Key Figures and Expressions
- Loop, Functions, and Graphical Analysis
- Extract zonal statics for areas of interest.
- Historical series using vegetation and water indices.
- Histogram Analysis to Define Slicing Thresholds
- Creating Masks from Indexes.

3.3. Land Use and Land Cover (LULC) Classification

Building on RS fundamentals, participants will acquire advanced techniques for supervised and unsupervised classification of satellite imagery. The focus is on accurate crop-type mapping and LULC change detection, enabling stakeholders to track agricultural expansion, distinguish rainfed versus irrigated areas, and monitor land-use transitions that affect water demand in the Andean basins

After the presentation of the concepts on Remote Sensing, advanced topics will be addressed focused on the supervised and unsupervised classification of satellite images. This will include a discussion of the differences between these two approaches, their respective strengths and limitations, and their suitability for different applications. The content will focus on practical applications relevant to the TDPS basin, including mapping agricultural dynamics, detecting land use and cover changes (LULC), and distinguishing between rainfed and irrigated agricultural areas. These applications are directly relevant to stakeholders involved in water resources management, agricultural planning, environmental monitoring, and climate change adaptation. Participants will



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learn how image classification can support evidence-based decision-making by identifying patterns of agricultural expansion, transitions in land use, and areas where irrigation may be increasing pressure on water resources.

In this way, the module will combine theoretical explanations with practical exercises in Google Earth Engine (GEE). In the theoretical step, we will take an approach to the types of classifiers and algorithms that exist, supervised and unsupervised machine learning context. In practice, users will be guided throughout the entire classification workflow within the GEE, ranging from spatial and temporal filtering and the creation of annual cloudless mosaics to sample collection, classifier training, map production, and statistical and accuracy validation of the results generated.

In this context, special attention will be given to the dynamic behavior of water in the agriculture of the Andean basins. The importance of practical knowledge and prior recognition of the area of interest for the correct definition and distribution of field samples will be emphasized. It will be demonstrated how to go beyond traditional vegetative vigor by integrating evapotranspiration (ET) data and spectral moisture indices (NDWI and NDMI) to track the water balance of plants throughout the year. From the detailed comparison between the rainy season and the dry season, participants will learn to differentiate the water supply from rainfall from that generated by irrigation infrastructure.

It is estimated that with this temporal approach, participants will learn to create statistical threshold masks based on water response in the dry season, allowing for automated and accurate separation of rainfed agricultural areas from those that rely on irrigation infrastructure. In addition, by the end of the module, participants are expected to be able to plan and implement a basic LULC classification workflow, assess the reliability of classification products, and interpret the results in relation to agricultural monitoring, irrigation mapping, and water resources decision-making.

All practical progression will continue to be integrated into the script repository in GEE, ensuring autonomy in the replication of workflows for different areas of interest.

Among the proposed topics corresponding to concepts, theory and practice are:

1. Image Classification Fundamentals and Algorithms

- What is image classification and the concept of spectral pattern



- Unsupervised Classification: Clusters and dimensionality reduction using K-Means and PCA
- Supervised Classification: Decision Trees (CART), Random Forest, and Support Vector Machines (SVM)
- The importance of sampling strategy and the impacts of spatial autocorrelation in watersheds
- Methodological Division of Samples: Training Samples versus Test Samples (Validation)

2. Processing and Convenient Image Classification Flow

- Building seasonal and annual image mosaics with cloud reduction
- Techniques for collecting, extracting pixel-by-pixel values and organizing training geometries
- Instantiation and training of supervised classifiers in GEE
- Performing the classification, rendering and export of the final thematic map
- Accuracy validation: Confusion matrix Global Accuracy, and Kappa Coefficient, K-fold

3. Change Detection and Mapping of Irrigated Areas

- Multitemporal Comparative Analysis: Map Algebra Between Different Years for Change Detection (LULC)
- Analysis of seasonality dynamics: Identification and behavior of dry and rainy periods
- Behavior and temporal signatures of agricultural crops: Rainfed versus Irrigation
- Integration of Evapotranspiration (ET) data and NDWI/NDMI indices for water balance analysis
- Seasonal histogram analysis in the dry season to define moisture thresholds
- Construction of hydrological masks to isolate and map irrigated agricultural perimeters

3.4. Water Use and Consumption Mapping/Estimation with Earth Observation

Participants will learn to integrate multi-sensor data to produce spatially explicit maps of water use, supporting improved accounting of abstractions and identification of inefficiencies in agricultural systems.

This module introduces the acquisition and processing of global hydroclimatic databases (such as CHIRPS, GSMaP, ERA5, and MODIS) to monitor the water cycle at the watershed scale. Participants will learn to extract daily, monthly, and annual



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historical series of precipitation and evapotranspiration (ET). Using cloud platforms, students will calculate the simplified pixel-by-pixel water balance ($P - ET$) and cross-reference these results with the land use maps generated in the previous module. The objective is to quantify the actual water consumption of Andean basins and isolate the water balance of irrigated versus rainfed agricultural areas, generating trend charts to support water resources governance.

Consolidating the land use and land cover classification skills developed in the previous block, this module advances toward the quantitative modeling of basin water flows. Participants will contextualize the main Earth Observation (RS) products geared toward hydrology. The characteristics and applications of precipitation sensors and products (CHIRPS and GSMaP), climate reanalysis (ERA5), and accumulated Actual Evapotranspiration data derived from MODIS (MOD16), for example, will be analyzed.

In terms of methods, the workflow will teach students how to perform temporal aggregation and homogenization of raw data to generate consistent historical series at monthly and annual scales. The main methodological approach will consist of applying map algebra to calculate the simplified water balance by subtracting actual evapotranspiration from precipitation ($P - ET$) directly at the pixel level. The analytical differentiator of this module will be the spatial integration (spatial overlay) between these hydroclimatic layers and the agricultural classes map generated in the previous module. Through zonal statistics, participants will learn to extract the water behavior of each target, allowing a direct comparison of water consumption in areas under irrigation infrastructure with areas that depend exclusively on rain (rainfed).

As results, participants will be able to produce spatially explicit water balance maps (identifying water deficit and surplus zones in the TDPS basin) and advanced graphical reports. These continuous charts will include long-term linear trendlines for precipitation and evapotranspiration for each land use class. At the end, students will deliver volumetric estimates of agricultural water consumption, providing crucial data and indicators for decision-makers to audit water abstractions, plan agricultural expansion, and mitigate water-use conflicts under climate change scenarios.

Among the proposed topics corresponding to concepts, theory, and practice are

1. Introduction to Earth Observation Products and Data Preparation

- Overview of global precipitation and reanalysis products: CHIRPS, GSMaP, and ERA5.



- The MODIS Evapotranspiration product (MOD16): Data structure, scaling factors, and resolution.
- Geospatial filtering methods and data consistency for watersheds.
- Integration of multiple climate sensors with different spatial and temporal resolutions.

2. Time-Series Processing and Water Balance Calculation (P - ET)

- Methods for aggregating and converting daily data into monthly and annual accumulated totals.
- Construction of long-term historical series (2020 to 2025 period) for the Lake Titicaca basin.
- Application of map algebra to calculate the simplified pixel-by-pixel water balance.
- Spatial identification of critical water deficit zones and climate seasonality in the basin.

3. Zonal Statistics, LULC Cross-Referencing, and Trend Analysis

- Spatial cross-referencing techniques of climate layers with land use and land cover (LULC) maps.
- Extraction of zonal statistics to quantify Evapotranspiration (ET) by land use class.
- Comparative analysis of water consumption: Irrigated Agriculture versus Rainfed Agriculture.
- Results visualization: Generation of combined charts and linear trendline modeling for water governance reports.

3.5. Mapping of Water Presence and Quality Associated with Water Sources

Participants will explore techniques for detecting and monitoring surface water bodies, reservoirs, and canals, using optical and radar satellite imagery, as well as selected water-quality indicators derived from satellite observations and spectral indices. The training highlights applications for tracking water bodies dynamics, high-altitude wetlands mapping, and potential water-quality changes, directly addressing monitoring gaps in the TDPS region.

SEI writes in detail

This module covers the use of remote sensing to detect surface water and selected water-quality indicators, and their changes over time. It explores techniques for mapping various water bodies using optical and radar satellite imagery. The module also introduces methods for identifying water-quality proxies, such as chlorophyll-a



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concentration and algal bloom risk, using established spectral metrics. The approach for water quantity and quality monitoring has a focus on water availability, ecosystem health, and management challenges in data-scarce regions. Building on previous modules about fundamentals of remote sensing, this module demonstrates how satellite data can support water monitoring when in situ observations are limited or inconsistent. It emphasizes applied methods for tracking seasonal and annual changes in water extent, identifying permanent and temporary water bodies, monitoring reservoir fluctuations, and assessing hydrological dynamics in general. These applications contribute to understanding the effects of aspects such as climatic variability and agricultural demand in the region.

The first part of the module introduces the physical and spectral principles of water detection using optical remote sensing. It reviews the spectral characteristics of water in the optical domain and explains how to perform calculation of water indices such as NDWI, MNDWI, and AWEI. The model will use available datasets from Landsat, Sentinel-2, or MODIS imagery. Google Earth Engine (GEE) will be used for accessing satellite data and processing, by applying procedures for filtering images, creating mosaics, calculating water indices, defining thresholds, generating water masks, and extracting water-area time series for selected sites. The module also will explore water-extent products such as the JRC Global Surface Water Explorer dataset, as a baseline for understanding long-term surface water dynamics. This dataset provides information on water occurrence based on Landsat imagery. The product supports the identification of permanent and seasonal water bodies, comparison of historical and recent conditions, and interpretation of water availability trends. The module also discusses the strengths and limitations of global products.

The second part of the module covers radar-based water mapping using Sentinel-1 Synthetic Aperture Radar (SAR). Radar imagery is valuable for water monitoring because it collects data day and night and in cloudy conditions, which is important where optical observations are limited. The module explains how to interpret Sentinel-1 backscatter over open water, and the associated challenges typical from this data type such as wind distortions over water, topography, vegetation, and urban or mountainous areas. For the procedure will use GEE and Sentinel-1 datasets available there, along with practical exercises using WetSAT-ML in Google Colab, an open-source workflow that applies Sentinel-1 data and pre-developed machine learning models to generate



water extent maps. The module will discuss differences between optical and radar approaches for water extent mapping and when each data source is most suitable.

The third part of the module focuses on satellite-based water-quality monitoring. It examines the potential and limitations of using remote sensing to estimate water-quality proxies. The training highlights chlorophyll-a and algal bloom indicators, using spectral indices such as NDCI, MCI, and FAI, along with band-ratio methods for Landsat, Sentinel-2, or MODIS imagery. For example, NDCI is commonly used as a proxy for chlorophyll-a in productive and turbid water. The module also explains how chlorophyll-a and algal bloom products support early-warning analysis and identification of potential water-quality degradation hotspots. The module will emphasize that satellite-derived water-quality indicators require careful interpretation. Chlorophyll-a and algal bloom indices are influenced by factors such as atmospheric correction, water depth, turbidity, suspended sediments, and local conditions. These indicators are intended as screening and monitoring tools and should be calibrated or validated with field observations for operational use. The goal is to provide spatially information to prioritize monitoring and identify anomalies to guide field campaigns.

All the topics will be addressed by practical exercises designed to demonstrate how remote sensing can address operational questions such as: Where is water present? How has the water extent changed over time? Which water bodies show seasonal changes? Are there potential algal bloom signals? Which areas require closer field verification?

Upon completing the module, participants will be able to develop basic workflows for mapping water occurrence and selected water-quality indicators using satellite data. Competencies include generating surface water maps, analyzing water area time series, applying optical and radar water indices, and interpreting chlorophyll or algal bloom indicators for water-source monitoring. All practical scripts and notebooks will be included in the shared course repository, following the structure established in previous modules.

Among the proposed topics corresponding to concepts, theory, and practice are:

1. Surface Water Detection and Monitoring

- Spectral behavior of water in optical satellite imagery
- Water detection using Landsat, Sentinel-2, and MODIS
- Calculation and interpretation of NDWI, MNDWI, AWEI, and related water indices



- Cloud masking, image compositing, and seasonal mosaic generation
 - Histogram analysis and threshold definition for water-mask creation
 - Extraction of water-area statistics and time series for lakes, reservoirs, wetlands, and canals
2. Long-Term Surface Water Dynamics and Water Availability
 - Use of the JRC Global Surface Water Explorer dataset
 - Interpretation of water occurrence, seasonality, recurrence, transitions, and maximum water extent
 - Detection of changes in water availability across historical and recent periods
 - Identification of reservoir fluctuations, drying trends, and expansion or contraction of water bodies
 3. Radar-Based Mapping of Wetlands and Water Permanence
 - Introduction to Sentinel-1 SAR imagery for water detection
 - Interpretation of VV, VH, and polarization-ratio responses over open water and wetlands
 - Advantages and limitations of radar imagery in cloudy, mountainous, and vegetated environments
 - Use of WetSAT-ML in Google Colab for wetland flooding extent mapping
 - Comparison between optical and radar-derived water products
 4. Water-Quality Proxies from Satellite Imagery
 - Introduction to satellite-based water-quality monitoring and its limitations
 - Chlorophyll-a and algal bloom detection using spectral indices
 - Calculation of NDCI, MCI, FAI, and selected band-ratio approaches
 - Use of Sentinel-2 red-edge bands for chlorophyll-a proxy mapping
 - Identification of potential algal bloom hotspots and anomalous water-quality signals
 - Interpretation of satellite-derived indicators as screening tools for field verification

3.6. Agronomic Balance of Crops

Led by Bolivian agronomic experts (IIAREN), this module examines the water, nutrient, and energy balances of key Andean crops under local edaphoclimatic conditions. Participants will analyze crop-specific water productivity, yield responses to water



stress, and best practices for sustainable intensification in high-altitude and semi-arid environments.

IIAREN writes in detail. We are preparing a MoU with the university; a specific plan will be developed with them during May and June.

3.7. Monitoring and Control of Water Use Efficiency in Crops

The final module focuses on field- and remote-sensing-based methods to assess and improve water-use efficiency. Participants will learn practical protocols for on-farm monitoring, deficit irrigation strategies, and performance indicators that link agronomic outcomes with hydrological and economic models.

The automated drip irrigation system was developed to optimize irrigation scheduling by applying water during the crop phenological stages with the greatest sensitivity to water stress, particularly the flowering and grain-filling stages in quinoa (*Chenopodium quinoa* Willd.).

The system enhances water-use efficiency while reducing farmers' labor requirements by fully automating irrigation operations according to crop water demand.

The irrigation management algorithm integrates a crop phenological calendar with a previously computed soil water balance, accumulated precipitation records, and short-term weather forecasts. Based on these datasets, the system automatically determines the irrigation timing and the required water application depth, ensuring that irrigation events are synchronized with the crop's physiological water requirements.

The system is equipped with calibrated flow sensors that continuously monitor the volume of water delivered, enabling accurate irrigation control and compliance with the minimum operational performance requirements.

The integration of crop phenology, soil water balance modeling, meteorological forecasting, automated irrigation control, and real-time flow monitoring constitutes a precision agriculture framework specifically designed for Andean cropping systems. This approach improves irrigation efficiency, optimizes water resource utilization, and supports climate-smart agricultural management under conditions of increasing water scarcity.

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